

Regional Oral History Office  
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University of California  
Berkeley, California

Global Mining and Materials in the Twenty-First Century Oral History Project

Roshan Bhappu  
Science and Values in the Life of a Metallurgical Engineer

Interviews conducted by  
Paul Burnett  
in 2014

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Roshan Bhappu, 2014

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## **Global Mining and Materials Research Project**

For over twenty years, the Regional Oral History Office (ROHO) produced in-depth oral histories of members of the mining community, under a project called "[Western Mining in the Twentieth Century](#)," which was overseen by Eleanor Swent. The 104 interviews in the project covered the history of mining in the American Southwest, Mexico, South America, and Australia from the 1940s until the 1990s.

ROHO has recently changed its name to the Oral History Center of the Bancroft Library, and with that change we proudly announce a new project entitled "Global Mining and Materials Research," which will focus on key transitions in technology, policy, and geopolitics that have brought mining to its current state worldwide.

Much has changed in mining industries in the years since the Western Mining project was in full production, including the increased globalization of mining operations, the decreasing concentration of mineable minerals in ore, increasingly complicated regulatory environments, new systems of environmental remediation, new technology for exploration, extraction, and processing, and new stories of political conflict and resolution. In addition to collecting interviews about mining engineering, metallurgy, and administration, we also hope to explore the history of information technology and data analysis with respect to mining, as well as the legal, regulatory, and policy history of the industries.

The interview with Dr. Bhappu was funded with revenue from the Hearst Foundation endowment for the Regional Oral History Office. Thanks also to former Western Mining Project Lead Eleanor Swent, Dr. Douglas Fuerstenau, and Noel Kirschenbaum for their advice and support while the Global Mining project was being established. Finally, we are of course grateful to Roshan Bhappu for taking time out of his busy schedule to speak to us about the past, present, and future of mining in world history.

Dr. Roshan Bhappu was chosen to begin this new project in part because his life history is truly global in scope, beginning in Karachi, India, and ranging across Europe, the United States, South America, Central Asia, East Asia, and Australia. He was also chosen because of his outstanding reputation in the mining, metallurgical, and international development communities, and he has authored hundreds of reports and research papers for his clients. He has been the president of the Mining and Metallurgical Society of America, and has received its highest award, among many others, for his contributions to several fields of research and mining practice.

The interviews with Dr. Bhappu were conducted at the Hilton Hotel in Tucson, AZ, from March 5-7, 2014. We met for lunch on the 4<sup>th</sup> to discuss our goals for the interviews. I explained my interest in how values inform the practice of science and engineering, and he agreed that this was a good subject to explore. He also hoped that this interview would be of interest to future generations of students who might want to pursue careers in mining and engineering. Dr. Bhappu was a gentleman throughout, courteous, humble, charming, and quietly devout. On my first evening in Tucson, he revealed himself to be immensely proud of his family, with accomplished children working in a variety of fields, some related to mining, some not. He also shared a perception, held in common with many in the industry, that mining is a much maligned

endeavor, citing the challenges in getting new permits to mine in the United States. He has worked hard to educate the public about the industry. Although he acknowledged the environmental costs of mining, he felt that the benefits far outweighed them. Moreover, he has spent his career trying to find ways to mitigate pollution from mining and treat remaining pollutants with responsible and cost-effective methods. Dr. Bhappu is an inveterate optimist, which is why you will not read in these transcripts about what he witnessed during the Partition of India. Of course, he was in a fortunate and privileged position in India, and he and his family have since prospered in the United States. But there are silences in this interview born of his worldview and his faith. You will also not read of the twenty-two hours he spent on an operating table, shifts of surgeons rebuilding his back after three other specialists had told him he would never walk again. He only told me this in order to explain why he could not sit for long periods of time in the same position. Though fortunes can turn in an unstable world, what mattered to Dr. Bhappu was the story of surviving and thriving, of living to tell of the extraordinary people he met, learned from, and influenced, and of the difference he made with his colleagues and family. At eighty-seven years old, he has spent over sixty-five years meeting the challenges in his work. “Good thoughts, good words, good deeds.”

Paul Burnett, Berkeley, CA, 2014

**Roshan Bhappu***Science and Values in the Life of a Metallurgical Engineer*

Introduction by Ross R. Bhappu, Ph.D.

It is an honor and pleasure to write an introduction for my father, Dr. Roshan Boman Bhappu. As you might imagine, Roshan shaped my views on what a career in mining could lead to and I chose to study metallurgical engineering largely to try and follow in his footsteps. Although small in stature, he developed very big shoes for me to fill!

I was born in 1960 during Roshan's days at New Mexico Tech and the U.S. Bureau of Mines and am the youngest of four children born to Roshan and Carmen. My siblings, Manek, Zorine and Soonalyn enjoyed Globe, Arizona and Golden, Colorado with my mother and father before I was born and it is interesting that both towns would shape my life and career decades later.

For as long as I can remember, dinner would be interrupted with phone calls. Our mother, Carmen, or one of the four of us would answer it and inevitably yell, "Dad, it's someone with the United Nations who wants to talk to you," or "Dad, it's someone with the World Bank," or "Dad, it's someone with a mine up in Canada." You get the picture. Private mining companies and foreign governments, doctoral candidates, journalists and scientists all wanted to talk to Dr. Bhappu.

I always thought my father would have fit perfectly in any of the Indiana Jones movies as a wise and colorful sage to whom "Indy" would have turned for advice. One can imagine Indy saying to a colleague, "Let's go ask Dr. Bhappu." After September 11<sup>th</sup>, 2001, he was contacted by U.S. government officials because of his deep and sophisticated knowledge of the region in which Bin Laden was hiding in Afghanistan. The White Mountain Range of eastern Afghanistan is rich in precious gems but also holds formidable places for terrorists to hide and our government wanted his advice.

We all took it in stride though and only now am I coming to really appreciate just how much my father has accomplished and how many lives have been changed for the better because of his work. Although he traveled extensively and was away from home a lot, somehow he was always there to guide us through the Science Fair at school, and he could play a mean game of tennis. When we watched fireworks on the 4<sup>th</sup> of July, he would identify the chemical composition of each color flare as it streaked across the sky. When we went for walks, he would describe the geology and mineralization of every canyon, colorful stone or unique outcrop - he brought each to life.

My earliest memories include always having Roshan's students, and later his clients, to our house to attend various parties and events that my family would host. Mining executives and students alike were regulars in our home and they always found time to include the four of us kids in their discussions. One even gave me guitar lessons, although unsuccessfully.

Growing up in Socorro was a treat. Whether it was sneaking into and exploring the military boneyard, wandering around campus, playing golf or exploring the wilderness trail, life revolved

around New Mexico Tech. Visiting Roshan's office was an adventure – it was filled with papers, books, a couple of slide rules and some great posters with sayings like, "Give a Hoot, Don't Pollute." A seemingly out of place poster for a mining related office, but certainly not out of character for Roshan as an engineer and professor. In fact it was always interesting to listen to him explain that pollution and mining don't belong together. He stressed that a good metallurgical engineer who is doing his or her job correctly will figure out how to get all economic elements out of the ore and make sure to "fix" the remaining minerals to keep them from generating pollution. He insisted that the best environmentalists were metallurgical engineers. My father's faith preaches, "Good thoughts, good words and good deeds," and among those good deeds was a respect and a reverence for this planet.

A story Roshan does not tell very often is that he was very active in community service and has always been passionate about education. Around 1971, he decided to run for the local school board in Socorro at about the same time my older brother decided to start an underground newspaper which was cutting edge to say the least. Needless to say, the newspaper did not go over well in this little, conservative town and Roshan was handily defeated in the election. That did not deter Roshan from continuing to volunteer and advocate for better educational standards.

Roshan and Carmen were both passionate about traveling and they instilled that interest in all of us children. In 1969, he took a sabbatical from teaching in Socorro and we moved to Ankara, Turkey for a year where he taught at the Middle-East Technical University. Part of this adventure was the journey to Ankara. I recall going to the Volkswagen dealer in Albuquerque where Roshan ordered a minivan to be delivered to our hotel in Paris. Who knew you could do such a thing without the internet! Sure enough, a few days later after flying to Paris, he gets a call from the front desk that his new car is being delivered. So off we went for a 32 day trip zigzagging across Europe on our way to Ankara. The amazing thing was I don't recall ever getting lost, and with six of us in a minivan for over a month, nobody was left behind (or left on the side of the road).

Moving to Tucson in 1972 took Roshan out of the academic environment and he quickly demonstrated an entrepreneurial spirit that was unknown to us. Mountain States Mineral Enterprises was in its infancy and Roshan left the campus of New Mexico Tech to become part of the executive team that built a very successful consulting, engineering and metallurgical R&D practice. In his new position, Roshan was always on the road - something common to all of us who work in the industry. We were always struck by the exotic locations he would visit and loved the slide shows he would play for us after returning.

In the 1980's, Roshan took another step in the business world when he and Joe Shirley acquired the R&D facilities from Mountain States and went off on their own by creating Mountain States R&D International (MSRDI). Joe soon left and Roshan took over sole ownership of the business. It is hard to believe that he has been with the same entity for over 40 years as of this writing, and it demonstrates Roshan's loyalty and passion for what he does.

You will notice in the interview that Roshan's Zoroastrian faith and strong religious beliefs have helped guide him through his career and personal life. He and Carmen, who had equally strong Catholic religious beliefs, instilled those religious beliefs in their children and we grew up in a very unique religious household. Every night we would pray together as a family using a

combination of Catholic and Zoroastrian prayers. We attended Catholic Church almost every Sunday and were always struck by how similar the messages of the two religions were to each other.

Roshan's faith was tested in the early 1990's when our mother developed colon cancer. The cancer was discovered late in its development and had already metastasized to a point where there was not much hope. She died about 14 months after its discovery following some very difficult surgeries and treatments, and Roshan was there every waking moment. Her role in shaping Roshan and her children cannot be overstated, and she would be delighted to know that my father is being honored with this interview.

Fortunately for Roshan, in 1993 another person came into his life who appreciated his world. He reconnected with Perin Shroff, a childhood friend from Karachi who had also lost her beloved husband. Shortly thereafter they were married and began a new chapter together that included Perin's son Homee and her daughter, Abbey and her family.

I chose to become a metallurgical engineer because of Roshan and ended up completing both bachelors and master's degrees in that discipline before obtaining my doctorate in Mineral Economics. It is a career path that has served me well and I attribute it all to Roshan. However, it has not always been easy being a Bhappu in the mining industry – expectations are very high. In fact, I will never forget giving my first professional paper at an SME conference in New York City in 1985 and finding the session chair to be extremely disappointed when he found out it was me and not Roshan giving the paper in his session! After graduating from the Colorado School of Mines, I joked that we ought to go into business together and call it “Bhappu and dad.”

Throughout my professional career, I have been amazed at how often I get asked if I am related to Dr. Bhappu. It happens all over the world, and the most unique place was in the jungles of Cameroon where a local geologist in a cobalt field office asked me if I was related and then pulled a copy of one of Roshan's books off of his shelf.

I am also amazed at how Roshan can remember a project he has worked on decades ago. It is not uncommon for me to mention a project and he will say something like “the mineralogy of that ore is fairly refractory and the grades are X% but we found that by doing a bit of pre-conditioning using Y and Z, we could improve them to...” Meanwhile, I have trouble remembering what I had for breakfast so, I certainly did not get those genes!

Roshan, or Poppi as his grandchildren call him, is one of the kindest people I know and I would be remiss by not talking about his kind heart. He is always the first to lend a helping hand to someone in need and I have never heard him say anything unkind about anyone. In fact the first time I heard him cuss, I was in my thirties and it was the “s” word. Does that even count anymore? When I would get in trouble my mother used to say “wait until I tell your father” which was the most devastating punishment of all, because we kids would never want to disappoint our father – a trait that continues today.

Roshan has led a fascinating and productive life and the interview below just scratches the surface of all that he has done and accomplished so far. His contribution to the sciences including mineral processing, hydrometallurgy and flotation ranks him as one of the mining

community's all-time greats. I hope that you, as the reader, will enjoy hearing in his own words just how much he has accomplished and how much he has given back, not just to the mining community, but to the people whose lives he has touched. I am so very proud to call him my father and hope you enjoy learning a bit more about him.



Interview #1 March 5, 2014  
Audio File 1

01-00:00:00

Burnett: This is Paul Burnett of the Regional Oral History Office, interviewing Dr. Roshan Bhappu for the Mining Project of the Business Series. This is interview one, tape one. Dr. Bhappu, you have a long and illustrious career that is not over. You're still in business. We'll begin at the beginning—we're in Tucson, Arizona—and it's a beginning that begins quite far from here.

01-00:00:46

Bhappu: Yeah, halfway around the world.

01-00:00:49

Burnett: Can you tell me a little bit about where you were born and your family?

01-00:00:58

Bhappu: I was born in Karachi, India, which later on became Pakistan, in 1926. At that time, Karachi, Bombay, all the metropolitan cities were different, in the sense that they were more or less following the British rule and government. So, our education was very similar to what one would get in the British schools. Only a few of us got that education. I was born in Karachi, and my life was very interesting because I had quite a few influences, the most important one being my family and the way we were brought up, as children.

My parents and my grandparents and all my ancestors originally came from Iran—Persia—and follow the religion of Prophet Zarathustra, or Zoroaster. We call ourselves “Zoroastrians,” in the English, and now we have converted to Zarathustri, which is the original name of our Prophet, Zarathustra. Our religion dates back, we don't have too much historical evidence, but about 4,000 years from today—2,000 years, at least, before Christ. Before that, they had gods and goddesses and there was no systematic religion to follow. Zarathustra, Zoroaster, came up with this Zoroastrian religion. He said that because if you look at all the nature, fire or light, sun, the moon, is the most important creation of God, he said there are no gods, goddesses, there's only one god. He called him “Ahura Mazda,” and so, all of our activities start with having a little thought about Ahura Mazda. Basically, the principle of that religion is good thoughts, good words, and good deeds. That encompasses all the things you do. So, from an early age, we were taught to be honest, to be happy, work hard, help with the family. So, good thoughts, good words, and good deeds were the, you might say, signature words that I followed. My grandfather followed it, my father, and so on.

My grandfather was born near Bombay, and what had happened is that during the Persian Empire, in 1500 B.C., Alexander defeated Darius, or *Darius*, and at that time, the Persian Empire extended all the way from China, Middle East, all the way to India. It was one of the biggest empires, but Alexander

defeated our king, and that became the decline. About 1500 years before Christ we were, you might say, the elite, you know? Then, again, our successors came into power, till about the seventh century after Christ. That was 1,300 years ago, and then Muhammad, the Muslim, defeated again the Persians. That came to be the low point of the Persian Empire. We were forced to convert, but our forefathers did not accept this. Since they have trade routes between Iran and India, many of them left Iran to come to India, and came to a place near Bombay, where they established a church. A church, to us, is a fire temple. Remember, we are not worshipping fire—we are worshipping God through fire, and we keep the fire burning all the time. So, they established the first fire temple, and so the life started near Bombay. From the beginning, teachings of Zarathustra was that you have to be a self-made person, you have to work hard, and make sure that you keep your family happy and that you don't have to be a king or a prince, but in your own life, you are that king, you are the prince, and you have to act accordingly.

So, the Zoroastrians did pretty well, and this is where the original Zoroastrian community started. Today, we are about 200,000 in the world, with about 80,000 near Bombay. Then, of course, we are very adventurous, so we go all over the world. Since we were a minority in India, and then again in Pakistan, we didn't get into politics or anything but we became professionals. So, my grandfather started work in the ice factory in Bombay, a small one. He was a self-made man. He learned about refrigeration and all that, and ultimately, with friends and family, he started the first ice factory in Karachi, in 1904. So, my grandfather started that, my father lived in that, and all of our family—we are four of us, one older brother and two sisters—lived in the ice factory upper story. So, we had a life, you might say, under an engineering environment. Machinery, compressors, and all that. It was a learning experience because every morning you went out and you see something different.

01-00:08:49

Burnett:

May I ask, did you work in the family business at all?

01-00:08:54

Bhappu:

No. Actually, in the Zoroastrian family, the son follows father, and so on, but my brother worked with it, yeah. I was completely different. I wanted my own things, to do my own thing, and so my grandfather was one of the biggest influences. He said that you must follow the teaching of Zarathustra, you must be hard-working, and he says, "Look, I didn't have education, but you have the chance, so become somebody, but start with a good education." So, I went to a local Parsi school. The name "Parsi" came from that original Zoroastrians in Iran lived around a province or an area called Paras, and the people who came from there were called Parsis. So, another synonym for the word "Zoroastrian" is "Parsi," because we came from Paras in the old days. Our forefathers and our people in the community were already educationally inclined, and they said, "We didn't have the chance, but you youngsters." So,

they established colleges, schools, libraries. The Parsi name became very famous, and education was the key. We have 98-99 percent literacy in our religion, and everything is subsidized by the community. All the education, scholarships, and all that.

That's what's wonderful today, so the people who influenced me were my grandfather, entrepreneur, self-made person, looking at engineering as a growing field. My grandfather's name was Kawasji, and I'll give you some of the names, and my grandfather was Boman, and my name is Roshan Boman Bhappu. The second name is always the name of the father, yeah. So, Kawasji, Amai, that's my grandmother, very religious, very orthodox, but fair. So was my grandmother. A lady's influence in the Zoroastrian community is very strong because they are the ones who take care of the children. Father is working most of the time, but father also spends quite a bit of time with the children. So, I grew up in a very religiously oriented family, and we had scientific papers, and you know, were just modern. Tried to keep up with the times, and our schools were very well run.

The principal of the school was Dr. Pithawalla. He was educated in England, and he was a geographer and a geologist. He tried to impress upon us that there are two resources of a country: the natural resources—and that means the water, the air, the minerals, all that—and then the human resources. He stressed upon that, that you cannot follow one or the other; you must cultivate both of these resources simultaneously. So, he kept all our students, my friends who went to school with me, always took part in education, and some became teachers. So, besides my grandfather and father, the third person who influenced me was my principal. He was a very knowledgeable person, he's tried to emphasize again the principles of Zarathustra, but he brought in English. We started without any English, in the kindergarten, then by matriculation, twelve years later, all of our exams were in English. On top of that, we had to take a second language, Persian, French, German, whatever you wanted. We had science classes, but most important, he believed that education and being a reading bug is not going to—you need to take part in your physical fitness.

So, from three o'clock to five o'clock or six o'clock, it was playtime. In the sense we'd play cricket, hockey, boxing, wrestling, ping pong, tennis, whatever you wanted. So, when we came home, we were pretty tired, and then we'd do our homework, which was compulsory. Then, we would eat about eight o'clock with the family. It's usually the family time because in the morning, everybody goes their way. In the afternoon, we are in the school. Then, in the evening, the family gets together.

01-00:14:44  
Burnett:

In this educational process—and it's an educational and a religious instruction—the emphasis is on community and service, I imagine?

01-00:14:55

Bhappu:

Community life. Community service, because as Zarathustra put it, it's no use being educated if you cannot transfer that knowledge to other people. He also stressed that there are poor people, they don't have the chance that you have. You have to contribute to the growth. So, if you go to Karachi or Bombay or others, if you look at a big building or a university, it's always a Zoroastrian name. What happened? Well, Zoroastrians became very successful because they were tradespeople, they went into business, doctors, lawyers, started companies. All their monies that they had, they put into charity. The term, "Parsi, thy name is charity," became a symbol. Originally, it was for Parsi or Zoroastrians, but when we found out that things were getting difficult, they opened the school for everyone. So, that is the biggest mark that Zoroastrians have left, if you look at the Tata family, automobile.

01-00:16:19

Burnett:

Tata is Zoroastrian?

01-00:16:20

Bhappu:

Tata is Zoroastrian. Dr. Bhabha, who is an atomic scientist, started the Atomic Energy Commission. Dr. Godrej became a metallurgist, but he went into making alloys, and his name was synonymous with safe, safety measures, and locks and keys and all that. So, they became very prosperous, but they also shared. So, early life, it was not like religious in the sense that you just sit down and pray and pray and pray. Start your daily life with a prayer and end it with a prayer. In between, if you have a little time, say a little prayer. It's not that you have to pray all the time, and all play and no work. So, we played hard, but we worked hard. We became scouts, and I told you that we became Sea Scouts because of the generosity of the English, you might say British, Navy officers.

01-00:17:32

Burnett:

Could you tell me a little bit about that? This is a religious minority inside an incredibly diverse – British India, at this time, was incredibly diverse, ethnically, linguistically, and culturally. You're a small group, but an influential group. Could you talk about the position of the Zoroastrian community vis-à-vis the British Raj?

01-00:18:01

Bhappu:

Right. Zoroastrians took part in activities, trade associations, and helped the British government in many ways. The British preferred us for jobs in important positions, so we became close to the British community. They were more British than Parsis in Karachi. So my father was very sports-minded, and he says, "Let's have a cricket match." So, he started a gymkhana, and he coached the Parsi Zoroastrian cricketers. Every year, we had a championship between the British, and then later on, the Hindus and the Muslims and many people came in. So, we had a very good rapport with the British, and they encouraged us, they would send us books from Cambridge University, and

they opened their door to us, and their embassy was always ready to help us in educational activities. We had scouting, but we did not have sea scouts, though we were right on the ocean. So, what were our activities? They were activities that were not climbing a mountain, but going to the ocean. So, Dr. Oakley, he's not a doctor but he was a commander in the Navy, says, "Let's start a similar scouting, but let's all of our activities be ocean-minded." We started small, but now it's a pretty big group. I think that later on, I think in Australia and elsewhere, they started sea scouting. I started when I was seven, and I was a scoutmaster when I reached sixteen and seventeen.

So, it was a good opportunity, and also, this is where we learned the British etiquette and how to behave with people, and to not look down on people. So, we encouraged not only the Zoroastrians, but everybody, all the youngsters from all the communities and all the religious groups to join us. It was a very, very, you might say, active group, and we contributed by giving service to other children in religious affairs, or you know, activities where children met. We became like leaders and mentors. So, that was one of the most important things that helped many of our generation because we were brought up in that environment, we were brought up traditional ways, but then we knew the other side, how successful the British were, and the Europeans, and then, of course, the American influence began to come in. The Americans came in just before and after the war. We had, because Karachi was an airport, obviously the [US Army] Air Force was established there. They would come in from overseas then land in Karachi, get ready to go to Japan and other active areas. This is where my grandfather and father supplied a lot of ice and provided refrigeration facilities for especially medicine. Otherwise, with 110 degrees, it would spoil in no time.

I mentioned yesterday to you that Senator Goldwater who was from Arizona, was the commander of American forces. He and my dad and my doctor, our personal doctor, became very good friends. When I told him that I was coming to the United States to study, he says, "As soon as you land, let me know. I'll be there to take care of you."

01-00:22:59

Burnett:

Of course, he is from this region, too, right?

01-00:23:02

Bhappu:

That's right, yeah. Of course, when I get to the education, I'll tell you. So, anyway, we had a wonderful influence from various sources that molded our life. We became religious, kept the religion in mind, we kept the education in mind, and we kept the sports, our sportsman's spirit and competition. From the beginning, my grandfather and father encouraged me to come to the office and see how they kept accounting. So, it was an environment in which you had to grow up.

01-00:23:46

Burnett: You absorbed and you learned just in the process of being part of a family.

01-00:23:53

Bhappu: Then, what happened is in 1947, after the World War, of course, the world had a great influence. Many of my older brothers and friends all went into the army, the navy, air force, and became successful. After the war, that was early '45, then India and Pakistan were created in 1947, and that split apart the original Indian environment and British environment. Now, we were suddenly a Muslim country, 97 percent Muslim. We were not needed because they say, "Oh, you were when the British arrived, we don't want you."

01-00:24:57

Burnett: So, you became associated with the Raj?

01-00:24:59

Bhappu: Right, that's right.

01-00:25:01

Burnett: And therefore *persona non grata*.

01-00:25:03

Bhappu: But they realized that we can help them with education and things, so the early days were very good. In the beginning, we were in turmoil, things settled down. Then, later on, after ten years, things began to – too many factions, too many different groups who wanted to rule, and Muslims being war-minded, or you might say, you know, they started fighting amongst themselves. Today, Pakistan, people don't even want to go there. To go down there and act with the United Nations, I used to, but after that, about ten years ago, I stopped going there because there was no security. Once I became a citizen here in the United States [1957], I brought my brother and sisters and all. Today, there are only about 1,500 Zoroastrians living there in Pakistan. So, during the war and after the war and after the partition, it became a completely different life. I graduated as matriculation in 1943, and it was at that time, Karachi was a part of the University of Bombay. Now, our university's not a big university, and there are now colleges and affiliated institutions, and they all belong to the Bombay University. In order to learn geology and things like that, I went to Bombay, in a place called Pune, which is about 120 miles up on the hills, where they had a geology option.

01-00:26:57

Burnett: May I interrupt you for a moment and ask you, the decision to study geology, is that a result of the principal who was a geologist?

01-00:27:08

Bhappu: Yeah, that principal, because we, of course, had the chemistry and physics and all those subjects. But Dr. Pithawalla started a geoscience option, like the class, and he would himself teach us about nature, what minerals are, how the

earth was formed, how the oceans, the rivers, the mountains, contribute to the civilizations. So, from the beginning, I felt that that was a fascinating subject. I know that in my ancient Iranian or Persian, we found a lot of artifacts and all that, so they were miners and metallurgists, you see?

01-00:27:56

Burnett:

They were a mining people. You came from a long tradition.

01-00:28:02

Bhappu:

So, it was Dr. Pithawalla who encouraged me to go into, and he says, "Go to the University of Bombay, but geology's only taught in Pune." It just happened to be that my grandfather came from a high priestly class, and he became an engineer, so his brother took over. So, I stayed with my uncle in a fire temple because it's a big community and a big housing project. They let me live in there.

01-00:28:44

Burnett:

So, there were quarters as part of the fire temple, and they could welcome people who were traveling?

01-00:28:49

Bhappu:

Right, right. So, it was a wonderful thing to know the people. So, geology, when I talked to my granddad, I said, "Granddad, I'm going to take geology and mining." He says, "You know, I made my money in water, making ice. You can make it out of dirt." [laughter] So, anyway, he encouraged me. Since Pakistan and India were divided, Bombay Province, which was Sindh, Karachi and all, was separated in a separate country, overnight. We lost all the contacts. So, 1947 and '48 were terrible years, and we didn't know where we belonged. We couldn't go to college, we couldn't do this, we couldn't do that. We couldn't get visa to travel, or anything. Everything was stopped. Then, the American Embassy was established in 1948, and I was one of the first ones to apply. I went to the local consulate and I said, "I want to study mining and geology." "Oh," he says, "that's a wonderful field," and he rattled off about twenty names. The Colorado School of Mines, New Mexico, Wyoming, every state has a school of mines, Columbia University, MIT.

So, I asked him, "If you were me, which school would you select? Because you said the standard of teaching and education is equal." He says, "I would select Colorado School of Mines," and I said, "Why?" He says, "It's a small school, there are only 1,200 students, it's very community-oriented and you'll make friends easily, and they will welcome you since you want to study." "But," he says, "the most important thing is that that's the only school of mines that has a brewery to go with it because that's in Golden, Colorado, with the Coors Brewery." So, he said, "That's why I would select Colorado." But he said, "Don't you worry about that, you'll get a good education." You were comparing education in the United States and in India and Pakistan. We had classes, originally about twenty-five to thirty students per class. When I

came to Colorado School of Mines, we also had classes. The first year, it was large classes, but in the junior and senior years, it was smaller classes—ten students, five students. So, you really learned the basics because the teacher had the time to spend time with you, and so, that was the difference. Because I had chemistry and physics and math, I came to Colorado School of Mines in 1948, and that was an experience, flying from Karachi to Tehran to Istanbul to London.

01-00:32:21

Burnett: In these short hops, all the way.

01-00:32:34

Bhappu: On Pan-American Airlines. When I came to, my goodness, New York, I didn't know what I was doing. So, I had requested the University of Columbia alumni to give me a room or something so I could stay there for a few days before I went to Denver, Colorado.

01-00:32:50

Burnett: Can we back up a little minute? Just for those years in Bombay-Pune, where you got your bachelor's in science, and there's tremendous chaos at this time.

01-00:33:07

Bhappu: Actually, I did not get my bachelor of science because I was a senior, but everything was disrupted, and they said, "You will have to wait for a long time before you get your diploma, so we can't cater to you." Then, I had to go back to Pakistan because that was the original country, and I wouldn't get a visa or a passport there. See, they considered me as an outsider in India.

01-00:33:35

Burnett: And an outsider in Pakistan.

01-00:33:37

Bhappu: Pakistan, too. We had influence, and so, I was able to get the visa. That whole time, and also at that time, I caught pleurisy. For six months, I couldn't do anything, so it also took time to recuperate. Pleurisy is one that affects your lungs, but it's not TB. I had to go through a very rigorous medical exam at the American Embassy with an American doctor, to make sure that I did not have TB. He says, "Pleurisy's fine. You won't suffer from that and you will not pass it on to others, so you are all right."

01-00:34:32

Burnett: Was the pleurisy treated in India?

01-00:34:34

Bhappu: Yeah, it was treated in India.

01-00:34:36

Burnett: With antibiotics?



01-00:34:38

Bhappu:

Antibiotics, and of course, we had our doctor, a friend who was trained in Vienna. He was a wonderful doctor, and he was a very good friend of Senator Goldwater. Senator Goldwater told him that he should start a soda fountain. [laughter] So, they had soda fountains in Karachi.

01-00:35:08

Burnett:

Wow! So, there was an American influence in Karachi prior to and during the war?

01-00:35:12

Bhappu:

Yeah. So, it is true that I was very lucky. I had been very sick and I could have died of that. It was caught in time. I was wasting away because it is such a very wasteful disease. You can't work, you're coughing all the time.

01-00:35:32

Burnett:

You can't breathe.

01-00:35:34

Bhappu:

So, those were the years. There are many things that happened in the year, but it's a different time. We don't have time to go into all that. I came to Bombay and I had to take a steamer, a boat, to go to Karachi because I couldn't go by land because, at the Pakistan and India border, there was fighting going on, and there was no security. So, we went by – my mother, who was with me, and we went by boat to Karachi. Once I got the clearance and I got the visa, I spent three years training. I was a very good athlete, so I did that, and I was able to move around. Because I had good education when I went to Colorado School of Mines, they said, "Tell us what you had, classes." So, I told them I had chemistry and physics and biology and all that. They said, "That's fine." "So," he says, "you will start as a junior, rather than as a freshman."

01-00:36:46

Burnett:

They gave you credit.

01-00:36:47

Bhappu:

They gave me credit—quite a few hours. I was able to graduate in 1950. Forty-eight, and in two years, I got my engineer's. So, all I did was take engineering classes and geology and mineralogy and metallurgy. Because I had pleurisy, the doctor said, "You cannot go underground." I had wanted to go into mining, so I switched to metallurgy because I couldn't go underground.

01-00:37:27

Burnett:

That shaped your destiny.

01-00:37:29

Bhappu:

That's my destiny. So, metallurgy was my second option. I came to Colorado School, a completely different environment. Smaller classes, one-on-one discussions, we had professors who were academic but all practical

professors. So, this is what the School of Mines was compared to, say, MIT, which was like a university, to big colleges.

01-00:38:02

Burnett: It has an experimental mine, right?

01-00:38:04

Bhappu: That's right, they had an experimental mine. Experimental plant, where I worked as a trainee.

01-00:38:10

Burnett: An experimental processing plant, as well!

01-00:38:14

Bhappu: That was part of my training, practical training, was at the Colorado School of Mines Experiment Station. The US Bureau of Mines and others were doing research there, so it was a wonderful thing. Good teaching, good experience, practical experience, and I thought the Colorado School of Mines was a godsend. It took me two years to get out. I took part in the student body, and every fraternity wanted me to join them. I said, "No, I won't, but I'll come and visit you so I can have a beer."

01-00:39:05

Burnett: In 1948, in Golden, Colorado, how many international students were at the Colorado School of Mines?

01-00:39:12

Bhappu: Very interesting question. Now, Golden is about twenty miles outside Denver, so you come to Denver and go to Golden. In those days, they had a tram, that if you didn't have a car, you can always go by tram there, every hour on the hour. The Colorado School of Mines was internationally recognized, so we had a good foreign student contingent, especially in geology, since Saudi Arabia contributed very heavily to the petroleum section, petroleum department. So, they used to always have petroleum engineers who were from Saudi Arabia or Turkey, Egypt, you know? A few Indian students, and interestingly, two additional Parsi students. It was wonderful to know that there were at least two students who we could talk to in our own language. So, that was good. But I felt very free to express myself, and the American students were wonderful to me. They just considered me as a brother, younger kid, and they would take me out on weekends. We'd go outing and all, so it was a wonderful environment. Completely different from what you would expect in India or Pakistan because it was a small school and more contact with the students.

01-00:41:00

Burnett: I guess because you grew up knowing Americans, your family knew Goldwater, I suppose you knew something of what to expect. Of course, there's popular culture coming in. There are films about the United States.

What was most surprising to you or unexpected when you arrived there? Did you have an image in your mind of what it would be like?

01-00:41:28

Bhappu:

No, I always felt that because we had the American soldiers in Karachi, stationed there, I found them very friendly and always obliging and giving information. Of course, they always talked about all the Presidents, and they said, "Do you know anything about history?" and all that. There were documentaries at the consul. They had a very active program, the American Embassy, so they had short subjects and taking you through rural areas to Chicago. Of course, my grandmother and mother and father says, "Chicago? They've got gangsters there!" So, that was the biggest thing they told me, is keep away from the gangsters.

01-00:42:21

Burnett:

Keep away from Chicago! [laughter]

01-00:42:23

Bhappu:

Chicago, New York. So, and big towns. I expected the United States to be what I saw and what I had read about, and I was practically living at the consul because there's so many magazines. It was good that I was exposed to that, and then I know that from New York, I went to Denver by a train, and the train stop was Chicago, and we had a three-hour break. So, I went out and I talked to the policeman there. I said, "Sir, I would like to see all of Chicago." He said, "How many hours do you have?" I said, "About two hours." All the people around me were laughing. He says, "Son, take that bus, it'll take you to this point, and then you take the other bus that's coming back, and you will see *some* of Chicago."

01-00:43:27

Burnett:

And you did.

01-00:43:28

Bhappu:

And I did. I saw the downtown area, I saw the lake. I thought that was beautiful. It was September so it was nice, but this was one experience that I should tell you about. In New York, I was there for four days, and I went to Broadway. I said, "I'm going to see a show." I'd look at this theater, that theater, that, and there were so many pictures and so many good actors, I couldn't make up my mind.

01-00:44:02

Burnett:

You were overwhelmed. So, you saw nothing?

01-00:44:04

Bhappu:

Exactly, I saw nothing! [laughter]

01-00:44:10

Burnett:

But you had that inspiration.

01-00:44:12

Bhappu:

I saw completely what I expected, and what I didn't expect is how hospitable the American younger generation was, and how you became a part of it. You became like a family. So, it was more than I had expected, and the teaching was superb. In our schools [in the US], you would go to a college or to tenth grade, or junior year, and you would have quizzes every month. In India/Pakistan, you have one exam at the end of the year, and they ask you questions from first day to the last day, so you had to cram up a year. I said, "It's so simple, I just learned that and they're going to quiz me on it." It became a good learning habit, so that's a big difference. [In India] We had one exam a year, and if you failed, you failed the whole year. That was something different.

01-00:45:26

Burnett:

Yeah, that sounds also like the difference between perhaps American- and British-style education.

01-00:45:33

Bhappu:

That's right, exactly. Yeah, we were brought up by the British standard, not the American standard. I became friends very well, and people, many of them were veterans, so they talked to me all because that was just after the war. They talked about their experiences. Some of them were in India and Pakistan, and some of them in Australia, in the Middle East. So, I had a good exposure of what the war was like. So, that was a wonderful experience.

01-00:46:07

Burnett:

In some ways, the United States just after World War II, the population was, in a sense, more cosmopolitan than it is today because 16 million of them were stationed all over the world.

01-00:46:21

Bhappu:

That's right, and they learned a lot of things. One guy says, "Oh, yeah, I know how to make a curry, how about it?"

01-00:46:28

Burnett:

Wow.

01-00:46:31

Bhappu:

I think education-wise, it's a wonderful education. People were very friendly. The interesting thing is the teachers that took a real, real interest in you, in what you wanted to become. If you made a mistake, they wouldn't talk you out of it or rebuke you, they would say, "Look, this is the way to do it." Many of those experiments were completely new to me. Using a microscope, we didn't have that kind of x-ray analysis. I had to learn about that. So, a good education, and the important thing was, I was able to cut down my time for getting my degrees because I didn't have enough workload in the second year before I graduated. So, the professor says, "Do you want to take a thesis? You want to go and continue to master's?" I said, "Yes, sir," so, "Why don't you

pick a thesis?" So, in India/Pakistan, there was a mine, chromite, in a place called Quetta, close to the Iran border. So, I asked my father to send me several hundred pounds of a sample, which took about two months to come by boat. I did the master's thesis on the processing of chromite. It was very well received, and later, when I went out [to Pakistan], I talked to the people and they said, "Yes, we know what you did for us." So, that kind of opportunity. Within one year, I had got my master's.

01-00:48:22

Burnett:

This was probably quite unexpected, for a master's student to say, "I have a connection over here." This is something probably new for the Colorado School of Mines."

01-00:48:36

Bhappu:

Normally, you would take some project locally, or a scientific project, but I said, "I want to be a practical man, too. I don't want to be just doing science." I said, "India/Pakistan needs chromite because they wanted to start a steel industry." So, I said, "I'll pick up chromite and come up with a flow sheet for treating chromite." That's where that experimental station at Colorado School of Mines became very helpful because I had mentors there who were leaders in the field, and they guided me.

01-00:49:21

Burnett:

Can you talk a little bit and unpack that work in producing the flow sheet for chromite? What kind of instruments did you use?

01-00:49:33

Bhappu:

We used the same instruments that are miniature processing equipment in the plant. So, instead of a big, sixty-inch crusher, you use a six-inch crusher. So, everything is scaled down, and the important thing is all characterization. That's what I learned because chromite, again, is heavy. Associated rocks have low density or specific gravity, so you can make a separation by gravity. But chromite is also slightly magnetic, so you can use magnetic separation—high-intensity magnetic separation. So, those were the kind of subjects I learned, and that molded my future plans. I, of course, didn't want to go for my doctorate necessarily, but I said, "Look, here is an opportunity to learn." Then, when Dr. Gaudin asked me to come to MIT, I jumped on it.

01-00:50:49

Burnett:

Can we back up? How does that happen?

01-00:50:56

Bhappu:

From the beginning, when I joined the Colorado School of Mines, they advised me, the faculty, that I should join the American Institute of Mining as a student member, which I did. Every year, we had an annual meeting, either in Denver or New York, and we had the necessary funding. So, they sent me to these meetings, and in one of the meetings, they did like a student challenge paper or something. I talked about the different charges, ion exchange,

positive and negative, and I say, “Because the minerals are also positive and negative under certain conditions, we can use that collector or the organic, where the positive charge will go with the negative, and negative-negative will repel each other.” So, Professor Gaudin came to, “How did you know the valence?” I just thought that’s logical. He says, “This is the kind of thinking I want. Come to MIT, I will get your entrance.” So, as soon as I finished my master’s, I went to MIT and I was there, so, it was completely different. In the School of Mines, it was pants and shirt and sweater; at MIT, everybody had a bowtie.

01-00:52:43

Burnett:

It was casual in Colorado?

01-00:52:45

Bhappu:

Yeah, very casual. So, it was completely different, and one incident, I went to Dr. Gaudin’s first class and I wanted to impress him, so I went to the campus store and got myself one of these bowties. He comes in class, “Okay, Bhappu, come here,” and he goes, [whistles, motioning the tearing off of the bowtie]. [laughter] He says, “That won’t do. This is MIT. This is not Colorado.” He took off his own bowtie and says, “This is how you,” right in front of all the graduate students, “tie a bowtie. You don’t have to impress anybody—do it yourself. That will be a lesson to you, is that you have to be creative, you have to do things for yourself. You can’t have others do things for you.”

01-00:53:35

Burnett:

Oh, because it was a clip-on bowtie.

01-00:53:38

Bhappu:

Yeah, that’s what I said. He took it.

01-00:53:42

Burnett:

And he said, “This is a real bowtie. Let me show you.”

01-00:53:44

Bhappu:

Yeah, he took off his bowtie and says, “Yeah, you see, this is how I would tie my bowtie.” So, next time when I see you, I see you in a bowtie, that it’s not an artificial bowtie. He says, “This is your education.”

01-00:54:01

Burnett:

How did you feel about that?

01-00:54:02

Bhappu:

I thought that was wonderful because I recognized in the sense that I knew I had deficiencies, and I didn’t think that he was making fun of me. I just thought that this is how you learn about these things. One of the classes, he came up, second semester, he says, “Do you know anything about music? Do you know classical music? Do you know Chopin?” I said, “No, I know I can

recognize...” He said, “That’s another class you’re going to take, music appreciation.”

01-00:54:34

Burnett:

Really?

01-00:54:35

Bhappu:

Yes. He says, “You know, you are working in chemistry and physics and math and all, so you are working in a scientific environment. But you must relax, learn to relax, and good music. When you are working at night on a paper or something, have slow music, so you know, it’s not going to disturb you but it will also not put you to sleep.” He was a humanitarian. Weekends, he would invite me to his home and say, “You know how to barbecue?” This is what sets these mentors aside, like Dr. Pithawalla, there is one individual I forgot, and I’ll just quickly mention it. We had a high priest of Zoroastrian culture in Karachi, and in every school day, the first class was religious training, and he used to come and talk about the religion: good thoughts, good words, good deeds. I told him that I was going to be United States, and I was going to study mining. He says, “Let me tell you something, that in our religion, literature—mining is not mentioned as mining, but making use of natural resources. Just as you make iron or copper, it’s a natural resource. But it also said that you will use that natural resource, but you will not pollute.”

01-00:56:30

Burnett:

That’s part of Zoroastrian tradition?

01-00:56:32

Bhappu:

That part of his message to me is that: use all the natural resources, but make sure that you do not pollute the water, the land, because people are going to be in your vicinity. So, mining, what you are going into is a very noble profession. But don’t make it difficult for others. So, I thought there were two profound principles given to me: one was two resources, human and natural, cultivate them together—which is where education comes in—and secondly, mine but do not pollute. Which, in 1948, was—

01-00:57:17

Burnett:

Very ahead of its time.

01-00:57:20

Bhappu:

I was at New Mexico Tech, later on, when I joined the mine. I was interested – that came with the regions – that we must start an environmental engineering program.

01-00:57:36

Burnett:

When was this?

01-00:57:37

Bhappu:

This was when I went to New Mexico School of Mines. I said, “A mining engineer without environmental expertise? That’s not going to work.” So, that came later, but that was the kind of teaching. I talked to my professors, “What do we do with the tailings?” They said, “Oh, there’s the ocean.” They never talked about retreating or reprocessing or polluting because that was not economical. It added cost to our project.

01-00:58:15

Burnett:

Is that because they were often mining in remote areas?

01-00:58:19

Bhappu:

That’s right, exactly. Later on, I’ll tell you that things have changed now, and that is when I’m working with the United Nations. This is the kind of training I got. I got pleurisy again. The Charles River, I was crossing that every morning and evening, and it got colder and colder, and in February, I went there in September, and then in February, I started coughing. So, by May, Professor Gaudin came to the conclusion that he says, “You can study here, but you will not learn anything. You will be sick and sicker than anything, and the doctor at MIT says no, you must go to a drier climate.” So, then I talked to my professor, Dr. Carpenter, head of the department at Colorado School of Mines, and he says, “You come on over and you select your subject for your thesis. If you want Professor Gaudin to be your guide, by all means, we won’t object to that.” This is unheard of—how far they go out of their way to help you—and I was not the only one. They did that for all the students. I think one of the advantages of a smaller school is you have a one-to-one contact. In a big university, you are one of the 300 in the class, if you learn or don’t learn, they don’t care. You are a number. That was the advantage of a smaller school. So, I think that education-wise, I was lucky. I got matriculation, went from Bombay University, turmoil started, couldn’t continue. Came to Colorado Mines, got my engineer’s degree, my master’s, I was going to MIT for my Ph.D., and then I had to come back to Golden. Now, I wanted to complete the thing, and they realized that once I went home, I won’t have a chance to come back. So, they gave me a fellowship, they gave me a nice retainer, \$110 a month.

01-01:00:55

Burnett:

Enough to live on.

01-01:00:56

Bhappu:

You asked me a question, what was my dissertation?

01-01:01:05

Burnett:

Oh, perhaps we should stop the tape and change, and then we can pick up that subject with the next hour.



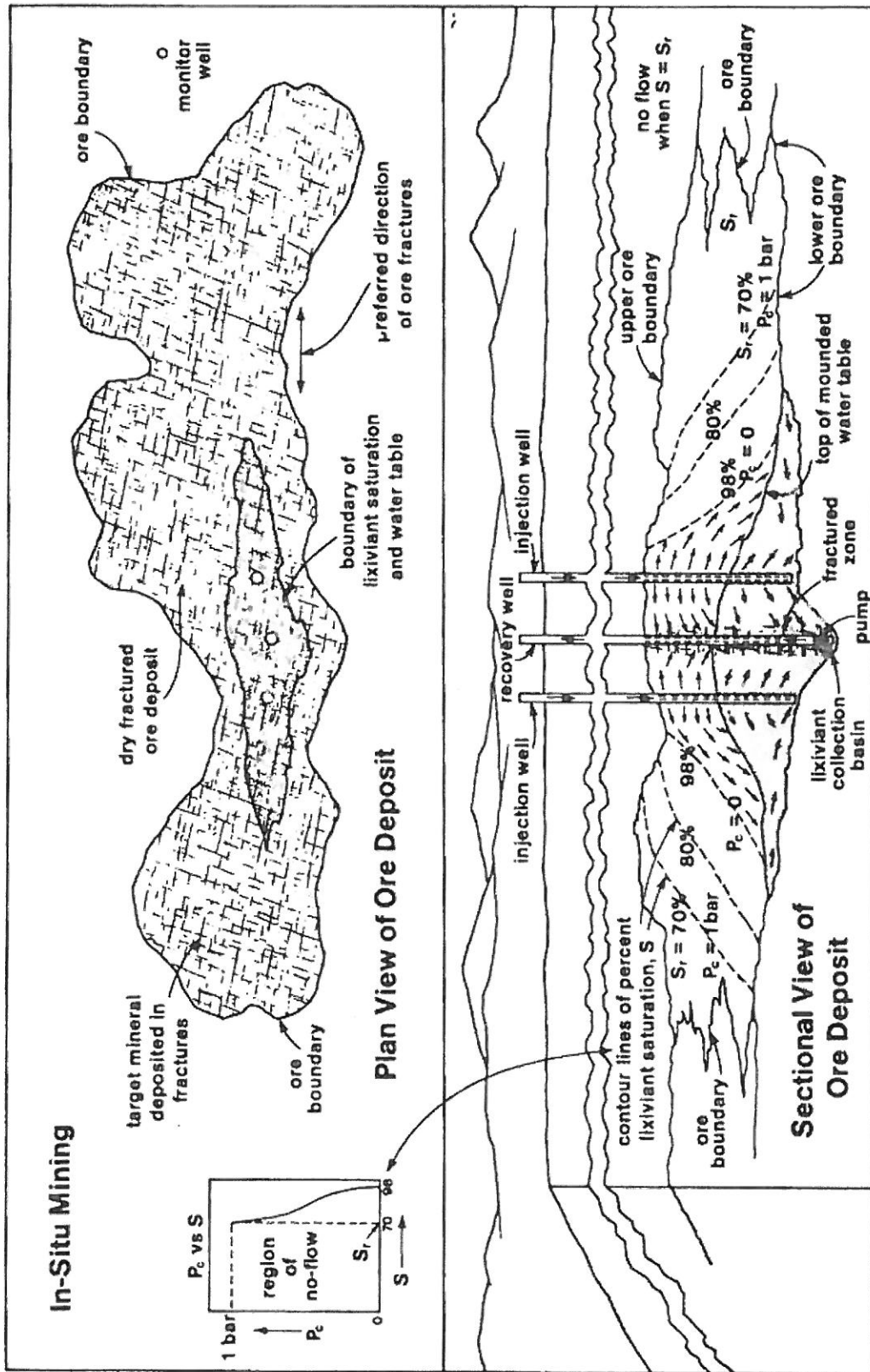


Figure 1. *In situ* mining.

From article: "A Review of Solution Mining – Part 3: In Situ and Heap Leach Mining" by Rudolph H. Jacobson, Jack W. Murphy and Paul B. Queneau, 1989.

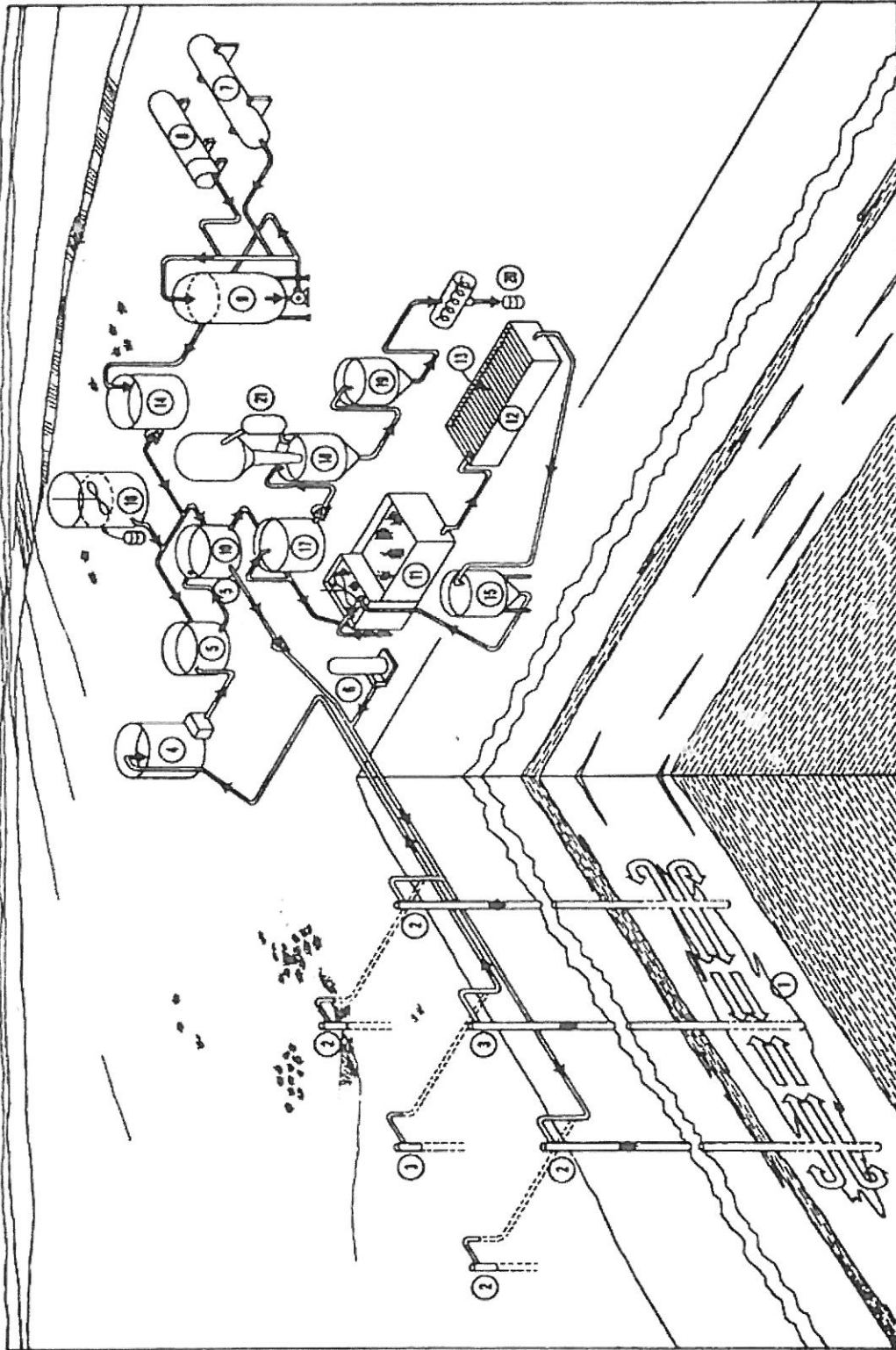


Figure 3. Copper *in situ* mining.

From article: "A Review of Solution Mining – Part 3: In Situ and Heap Leach Mining" by Rudolph H. Jacobson, Jack W. Murphy and Paul B. Queneau, 1989.

## Audio File 2

02-00:00:00

Burnett:

So, this is Paul Burnett with interview one, tape two of the interview with Dr. Roshan Bhappu. Dr. Bhappu, we're going to start talking now about your dissertation research. You mentioned this encounter when you were at a conference, and Dr. Gaudin from MIT noticed your work and asked you to work with him. Could you tell us a little bit about Dr. Gaudin's research and why he was interested in your work, and how that developed?

02-00:00:46

Bhappu:

Yeah. Professor Gaudin was considered like a guru of our metallurgical profession. He got his education originally at Montana School of Mines, also Columbia, then he moved to MIT. One of the most important things of being a good teacher is also being a humanitarian. You can be an excellent teacher, but if you do not have patience with your students or you berate him for making a mistake – what I learned is that you can be a miner, but don't forget to be a gentleman. That was his message. He says, again, they go together. Not that you are trying to impress somebody, that you are a professor, you are trying to maintain your dignity. You are humble, but at the same time, you don't have to wear broken, big patches on your pants.

02-00:02:00

Burnett:

Right, it's not a monk's existence, yes.

02-00:02:04

Bhappu:

So, that is what I learned from Professor Gaudin. He started, actually, his MIT career with smaller classes because MIT department was always there, for a hundred years, and many of their outstanding engineers came from there. They were scientists, but they were more engineers, and Professor Gaudin, Professor Taggart, they are in a class by themselves, came up with the idea that unless you go more deeply into the mechanism of the process, the character of the mineral, the chemistry that is involved, you cannot make separations of one particle from another, unless you can identify it. You can quantify it, you can look at the physical chemical properties of it, look at the charge on it, and then you'll come up with a process based on the character. But it's not only the character or the characterization of the mineral you want to recover, but a majority of the particles are gangue, or worthless. So, you don't want to bring them up in your concentrate. You want to bring only the copper or molybdenum or gold or silver, but that you don't want to bring the quartz, feldspars, so there is a difference in the character of these two minerals.

By doing an examination of pure minerals, you will be able to come to develop the process successfully. So, he emphasized surface chemistry, and the physical and the chemical nature of the particles. That was his teaching method. If you go to these classes, they are all surface chemistry, because

unless you know the surface, you cannot distinguish one from the other. Then, if you look at the work that Fuerstenau did, Doug, he was with me in school and his thesis and experiments were more inclined towards the theoretical, working with pure minerals. So, that's one thing I learned at MIT and Professor Gaudin, is go to the basics. That's where you will find the solution.

02-00:05:24

Burnett:

Can you distinguish, for our readers and listeners, surface chemistry?

02-00:05:32

Bhappu:

Every particle has a surface, and that surface has a nature where it is positively charged, negatively charged, or like graphite or carbon, it's a natural floater. It has its own hydrocarbons available to float. Molybdenum, molybdenite, which is a molybdenum sulfide, is a very important mineral in the case of alloys. All the Navy ships, all the heavy machinery has molybdenum with iron. It's an alloy. Molybdenite occurs as plate-like crystals, so once you recognize that, just the little froth or foaming will bring it to the surface because it's got natural floatability, just like oil. It repels water, but it likes air. It's water repellent and air avid. That's the way we describe them. The second property that you have is that some minerals are higher density, specific gravity, than another one. If you look at quartz, feldspars, they were gangue material, worthless material. They are always low. They are silicates, carbonates, they're about 2.5, 2.6, 2.7, 2.8, maybe 2.9, but when you look at the sulfide mineral of metallic sulfides, they are 4.5. So, that is a big difference.

02-00:07:32

Burnett:

Denser, yeah.

02-00:07:34

Bhappu:

Yeah, density difference. So, you take advantage of the density. You can put it on a shaking table, you can put it on a pulsating jig, and the lighter particles will come up and heavier will go down. We know that, and that's the way of concentration. All our methods of concentrating, like jigging, they are all based on differential gravity or specific gravity, density. So, that's the second principle of the mineral. The third one is a magnetic susceptibility, like iron, magnetite, iron oxide. You put it and a magnet will pick it up. On the other hand, titanium, chromium, has a little iron, and an ordinary magnet won't pick it up. When it's magnetic susceptibility, iron, you can pick up iron filings, your nail, you can pick it up with a rotary magnet. Alloy-type material, or like titanium oxide, it's not magnetic, but under induced magnetism or high energy, it becomes active. So, we call it induced magnetic separation.

02-00:09:10

Burnett:

So, you would use a strong electromagnet to excite, effectively?

02-00:09:17  
Bhappu:

That's how you make separation. So, you are taking physical properties. The other one is electrostatic. That is oppositely charged. So, you have a high intensity current going through, and it's just negatively charged or positively charged, it will throw it where it is repellant. So, this plus and minus always comes out very productively. Now, they are discovering other, for instance, a lighter mineral that is whitish, has a dull color, or very bright color, when you impinge a—

02-00:10:11  
Burnett:

A light source? Like a laser?

02-00:10:15  
Bhappu:

Not laser, necessarily, but a ray of light, it reflects, depending upon the surface. The darker the surface, it absorbs, the brighter the surface, the angle of reflection. So, reflectivity is another method where if you have dolomite, which is a darker carbonate than calcite limestone, which is whiter, you crush them, put them on a belt, and impinge rays on them. Some will reflect, and electronically, you pick that up, and it automatically pushes it out of the path. Or when it falls down, when it's drawn closer to the belt, the other is away from the belt.

02-00:11:12  
Burnett:

Those are recent technological advances?

02-00:11:13  
Bhappu:

Those are recent. They're like radiation; uranium ores can be treated very easily. Put it on a belt, radiation picks it up, and out it goes. So, those are the new ones, and I'm sure that in the future, we'll have more. So, standard methods are gravity, then you come to magnetism, you come to electrostatic, you come to reflection of light. Gaudin and his workers said, "Well, what else do we have? If they don't have these properties, how can we select it?" Then, they found out that this charge on the surface, it's very critical. What you are trying to do is make that surface attractive to the bubble, of air bubbles that bring you to the surface like a balloon, or it drops. If you have copper sulfide, this organic molecule comes and attaches itself. Positive, negative copper. The tail that's away from the surface, when you bring in iron bubbles, they stick to that. That's what makes it float. By changing the surface, you can make some excellent separations.

02-00:12:52  
Burnett:

So, you're talking here about froth flotation, which is an old process.

02-00:12:59  
Bhappu:

It's an old method by itself.

02-00:13:01  
Burnett:

But the new part is adding reagents that will—

02-00:13:07

Bhappu: Make the surface more attractive to the bubbles, air bubbles. We call it air avid, it likes air, and water repellent, it repels water.

02-00:13:21

Burnett: Air avid and water repellent, okay. So, Gaudin is working on this?

02-00:13:28

Bhappu: That was his major, major contribution.

02-00:13:34

Burnett: Dr. Fuerstenau was also influenced by him? He was obviously working with him. So, how old a research tradition was that, when you started?

02-00:13:45

Bhappu: Flotation? Old days, they had only gravity units, then they got into magnetic, electrostatic, then came flotation. Flotation started around 1916 and became stronger and stronger in 1950s. From 1950 to '70, that was the biggest thing that you could learn, was the flotation. Many of our flotation experts were trained by people like Gaudin and his students, who became professors.

02-00:14:20

Burnett: So, he was really a center for that kind of research?

02-00:14:21

Bhappu: He was a guru, yeah. He imparted the knowledge and then his students spread it out. People from all over the world come here, and everyone in Australia or New Zealand or India who's doing this work is usually trained at MIT or Columbia University, and then Maurice Fuerstenau, Doug's brother, went to Reno, Nevada, Nevada School of Mines. So, some schools became a center of excellence in flotation.

02-00:14:58

Burnett: I guess to distinguish it from the nineteenth century variant, it's a reagent-mediated froth flotation? Is that what you could call it?

02-00:15:12

Bhappu: You remember the old series called *Have Gun—Will Travel*? I wrote a paper called, *Have Flotation—Will Separate*. You can separate anything. You can separate paper, garbage, seeds, organic particles, anything that has a different surface, you can separate. So, today, we are separating scraps and dust, all those bad things because as long as there is a difference between the two particles –

02-00:15:50

Burnett: Right, right, for clean rooms! So, ionization of clean rooms is a descendent [of flotation techniques]?

02-00:15:59

Bhappu:

That's right. Many, many of them, especially – we'll go into rare earths [later in the interview], and that's where it comes in handy. Like, copper sulfides all over the world, millions and millions of tons of ores are treated. I told you we have several million tons treated in the 100-mile radius of Tucson – they all use flotation, and the reason is that they have one particle out of a thousand particles of waste, one particle of sulfide. They have the right reagent, the right condition, and up it comes.

02-00:16:40

Burnett:

Right. The reason, or one of the big drivers for the popularity of this process, has to do with the lower and lower concentrations of the ores that you're looking at. They're forced to use this process.

02-00:17:00

Bhappu:

The challenge of the century is if you look at the mineral resources like a cone, this is from year one, and this goes to, say, 4,000 years from now, or whatever. We are mining the apex right now, higher material, and the resource is limited. But the resource will come on bigger and bigger, but the grade will go lower and lower. That is where you've got to distinguish one particle from the other, so the surface chemistry of flotation is becoming a very bright topic, and everybody wants to do that.

02-00:17:42

Burnett:

We now know that there are deposits that were never considered before because they were such a low parts per million [grade].

02-00:17:55

Bhappu:

Like I said, rare earth is a very good example because they're only parts per million instead of percentage. Unless you learn about how to alter, it's not only what is naturally present, but by application of different reagents, different pH, difference for electroforces, you can make the differences more and more, so it doesn't have to be just the gravity. Maybe two particles are very close—for instance, you have copper sulfide and you have zinc sulfide—they tend to occur together, so when you float, you float both of them together. Now, you have to distinguish copper sulfide from zinc, so you take surface property of copper and go deeper into the chemistry to make a separation.

02-00:18:53

Burnett:

Is that what people refer to when they talk about a flow sheet, that you might have six minerals that are useful in a body of ore, and it's a process of elimination, right? Effectively, you're disaggregating, literally.

02-00:19:10

Bhappu:

The most important principle is liberation. You cannot make a separation unless the particle is free. If the particle is joined with the gangue particle, you may or you may not pick it up because flotation is strong enough that if the 10

percent of the surface is avid, you can make a separation. But if it's 100 percent, then you can't make a separation. This is where the crushing – because when you mine, you may have a twelve-inch or a twenty-inch boulder. The mineral is right in the center, so you crush it down by what they call jaw crusher, ball milling, and then liberate size, and then go into flotation.

02-00:20:13

Burnett:

So, there are two basic processes in modern mining. Well, there's more than two, but there's a physical comminution, is that right? Which is to crush.

02-00:20:26

Bhappu:

It's very, very critical because, as I said, if you want to make a very high-quality product, you'll have to make it into individual, separate particles. So, what they do is they pick up all the particles, good and bad, and what they call middling. There's mediums, and we call it rougher, rougher flotation. Then we, instead of grinding everything on the top, it's a very expensive process, we pick what we call a rougher flotation. So, if it's 1 percent copper, we make it into 10 percent copper, then we regrind it for more liberation. Then, when you pick up the product, it'll be about 20-30 percent copper, which is ready to go to the smelter. So, it's stage comminution, and I'll go into this in a little bit of detail, because the Department of Energy was very much interested in how much energy goes into it. Our company did that work for them, and I'll mention that as part of the research. Most of the research today is in flotation, but besides the physical and concentration methods, we also have the reverse called chemical concentration. That means that instead of removing a particle intact, if it is soluble in acid, we use acid leaching. Like chrysocolla, copper oxides, mostly copper oxides everywhere, if you look at the mine, the waste has some copper as oxide. They're not sulfides, so they will not respond to flotation, but they are still there. So, if you just put a little acid solution in the heap, it'll leach.

So, the first is the physical method, this is how we developed, physical method, then you come to the chemical method. If it's a chemical method, if it's successful, all you have to do is bring it into contact with the acid or a base or a certain chemical that will dissolve, then you make it separate by filtration. The solution comes out, or overflows, then you go into subsequent extraction of copper or iron. Those things like calcium and sulfates and all that, they are of no use to you. Then, you bring them as calcium sulfate, as gypsum, settle it out. So, that's how you make what is called hydrometallurgy. One is the process called the physical separation; the other is the hydrometallurgical separation, and actually, hydrometallurgy is dissolving one mineral out of all the rest. Once you dissolve it, you separate the liquid from the solid by filtration, and then again, you go back to the old method of flotation, and say, "Copper is attracted to this organic in the flotation. Now, I'm going to use the same organic to make the separation." So, we called it solvent extraction. All the copper goes into the solvent.



That solvent is mixed with oil, kerosene, so after mixing, you let it settle, and all that copper is with that organic product, compatible, but now it floats. It's contained in the kerosene, so the kerosene is taken out, and the barren liquid goes to waste after treatment. That's hydrometallurgical. Once you pick up the copper by solvent extraction, now we are making about sixty-five to seventy grams per liter, which is a pretty strong solution. And there is no lead, just copper—and then you go to electrowinning or electrolysis to make copper metal. So, physical separation, if it works, you make a concentrate, ship it to the smelter. If it doesn't work, you go to the chemical separation. You go to solvent extraction to collect what you want, throw the rest away, and then that collective one then goes through, strips it, and you can now make a very strong copper sulfate solution that goes through electrowinning.

So, these are the common processes, and that's how you deal with a flow sheet. First, you make mineralogical examination, you look at the character of the minerals, is that large differences in the character, you take advantage of it. Gravity, surface. Now, you have made a rougher concentrate. Then, you go to the smelter, and the smelter will not accept anything that's at, like a copper smelter, 25 percent, something like that, or 30 percent. They won't accept 12 and 15 percent unless it's a custom smelter, then they will accept it because they can mix it with the higher-grade material. So, that's a continuing process. First comes mineral processing, then comes smelting and refining, and then going into alloys and all that. So, that's metallurgy.

02-00:26:58  
Burnett:

The big picture of it, yeah.

02-00:26:59  
Bhappu:

You mine it, you drill it, examine the core, determine the mineralogy, go into testing, physical and/or chemical, and now there is a biological that'll come next. Then, you go to smelting, and then to the products.

02-00:27:20  
Burnett:

To back up to near the beginning of this process, there needs to be exploration and identification of a body, of a vein, because when you do a sample, you have to know the total size of that sample.

02-00:27:36  
Bhappu:

That's right. So, this is another discipline. First, the geology comes first, he looks, he says, "Oh, this is a likely spot." For instance, if you go around and if you see the reddish soil, you know there is iron. Where did the iron come from? It came from iron sulfide in the ore, which was dissolved by bacteria or by oxidation, creating iron hydroxide, which is red. So, you fly over the countryside, "Yeah, that's a good spot, let's put a drill." That's what the geological training is. The next step is to drill, collect samples, and make a complete analysis of the metal. What does this contain? What's more important than the valuable, is what is the worthless material, because it might

interfere. Pyrite is a common interferer. You don't want pyrite—they want copper sulfides, zinc sulfide, lead sulfide, but pyrite is depressed by lime, so you raise the pH to about eleven, and it coats the pyrite crystal with hydrogen oxides, OH ions, and it depresses. So, you use pH as an activator or a depressor.

02-00:29:03

Burnett:

There are all these variables. You've got electric charge, you have pH level.

02-00:29:10

Bhappu:

I bring this out that is important, it's where this thinking comes in: we know that the charges are important. However, to measure a charge and use an instrument to do that, it's very expensive. Thousands of dollars. So, when I was stationed in Turkey, this student asked me, "You know, we are poor, we don't have that machine." I said, "It's very simple—all you do is pulverize the rock, okay? Then, you put it in the water at a pH of 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, and where you have the most settling, that's where the 0.0 charge is. That's where positive and negative particles attract each other and they'll fall down. In the negative, they'll stay up, so you establish a zero point of charge, and then you can go further. So, there are little tricks of the trade. In developing countries, that's what you have to do. Yet, in the old days, that's what we used to do here. Now, of course, we have all these instruments of x-rays and all kinds of optical instruments. We didn't have that. So, you have to develop a different kind of your curriculum for developing countries.

02-00:30:49

Burnett:

We were talking off-camera about interdisciplinarity, and that a good mining engineer needs to be much more than that. So, economic considerations come into play with the energy-intensive nature of it. What's the most efficient way? This is something that becomes your passion, as we've said before, right?

02-00:31:15

Bhappu:

Let's see if in the afternoon session, we'll have the time to talk about it. Then, I will tell you about this energy consideration. We'll look at it in the afternoon session.

02-00:31:29

Burnett:

So, we've given a great overview of the kind of processes that are in play now, but also in the 1950s.

02-00:31:39

Bhappu:

The question is first, you must understand the mineralogy, so when a sample comes through our company, we ask the geologist, "Do you have the mineralogical profile?" "Oh, no, I can see it." No, let's send it to the mineralogist. He makes thin sections and gives us a picture of how the fine particle is associated. It tells about liberation, what are the core things that are there. So, mineral analysis and characterization is the key. Once you have that

information, now you know the physical properties: density, magnetic susceptibility, positive and negative charges, things like that. So, you can do a flow sheet development, one at a time. You compare the gravity against flotation, and normally, you find that the flotation is the best because you get more liberation, and you're picking up more of the clean particles by flotation. Then, you say, "All right, I've got a concentrate, should I sell it to the smelter?" The smelter will give you a charge, a cost analysis. It's called smelter schedule, and you say, "Oh, well, if I sell it to the smelter, he's going to take most of the profit. Maybe I should clean it up, maybe I should leach it and take one part of it?"

Then, once you have a process—crushing, grinding, flotation, re-cleaning—and you go to the engineer, and he'll make a cost of each unit operation and give you a capital cost and an operating cost. That comes into engineering design, construction. You need that because after you do the test, you come up with what is called mass balance. That copper you started out at 0.3 percent, where is it? Where is it going? So, you need to make a complete balance. If it is arsenic or something, you need to balance with that because that may be a penalty if you sell it to the smelter. So, that's how you develop a flow sheet. It's step-by-step process of identification and having experience to see which reagents or which chemicals will dissolve it.

02-00:34:28

Burnett:

So, it's an engineering process, it involves chemistry—

02-00:34:34

Bhappu:

It's physics, chemistry, and I think now will be a good time to bring in biology, too. Biology is a newcomer, and it seems that many of our deposits were created in the geological time, geological age, over millions of years, by bacterial activity. One of the things I told you was that pyrite oxides, puts iron in solution, precipitates at a higher pH, you get acid mine drainage and all the like problems, okay? So, bacteria, I didn't realize that bacteria played this. I know about biology, and I'll talk more about it, experiences with different projects. But now we find that biology plays a very important role in oxidizing. So, the surface has changed because now it's an oxide, so it will not react. Or, it's very finally disseminated. You have too much energy going into liberation. Well, we can use bacteria to dissolve the mineral, not the metal, the mineral.

There are two kinds of bacteria. One is oxidizers, and all the sulfides are oxidizers. You want to do that because oxide becomes soluble in acid, so you can convert the sulfide to oxide by oxidizing. They're called thiooxidants. On the other side, there is thio-reductants, the reducing bacteria. One is an oxidizer, one is a reducer. Now, where does that come in? Well, if you have contaminated water of copper, nickel, all that, going to waste or pollution, you would use a reducing bacteria because usually, it's in a sulfate media. It

breaks down the sulfate into hydrogen sulfide, which then attracts the copper/ lead/ zinc as a metal, as a mineral, and settles out. So, you have the oxidizers, and then you have the reductants, and many new processes, especially for uranium and rare earths and copper, even copper, is based on [this new process]. Gold, for instance, you use cyanide. But if you have arsenopyrite, which contains gold, it will not dissolve. But bacteria will break it down because it's a sulfide. So, biological sciences are now becoming more attractive as a less expensive option.

02-00:37:48

Burnett:

We'll talk about that in another session. We've got some time booked for that. So, if we can perhaps return to your dissertation research that you were doing?

02-00:38:02

Bhappu:

What happens is that when the particle is free, if you take copper sulfide, lead sulfide, zinc sulfide, or quartz, if you look at the particle, it has its own identity. But when you have finer and finer and finer particles, they lose their surface characteristic, and the electromotive force becomes very prominent. So, rather than showing individual characterization, they all behave similarly because the fine particle has a lot of surface energy. So, it masks the other properties that you are looking at. The only way you can find that out is by using pure minerals. So, I took lead, I took clay, and I took quartz, and found out that up to about five microns, they keep their identity, but when they go finer and finer, they lose their surface and they all behave similarly. So, that was, you might say, like a breakthrough because the biggest problem that we face in the mining, flotation, gravity, is fine particles. They are notorious. We lose a lot of gold and copper, and any valuable [mineral]. The finer the particle, the finer it gets, they lose their identity. So, that's where electrometallurgy or chemical metallurgy comes in, because physical separation is not possible because they have lost their identity.

02-00:39:52

Burnett:

Right. So, comminution is this process of getting it to a uniform size?

02-00:39:59

Bhappu:

From coarse material all the way to the finest size.

02-00:40:02

Burnett:

But you can go too far?

02-00:40:04

Bhappu:

I measured their surface energy.

02-00:40:08

Burnett:

Right, so it's possible to grind too far, to the point where it's no longer detectable?

02-00:40:13

Bhappu:

That's right. At that time, you should go to smelting or refining or something else because it's too expensive, and not only that, but the new particles—because clay behaves like a sulfide. You can't separate the two.

02-00:40:32

Burnett:

I've read about pelletization. Is that a process of taking something fine and making it—

02-00:40:37

Bhappu:

Yeah. That's called flocculation. There are certain organic compounds or inorganic compounds that will flocculate. Clay is the most important. It's something like a silicate, sodium silicate. It's a charge, but it combines everything. Or sometimes, it's dispersive. So, both these mechanisms come in play because sometimes you want to make an agglomerate or, for instance, if your gold particle is very, very fine, but liberated, you know that you've got to use lime for dissolving gold in a cyanide solution. But lime also acts like an agglomerator, or a flocculator. Instead of fine particles, now you have half an inch, quarter-inch particles to leach. So, all your settling problems are eliminated, filtration, and all of that. So, flocculation and dispersion are both important. When you go to an iron mine, they pelletize because in a blast furnace, they'll be blown off. So, pelletizing with lime, and one of the best is sugar. Guar is a very good pelletizer, and it disintegrates into sweetness in the end, so you don't have to worry about it as a contaminant. So, molasses, these are the agglomerators.

02-00:42:28

Burnett:

So there are these techniques for preparing it for analysis, preparing it for separation, and for final smelting.

02-00:42:36

Bhappu:

For final processing, yes. Now, there are people who specialize in agglomeration, and especially in Michigan, where they have a lot of iron ore mines. Iron ore is sometimes, of course, very fine, so they have to agglomerate. On the other hand, sometimes clay particles are terrible. They float very readily, they are so fine, they just behave like a good material. The bubble doesn't care whether it's good or bad, just as long as it's non-polar, it'll pick it up.

02-00:43:18

Burnett:

Can we talk then about you finish your dissertation, and you have a first job as a project engineer at the Colorado School of Mines, at the Research Foundation. Can you tell me a bit about that?

02-00:43:35

Bhappu:

At the Colorado School of Mines and all school of mines, have a research foundation, usually when the US Bureau of Mines was operating. They felt that they should put up their laboratory or their station at the school of mines

so there is close collaboration. Now, Bureau of Mines is gone, so people have to come up with the experimental plant because we are not trying to make a theoretical metallurgist. We want him to be practical, and when you do flotation, understand the theory, but you take the theory in the practical laboratory and try it out. So, experimental plants and centers at the metallurgical level is a common phenomenon, especially in the older days. They used to be called, it was usually endowed, and usually supported by industry because they are the beneficiary. So, when I came to Colorado School of Mines to do my doctoral dissertation, I had all the practical, all the coursework, and I also wanted to earn some money. So, they said, "Come on to our experimental plant and see what you can do to help the industry by solving practical problems. Interestingly, one of the projects was rare earth from Mountain Pass, a long time ago. You get acquainted with them, then it is not only a very nicely professional, but you also are requested to make a lecture to the students or demonstrate for them. So, you become a professor also in the same time. Experimental mines have an assistant professorship.

02-00:45:47

Burnett:

You were a kind of a postdoctoral researcher?

02-00:45:49

Bhappu:

That's right, exactly.

02-00:45:54

Burnett:

So, that was at the research foundation?

02-00:45:57

Bhappu:

Right.

02-00:46:00

Burnett:

So, this is going into the 1950s?

02-00:46:03

Bhappu:

Nineteen-fifties, '54, yeah.

02-00:46:09

Burnett:

So, did that lead to any contacts in the industry?

02-00:46:15

Bhappu:

Definitely. That was the most important way of getting acquainted, especially local industry, Colorado mines, New Mexico, and California, Utah, they all worked together.

02-00:46:32

Burnett:

It's all part of a community?

02-00:46:34

Bhappu:

Community, and you know the professors, you know the leaders, and some of your own colleagues are working for another one. This gives you a start for

the future because you don't make a career out of experimental [research]. You can do that, too, if you like teaching and passing on the information, but this is more for experience than anything because you have some older people who have been there for years, and they impart knowledge to you. So, the experimental center is not only to experiment, but to come in contact with the industry, to come in contact with leaders, processing people who had worked for forty, fifty years, and they are ready for retirement. They want to do and contribute their last thoughts to the young generation.

02-00:47:30

Burnett:

So, in the agricultural and mechanical colleges, there's this principle of the extension service, right? You go out and you demonstrate new techniques to the farmers. This is kind of an extension service for the industry.

02-00:47:45

Bhappu:

That's right. Usually, tied up with the school, it's a part of the school, because it gives them additional facilities and equipment to demonstrate.

02-00:47:58

Burnett:

So, can you talk a little bit about the project you did for them? Or was it multiple projects that you did?

02-00:48:05

Bhappu:

The idea here is twofold: one is a major problem that's facing the industry, and that becomes your major project. On the other hand, a guy will come and say, "Hey, guys, I think I've got some manganese here, would you prove it out?" I said okay, we put it through x-ray diffraction and get a pattern and [we tell him] "yeah, you have some, but hey, you forgot there's more lithium than gold." He then says, "Now what do I do?" That's how it starts. Out of a hundred projects that will come to us – it's a good background for diversity – a hundred projects, maybe two or three may be legitimate. The others are, oh, the guy thinks he's got gold. Everybody thinks he's got a mountain full of gold.

02-00:48:57

Burnett:

So, there's this process of service, again?

02-00:49:01

Bhappu:

It's a service, and all the Schools of Mines have a Bureau of Mines [office], and they provide the service.

02-00:49:11

Burnett:

We'll go back to talking about the specific, major project that you faced, but you mentioned that the Bureau of Mines is no longer in existence.

02-00:49:18

Bhappu:

Yeah, it was disbanded. It was a big shame and a real crime. It was government-supported. Every Tom, Dick, and Harry could bring their ore to

them. They would say “no, good, bad, we’ll do this and that,” so that was a good service. It was also research. Some of that ore, this is like rare earth or this is uranium—how do we recover it? They want to make sure if it’s uranium and thorium, the radiation doesn’t affect them. So, they do a good service to the industry, and the Bureau, every year, hundreds and hundreds of publications of specific interest, just the mineralogy of the ore, or flotation characteristics, or this occurs in a formation and there is a mine adjacent to it. Does the ore come into this new formation so we can open a new mine? So, we can have geologists, we can help—is there some bacterial activity or is it oxidizing?

Pyrite is notorious. It’s actually a copper sulfide, cuprite, you put it in a microscope, go get your lunch, come back, and the darn thing has a ring on it. It oxidizes that fast. Then, it loses its identity, so then you have to scrub it. So, you blunge or scrub like cloth, put pebbles and pebbles and clean the surface out. So, before flotation, you have an agitation and a blunger, or we call it an agitator. Or, actually, surface cleaner, using the particles themselves.

02-00:51:36

Burnett:

So, it’s just a physical agitation, basically? So, that was one of the major research projects that you were doing there?

02-00:51:43

Bhappu:

That’s right. Those were the kind of projects, and sometimes it occurred that if it was a gold project and if it was a placer, it was mechanically and geologically set up. So, why treat the whole ore and leach it? Why can’t you just selectively pick up the gold? The gold appears fine, so you take the material, crush it down, put it in a plate, and you use a gold pan, and you see the gold beads. So, you can see that it’s there, and gold is one of the most easily floatable materials because it has that metallic surface.

02-00:52:28

Burnett:

That’s the ultimate agitation element?

02-00:52:35

Bhappu:

So you have two advantages: one is that you will lose it anyway, by other gravity methods, except flotation. But if you go to leaching, then you will have to use cyanide. So, why not pre-concentrate it and then go into a smaller cyanide plant, which would be more environmentally attractive?

02-00:52:57

Burnett:

So, this is early 1950s?

02-00:53:01

Bhappu:

Cyanidation is 100 years old, yeah.



02-00:53:06

Burnett:

But you're talking about taking a mentality that was brought to you by your Zoroastrian tradition and your education to think about not only efficiency, which is always the concern, but also this concern that why use a harmful chemical that would be in the environment and that would pollute?

02-00:53:33

Bhappu:

This is why, today, there is a big push to displace cyanide in gold leaching. There is a big effort all over the world, and there are some new reagents that are more acceptable. My question is, is that if you can do it by physical means, let's do it. Don't go to chemicals unless it's necessary. If you use chemicals, use it, but recycle it, so it doesn't go out into the tailings.

02-00:54:17

Burnett:

There's a whole bunch that we can talk about when we're talking about recovery.

02-00:54:21

Bhappu:

You're talking about the simple processes that Japan—I used to be very close to the Japanese—they had a plant and the tailing had soluble copper and zinc going out in the tailings, and they were worried about it. So, the Japanese guys came and said, "You know what we did? We put that little organic [chemical?] that we use for flotation of the particle, well, we put it in the solution, it picks up the copper and comes up on the surface with the bubbles." So, they use flotation on the liquid—

02-00:54:55

Burnett:

Flotation on the tailings?

02-00:54:57

Bhappu:

On the tailings, to pick up the soluble part.

02-00:55:00

Burnett:

So they're reprocessing the tailings, using the same techniques?

02-00:55:02

Bhappu:

[technical difficulties required Dr. Bhappu to recreate the following paragraph during his editing]

Yes, in general the tailings are now processed to recover about 50 to 60% of the residual values by using new and elaborate techniques not only to recover the metals, but in many cases, be feasible to ameliorate associated environmental problems. These techniques include upgraded gravity, magnetic, electronic sorting, etc., to recover one third to one half of the metal values from these tailings. Such tailings can cause lots of environmental problems by washing out the toxic slimes and also cause acid drainage by torrential rain; especially from uranium tailings. Thus, processing of tailings from older operations in the Southwest mines became quite critical.

Burnett: And with recycling, you could do the same thing.

Bhappu: That's right. That's right. The environmental approach is very attractive. Take for example the airplanes that are scrapped. Aluminum is lighter than copper. [Ed. Note: Here Dr. Bhappu talks about how separation techniques are applied to post-consumer recycling.]

Burnett: So there's a flow sheet for recycling.

Bhappu: Recycling is one the bigger challenges.

### Audio File 3

03-00:00:00

Burnett: This is Paul Burnett, interviewing Dr. Roshan Bhappu for the Mining Project as part of the Business Series for the Regional Oral History Office. It's March 5, 2014. Dr. Bhappu, we left off talking about your first job, and then you were hired by Miami Copper, in Arizona. Do you want to tell us how that came about?

03-00:00:43

Bhappu: After my experiences with the Colorado School of Mines and Research, I was looking for a job. In that interim period, I went to visit my parents. One of my friends was working in Arizona, and he also used to work with me at the Colorado School of Mines Research Center. In those days, we had a telegram. It said, "Roshan, are you interested in coming to Miami?" So, I shoot back and said, "Yeah, Miami, Florida, sounds great." The answer comes, "Miami, *Arizona*." [laughter] "Well," I said, "Yeah, I'll take it." What happened is that the Miami Copper Company had been in operation since the late eighties, early nineties, and it was an old mine, but they were now coming to the close of what was known as the deposit. So, they gauged there 150 million tons. After about seventy years, they were just about ending the project, or the mine itself. They told me but at the same time, they were trying to bring in another operation, not about ten kilometers from the Miami mine. It was called the Sleeping Beauty mine. The formation was looking like a Sleeping Beauty. So, I said yeah. That was a challenging assignment.

So, when I came to the general manager, he says, "Welcome, we are very happy to have you. Roshan, we have two problems: one is to extend the life of this Miami operation because we are using a block cave method of mining," where they opened the ground underneath and let that go. Well, it's a block cave, so they were caving the block and then bringing it up to surface. He says, "Because of our underground operation, our costs are high, so we have to close that mine. We can't afford it. But we are leaving about 150 million

pounds of copper, of low-grade material, and you have about four or five years to come up with an answer. You are the Chief Metallurgist now.” So, I said fine, and the other thing is we had a new mine coming up, and we got to make a flow sheet for that. Looks similar to the old Miami mine, so it shouldn’t be very difficult. “That’s fine,” I said. I had a staff of about three metallurgists and three assayers, and then, of course, the whole mining operation, the mine superintendent, the plan superintendent, and so we suggested this—how can we extract what is left behind?

The question that came up is, if we cannot mine it, can we put a solution in it? Because this is from 800 feet deep to 1,200, so, 400 feet of mineralized, broken rock. So, I looked at the samples at different heights and levels, and found out that the chalcocite, the copper sulfide, was in fracture fillings. When it burst, when it got caved in because they undertake so many percentage of the rock underneath in the remaining caves. So, it was a fracture filling, and in breaking, they exposed the mineralized areas. They didn’t realize that. When I examined the old cores and all underground, that’s what I found. So, I told them that what we’ll be doing is an in-situ leach.

Why in-situ? First of all, it’s a caved-in area, so the mineralized block, although only 0.3 percent, in the breaking, the edges or the fractures are open. So, we don’t need a finer grind, we don’t need a grinding operation. Copper there is going to come out because it’s on the surface, with the fracture. So, we’ll inject a low-grade solution of 5 percent sulfuric acid, and we will then let it go to the bottom level. That was truck haulage in the old days, and it was still open. We will let all that solution drain into the lowest level, which is a collection gallery. We’ll collect the solution and bring it to the surface, recover the copper, and then put the raffinate or the waste solution back, and just keep on going.

So, I went out to the Miami office in New York, and the board of directors, they said, “How are you going to do it?” I said, “I’m just going to inject solution, just let the chemicals do the work, and I’ll pump in and pump out, just like acid or oil.” “Oh,” he says, “well, that’s very novel.” The other thing I found out is that if I took the solution from the mine and put it, you see, actually, the leaching agent is ferric, iron-3, ferric sulfate, which eats away the copper.

03-00:07:23  
Burnett:

But it’s sulfuric acid?

03-00:07:25  
Bhappu:

Basically, the iron is already there from the pyrites and all that, so iron is already there. All we have to do is put the acid, but I found out that if I take that solution, I wanted to see if I can work the ferrous because ferric, it is eaten up, and ferrous is created, so it just keeps on. I could not regenerate the

ferrous to ferric, if I just put all the air, all the oxidant, everything, nothing happened. So, one time I said, “Well, there’s something in the soil, maybe.” So, I took the soil, and it’s not it. Percolating the solution, and suddenly I got the ferric. So, at that time, US Bureau of Mines was in Pennsylvania, and the coal mines were facing the [problem of] acid mine drainage. Acid mine drainage is the old pyritic content of the coal that oxidized and put iron in solution with the acidity because it’s a sulfide, so it oxidizes to acid. But when the solution went into the river or the water course, when it reached the pH of 2.5, all the iron that was in solution precipitated as ferric hydroxide, yellowish-red color, and all the streams began to look dirty. That is the acid mine drainage, that’s what they were looking at.

So, they had a big research group at Cincinnati Lab, and I sent them a message to say, “Would you please tell me why I am getting conversion of ferrous to ferric? Not from the solution, but when I use the soil in conjunction.” In a month, they said, “Oh, this is a bacterial activity. This is an oxidizing bacteria that is creating the same problem in the coal mines, so that’s what you have. You have bacteria in your soil, the surrounding soil of the mine.” I say, “Is it unique to Miami?” “No, no, no, it’s anywhere in the world you have sulfides, you’re going to create oxidizing bacteria. They are self-generating, and they’re not artificially created. It’s just the natural way nature works.” Many of the deposits were created by this bacterial activity on the surface. So, when I was talking to the board of directors and I thought I might get some help from the bugs – so it’s a bug leaching – they nearly threw me out. I said, “No, this is how it works.” He says, “Okay, we believe you, we’ll give you 100 foot by 100 foot block. Prove it to us.” So, I took a big pipe and filled it with about 800 feet of ore, forty feet high, and started percolating solutions, first with artificial bacteria, and then without bacteria. I got the same copper recovery. So, this proved that it would work whether you have bacteria or not, but you can enhance the activity if you have the bacteria present.

03-00:11:18

Burnett:

So, this biological factor was known to the mining community?

03-00:11:26

Bhappu:

It was known to the environmental people in the coal industry, and the Bureau of Mines is interdisciplinary, yeah.

03-00:11:37

Burnett:

Right, so they had picked this up as an observation.

03-00:11:40

Bhappu:

They had already proved that this oxidation is because of bacteria, and if you kill the bacteria by putting bactericide, you don’t get anything. We proved that to satisfy ourselves. So, we started this block and started injecting solution. One hole in the center hole, and picking up through four holes, recovery wells,

in the four corners. The solution would migrate like that, and we started getting copper in solution. So, first we did it with the bacteria, then without the bacteria, to prove that it was actually bacterial activity in nature that was helping us. It seemed that that was a convincing proof that the bacterial activity was responsible, at least half or mostly, but acidity alone was enough to create oxidation from ferrous to ferric. So, all we had to do was to feed the bacteria. They require certain nutrients and so on, which are naturally available, and so, we proved that in about twelve to eighteen months. Then, we had about 150 million tons' block. So, we put monitoring wells, so we needed to monitor that the solution was not migrating out of the field, that there was what they called a circulating natural—

03-00:13:36

Burnett:

A natural reservoir, right.

03-00:13:39

Bhappu:

A natural reservoir, right. So, we did that and started the operation, full operation, in 1959, just before I left. The whole operation was going on because we had about several square miles of area to cover, but we had only 10,000 gallons a minute flow. So, we had to select where to manage it, and that was leach management, which was a modeling process. So, after we proved that it works, they said, "How long will it last?" The copper that was in solution, we already used to sprinkle dumps with acid and pick up that [a process called dump leaching, where you let a leaching agent such as acid percolate through a pile of broken ore on the surface and recover the metals in solution from underneath]. That was happening already. Now, I was just taking it down into in-situ, and we had a precipitation plant in which we used iron scrap. The copper solutions would move through the iron, iron would go in solution, and copper will precipitate out. It's called a cementation process. So, we use the same process, cementation or precipitation, and using scrap. Everything worked good, and we started making good progress.

About ten years later, they called me up when I was in Socorro, says, "Hey, how long will this thing keep on going?" I said, "As far as I'm concerned, it can go on for ages." I said, "How many pounds of copper have you produced in ten years?" They say, "Oh, well, we have produced about 15 million pounds by right now." I said, "How many did you leave in the deposit when you ceased the mining operation underground?" "Oh, about 150 million." So, I said, "You only recovered part of it, so you can go for another fifty years." They want to know if they can put in a solvent extraction plant rather than a cementation plant—because I told you that the copper goes in to the organic, which is floating in the oil. We call it SX/EW, solvent extraction, electrowinning. "So, we are going to invest about \$20-25 million in that, do you think it's worth it?" I said, "Sure, because what I had shown is that theoretically, I would come out when I started the operation with the lab, modeling, we come out at four grams per liter, and I predicted about twenty,

twenty-five years before it came down to 0.5. They are now already proving that you will go up to 0.1.” So, I said, “There’s no risk in putting in the money—let’s just go ahead.” So, they went and ’59, so let’s say ’60, fifty-four years later, it’s still operating. They have picked up more than a hundred million pounds of copper.

03-00:17:24

Burnett: A hundred million pounds?

03-00:17:25

Bhappu: Yeah. Without any effort. I said, “I wish you had given me one cent a pound royalty!”

03-00:17:34

Burnett: So, it was 150 million pounds left in the ground?

03-00:17:39

Bhappu: Right, 150 million pounds of copper, not ore.

03-00:17:46

Burnett: So, they wanted to extract that, and two-thirds of that has already been mined?

03-00:17:49

Bhappu: I told them that rather than close the mine and shut the operation, let’s do the injection. We have complete control over it, all the solution is not going to migrate, it’s going to go to the lowest floor. We’ll pump it up, we’ll take the copper, and put the solution. So, we have a metallurgical-economic solution, and an environmentally attractive solution.

03-00:18:11

Burnett: And, this seems to be applicable to all kinds of situations, but especially remediation of existing mines.

03-00:18:23

Bhappu: That’s right, it can be. Okay, so, that’s my big challenge. I made a name for that, and everybody who came to me said, “Can you do this, this?” I said fine. That’s a classic example, and now everybody is following it. Now, what happened is after I left Miami Copper, for Socorro, which is the New Mexico School of Mines, one of the local managers of the mine was an alumnus, and he had talked to the president. He says, “Why don’t you invite Roshan to come to New Mexico, to offer him a good salary, Chief Metallurgist, and put him in the New Mexico Bureau of Mines?” He talked to the Bureau of Mines, and I knew the guy who ran the Bureau of Mines. We were all friends, so I accepted the challenge. So, my family and I, we went to Socorro. I was thinking I might stay there four years, six years, ten years. We stayed there fifteen years, and started out, I was also giving lectures to the metallurgy department and the mining department.

After two years, seeing what I was able to do with the staff, and I talked to all the staff, which was interdisciplinary. We had geologists, miners, chemists, biologists, groundwater hydrologists, petroleum – 120 professors. So, I went to the board of regents and spoke to the president, Colgate, and says, “Look, this is interdisciplinary, and we should make an in-situ research center out of New Mexico Tech, and offer graduate degrees, okay?” They went to regents and got the okay, and we started the In-situ Mining Research Center.

03-00:20:49

Burnett:

That was '62?

03-00:20:51

Bhappu:

Sixty-two. I went there early '60.

03-00:20:56

Burnett:

Just to put the timeline in here.

03-00:20:58

Bhappu:

Yeah, in 1957-59, Chief Metallurgist, Miami Copper, and '59, Senior Metallurgist for the State Bureau of Mines. Actually, it was '60, end of '60.

03-00:21:18

Burnett:

The embedding of the State Bureau of Mines in the New Mexico Institute, it was already there, and the institute grew up around it?

03-00:21:25

Bhappu:

Yeah, all the school of mines had an experimental plants and Bureaus of Mines, that worked closely with the US Bureau of Mines to encourage localized options. So, I started with the State Bureau of Mines and Mineral Resources, and also, the research professorship continued. I used to offer one or two classes a semester, and kept it to extraction using in-situ, new mining methods, biological methods, and so on. It created jobs for the research group and also the teaching was done simultaneously. All my students went into the experimental part of the operation, and actually worked with the samples and all that. So, it was more like a graduate course.

03-00:22:25

Burnett:

These are techniques for essentially seeding a mining site with the nourishment for bacteria?

03-00:22:38

Bhappu:

Most of them, they get nourishment from the soil, but after you have excavated that, some of the organic material has been depleted, it usually is ammonia, a little bit of phosphate, things that's like nutrients. The same thing that is good for a human body. They said, “Now, why don't we start this research center?” So, they made me vice president of research for the whole institute, and I had 120 people to work with. So, we had sat down and we all talked about what targets we should look at. We have minimum budget, we

have many people, and we need to be teaching also at the same time. We found out that uranium was getting popular, and New Mexico had many, many uranium mines, and also Texas. The first operation was in Grants, New Mexico. That's where the atomic energy and everything was. So, we said, "Well select a simple target, not too deep, layered soil, so that it was more like a stratification, okay? Layers. It was not jumbled up. So, once we went into the 450 feet we are in uranium for about ten feet or so, and then out.

I had the hydrology group say, "All right, if I inject here, how do I recover the solution?" So, they made modeling and came up with the pattern, what you call the injection pattern, drilling pattern. In the first two years after we started the first in-situ operation in Grants, New Mexico, with Anaconda Company, and we were successful. Everything was in our favor. The right deposit, the right fluid flow, because the fluid flow is very critical. If the fluid flow is not very high, we have to induce it, just like fracturing. We can use fracturing or we can use high pressure. So, the petroleum department was right there, and they started contributing their technology.

03-00:25:20

Burnett:

The initial inspiration for you came from oil and gas, is that right? Initially.

03-00:25:27

Bhappu:

No, no, that was for fracking. What I'm saying is you don't need to frack. What we would do is we would go underground, excavate 10 percent of the cut, and then cave in. So, that was easy to do, but if you had stratification deposit, the solution would not penetrate that ten-foot layer. The solution would just move along, and then we can pick it up, and we started that as an experimental plant. Next thing we know, people started asking us how to design an in-situ leach. In-situ leach became a very famous institute, and every year, I used to have a seminar, an in-situ leach seminar, through New Mexico Tech, where we would invite guest lecturers, other people who wanted to know about that. We had a one-week seminar on in-situ leaching, which became very popular. The copper people started using it.

Of course, uranium leaching is renowned. There must be more than 100 mines operating in the United States, based on this principle. Now, we are going after copper. In Australia, they liked my idea, and they went after gold because the gold had migrated down to the bottom of the layer. It was about 400 feet, and that's where gold being heavy couldn't penetrate further. It was settled out like a deposit, so they started putting cyanide and pumping it out. In-situ can be used for practically anything, including rare earths. When I go to talk about metals, that's when I'll talk about it. In-situ is a very simple method of fracturing the rock or taking those horizons that are favorable to solution migration, and start adding acid or alkali. Some of the copper and uranium ores are low-acid consumers, so we can use acid for them. Those that are high in calcite, calcium carbonate, the acid consumption is very high. We



found out that we could use calcium carbonate solution with sodium hydroxide. Raise the pH because the minimum solubility of uranium oxide is 5.5. So, it's soluble in acid, soluble in base. Depending upon the acid consumption, we could change that.

03-00:28:35

Burnett: Right, to get the maximum.

03-00:28:36

Bhappu: Some are alkali operations, some aren't, but the principle is the same: once the uranium goes into solution, you use solvent extraction or ion exchange to pick up the uranium and vanadium, and some molybdenum.

03-00:28:53

Burnett: I just wanted to clarify and go back to the original idea for solution mining, injection of a fluid, and recuperation of the fluid and recycling. Prior to that, there was an understanding of solution mining in mineral processing, but not recovery.

03-00:29:19

Bhappu: We used to call it heap leaching and dump leaching because low-grade material from the open-pit mine would be put down on the surface. They still had copper, and if you did not regulate that, it'll cause a problem with acid mine drainage. So, we started percolating solutions. Heap leaching, dump leaching, became our favorite subject, and the in-situ was an extension of that. The Miami Mine gave us that opportunity to prove that.

03-00:29:57

Burnett: Now, there, the technique for drilling, injecting fluid, and recuperation: that's oil and gas engineering, no?

03-00:30:10

Bhappu: That's hydrology. That's geohydrology and those are the guys, engineers, hydrological engineers, come up with the model depending upon the permeability. In the lab, we run a permeability test: so many darcy is a measure of how permeable the rock is. So, we take the core and we push the solutions through it. Sometimes it goes right through, the darcy is about 3.0, it is very porous, or it would be 0.3, or 0.03, where you have to induce pushing. So, pressurizing came out next, breaking rock came out, and then actually, mining to create what we will call an in-situ block cave. You would go in, put pillars to hold the rock, just before you go out, you blast all the thing, and everything will come down. It won't go to the surface. Then, the Atomic Energy Commission asked me, after they said, "Can't we use atomic energy for that?" I said, "Sure, but it's too wild. You've got to control it."

03-00:31:37

Burnett: Oh, they were asking about blasting with fission.

03-00:31:39

Bhappu: Yeah, right, it's a peaceful use of it. That was at Berkeley.

03-00:31:46

Burnett: Well, that's Edward Teller, I guess.

03-00:31:48

Bhappu: So, they asked me, "Can you?" I said, "Sure, you can use that for leaching application." Of course, they used to make harbors, peaceful use, and we found out that since we were already using it for uranium [extraction], we know how to control it and all. So, it's a peaceful use of energy, so you can use that block caving and things like that for that purpose. So, of course, every company, every country started contacting United Nations, they say, "Can't we get this technology?" The United Nations offered me a consultancy in about the third year that I was there, where I would put in forty-five days a year, in United Nations.

03-00:32:41

Burnett: This is in '64?

03-00:32:44

Bhappu: The UNDP, as a consultant.

03-00:32:48

Burnett: They came to you?

03-00:32:49

Bhappu: Yup, they came to me and offered me a consultancy service. They said, "During the summer, we would like to have you work with us. So, I used to work in New York in that big, tall building, on the twenty-sixth floor. In-situ was only one of them. They also wanted me to look at other projects. So I talked to my family and I said, "Well, during the summer, we'll move to New York." We had a nice little apartment, and we enjoyed that. It gave me an opportunity to come into contact with people from all over the world. So, New Mexico Tech was the foundation to cultivate and grow the in-situ as well as dump leaching, heap leaching, biological leaching, and we had two of the famous biologists in the mining, are Corale and Jim Brierly. They're a husband and wife team. Corale used to be my assistant, and Jim was the professor in biology. They took a keen interest in biological research, so we started the biological research because the bacteria was there. We tried to extend the application of bacterial activity. Those Brierlys now are the chief people—they consult for everyone.

03-00:34:39

Burnett: They are the gurus now.

03-00:34:40

Bhappu: Yeah, but they always say, "Yes, we learned it here." One of the guys, Dr. Roman, who works with me, he's a consultant, also. He's my right-hand man,

and he specializes in chemical metallurgy but modeling. So, he's modeling all these things, and we can take one rock, say a two-inch piece and a half an inch, and looking at the extraction curves and the way data forms, we can extend, we have what is called a shrinking core model. The leaching occurs from outside-in, so the core is shrinking. The mineralized core is shrinking. It's a big piece, but the solution keeps on going till the core is left. Copper sulfate or uranium migrates out by a capillary action, and we pick it up. So, we model, and we can make an economic model, time versus recovery, based on two tests, one coarse and one fine, and in between the two, once we have that key value, we can go to twelve-inch piece or half an inch piece.

03-00:36:03

Burnett: It's all scalable?

03-00:36:04

Bhappu: It's scalable. This is how we predict dump leaching and heap leaching.

03-00:36:10

Burnett: So, you developed all of these tests to determine the feasibility of the study?

03-00:36:20

Bhappu: That's right. Though, we didn't call them tests. We do that all the time because otherwise, to determine the best variables or parameters, we have so many that you'll have to run hundreds of columns. But with a limited number of columns, properly done, with strength of the solution, with size of the particle, with density, all this we put into the model and say, "This is what would happen in a big operation," and then prove it in practice.

03-00:37:05

Burnett: So, it's a synoptic view. It's not a complete view, but it gives you a certain percentage of accuracy and predictability?

03-00:37:12

Bhappu: Well, there is always that, but then what we always do in the operation, we go into the field and demonstrate it. That's part of what we call pilot plant. There are three operations starting up, but before we did the test with them, I said, "You put in \$30 million." This is a pilot plant because you've got millions and millions of pounds of copper or uranium, and you don't want to take a risk, but you take a certain area, certain blocks, and not only one block, but have a series of blocks, so you are leaching maybe ten blocks, instead of the whole five square miles. This is how we help the industry, and so, New Mexico Tech was a great opportunity to prove processes, to work with students, foreign students, we had a lot of foreign students, so once they were there, they will say, "Would you please help us?" We'd send them to undergraduate school, or give them opportunity to go and work with the industry, learn the trade. While working at Socorro, I got the idea, [looking at notes] oh, this is wrong, "UNESCO consultant, '69-'70."

03-00:38:52

Burnett:

Oh, that was just one moment, but there's multiple consultancies throughout, to the eighties?

03-00:39:00

Bhappu:

In 1969, the United Nations says, "Look, you are our consultant in mining metallurgy, could you please go to Turkey on your sabbatical and spend one year, minimum, with the Middle East Technical University in Ankara, Turkey, to update their mining and metallurgy departments. The Ford Foundation had given them \$10 million. Several years ago, they started the department, but it was never upgraded. So, my task was to bring in new research, teach new students, train more professors. Ankara also had the Turkish Bureau of Mines office, just a mile away, so we collaborated. I saw a lot of Turkey because I had graduate students, and I would select one of them, and he would take me on the weekend. They got Friday off sometimes, Friday, Saturday, so we'd go to his hometown and he would show us all the things, the archaeology, so that's how I traveled and learned a lot of things.

03-00:40:24

Burnett:

It's a very rich place for history and ancient civilizations.

03-00:40:29

Bhappu:

One time, we were on the Mediterranean Coast, and this guy says, "Sir, this is where Anthony kissed Cleopatra." I said, "How do you know this spot?" He said, "Sir, in the old days, the ocean came here, and I don't know where, but she kissed him so many times, you can select your spot." [laughter] So, those were good guys.

03-00:41:03

Burnett:

So, you were at the New Mexico Institute of Mining and Technology, and you pioneered and ushered in pioneering research? You facilitated –

03-00:41:13

Bhappu:

Two things. One was the in-situ leach, or leaching in general, and second was the bacterial use, yeah.

03-00:41:22

Burnett:

But you're also a director of research.

03-00:41:25

Bhappu:

We had many other projects going. We did work for Kennecott, the Bingham mine, that was operating for sixty years. They were leaching, but they didn't know what it was. They put 400 million tons, they didn't know what was happening. So, he says, "Can you see what's happening?" I think that with my modeling I can see what's happening, so we drilled forty-two holes, collected the samples every ten feet of all the forty-two holes, we examined each for oxidation, bacterial activity, and amount of copper left. We came out with a map of certain portions of the deposit were never reached by the solution

because in the old days, all the waste was dumped through a railway line. The railway would come and dump it. Then came the trucks, and the pattern changed. You could see the difference in the way the material was settling. Based on that, we showed them where the values were and where to recover that, so that was part of the Bureau of Mines service, research. They paid all the men, and then we trained a lot of kids on the project. So, I think that a school environment, college environment, we are not taking as much. Now, in Tucson, we are doing very well now. We have local AIME, SME is working, they're all working together. Each summer, we send students out to each of the contractors in the mine, so they can learn the trade.

03-00:43:22

Burnett:

So, the University of Arizona is very profoundly connected?

03-00:43:26

Bhappu:

Yes. Well, all the bureaus were, and all the schools of mines were. But since I moved to Arizona in '72, I've been close to the university. I used to give lectures and all. Of course, now things have grown too big, but I'm still advising them, AP college, co-operative research. I also started cooperative research during the school time. Each student would work with me for ten hours a week. Only ten hours. He would put two hours per day in a training program, and we would pay him to work, so that he can make some extra money and go to school. Much of the research was done for the mining companies, so they actually contributed.

03-00:44:30

Burnett:

Right, this mutual benefit, yeah.

03-00:44:32

Bhappu:

Mutual benefit. So, to me, if somebody was to say, "What was your highlight?" I would say that what I'm enjoying today, I equally enjoyed when I was at Socorro, for fifteen years. It was just a wonderful opportunity to learn more and more about different sciences, more about the mining industry, more about the professionals, more about the students or the future engineers, and more about different countries—especially developing countries. All my projects were a part of the United Nations. One of the things that I did with the United Nations was in Pakistan.

03-00:45:35

Burnett:

In essence, you came of age, professionally, at a time, when you came to the United States, Truman announced Point Four in 1949, so technical assistance becomes official US foreign policy at that time.

03-00:46:05

Bhappu:

That was one of the projects that we worked on in the United Nations Development Program, was that we, in Tucson, had a Gem and Mineral Show, which was very popular for many, many years. I used to meet a lot of people from developing countries bringing their gems and minerals, and they wanted

to know what they should be doing. So, I approached the United Nations and said, “Why don’t we set up a seminar program? Every two or three years, we will have a seminar at the trade show.” Also, in developing countries, it’s held every five years, a two-week seminar. One of the things we found out, that all these people, there were hundreds of gem collectors and gemstone industry people, we tried to tell them how to mine, how not to injure the rock and the crystal itself because that’s what they are selling.

So, I had a couple of guys on explosive technology, and so, my first assignment was to Pakistan. The northern part of Pakistan, between Pakistan and Afghanistan, there is a lot of mineralized gemstone minerals occurring—especially emeralds and rubies, sapphires, and tourmaline. So, what I set up was a way how new technology can help old miners. What we tried to do is to train them to look at the character of the mineral, how to separate different gemstones and make just home-made tests to see what is the specific gravity, density, things like that. So, that became a very challenging assignment because none of them could talk, they were not scientifically oriented, some were. So, we picked some of the students or teachers from their geology departments and others to become as teachers to them. We would train them in English, and then they would translate that in Pashto, or whatever it is. This is just a simple outline of what methods are available, and how do you develop a flow sheet. Well, you remember I talked to you about scrubbing? Well, some of them, you don’t want to blast the gemstone deposit; you want to tumble it, to separate the sand and clay.

03-00:49:49

Burnett:

Gently, yes.

03-00:49:52

Bhappu:

We didn’t have a gentle device – so I saw a little cement mixer, I said, “Bring it in.” So, we started using a cement mixer, putting fifty pounds of mineralized rock and scrubbing it, and then they would pan it and let it go or flow. Lighter particles would go and heavier particles would stick to the canvas, and that’s where the mostly rubies were. Emerald has the same gravity as limestone, so that’s difficult to settle, difficult to separate, but it is in close contact with silicates, which are low, so we use the heavy media separation, threw the gangue away. Most of the calcite and emeralds stay below. We add a very diluted acid to decompose calcite, and it leaves the emeralds behind. So, things like that, they never knew about. So the seminar was all built around homemade industry and homemade appliances, the things they use in the kitchen. So, it was very challenging to transfer this knowledge to them. They became quite proficient after a while, and came up with their own ideas of what to do.

03-00:51:33

Burnett:

Once they understood the principles at work, right.

- 03-00:51:34  
Bhappu: Once they understood them, then they said, “Well, we can apply that.” For instance, they had a little waterfall, and I told them that you need some kind of moving water to wash out the silt. So, they built their own little stepped waterfall, and picked up the coarsest particulate at the top and the finest at the bottom.
- 03-00:51:58  
Burnett: Who are these people?
- 03-00:51:59  
Bhappu: These are old miners.
- 03-00:52:02  
Burnett: They’re small scale?
- 03-00:52:04  
Bhappu: These are home scale, so it’s handpicking. Everything is handpicking.
- 03-00:52:09  
Burnett: How much would they be making in a year, doing this kind of work?
- 03-00:52:16  
Bhappu: If they sell, like let’s take a good emerald. One particle of emerald at ten grams, will be worth between \$8,000 to \$50,000, depending upon the purity quality. The problem was the poor guys work hard, they recover the jewels, and afterwards, some Americans and British and Germans—mostly Germans and Japanese—come and pick them up for \$5 a gem. There’s no control over it, and \$5 is a big payout.
- 03-00:53:18  
Burnett: Right, but then the actual value of that is an order of magnitude greater.
- 03-00:53:20  
Bhappu: It’s so much more, that’s right. The other thing they did is many of the laborers, when they came across a diamond or an emerald or a ruby, would put it in their mouth. The next morning, they would dig it out on the other side, and sell that. So, half the gems were already gone. So, we came up with the idea that you will not do any handpicking. Everything would be handled mechanically to a certain state. Whatever is heavy will go into a box that has a lock on it, and it’ll be cleaned out every night. Then, the government says, “But look, I’ve got 1,000 people working in this little valley, what am I going to do with these 1,000 laborers?” I said, “I’m only going to use 10 percent of them, and the remaining 90 percent, you’re going to show them how to make jewelry.” They are psychologically very artistic, those old ladies of Persia, Iran.
- 03-00:54:37  
Burnett: Right, legendary.

03-00:54:38

Bhappu:

And Afghanistan. Even you can take a small, bad stone, still polish it and put it in a little formation, like a flower, and you can sell that. So, we would start a cottage industry, so we'll use their wives, their kids, and whoever wants to work. Part of the United Nations program.

03-00:55:01

Burnett:

So, that was part of your development planning? So, moving from extraction to light industry?

03-00:55:11

Bhappu:

It was interesting, the head of my department at the United Nations was a Jew, and his assistant was an Arab. The third assistant was a Chinese guy, and I was Pakistani, was a consultant. [laughter] That's what the United Nations is about. We will use a big name, but there is more good done by United Nations that never comes out in the public. Only big headlines come out, and that's not fair. The support of United Nations, who else is going to do that? Of course, we have some good Presidents who come back and start educational programs, and that is commendable, but we should be supporting United Nations and work closely with them. I think the mining became a traditional industry, is a good choice, because either they kill themselves or they poison themselves or they are robbed—there is no security. One of the things we did in Brazil is the gold miners picking up, I said, "Pay the miners for the gold right on the spot, and if the gold stays," in those days, it was \$35 or \$300, "pay him 10 percent more than what they will get in the market." So, he's not forced, but to make more money, encouraged to look [not to try to smuggle the gold out].

The other wonderful experience I had is in Brazil, Brazil is a very mineralized country, and mining is the backbone of the Brazilian economy. Gold is very prevalent. There is one area called Serra Palada, big area, with an open-pit mine, and at any one time, 60,000 miners are working in one locality, one mine. They can only go three meters by three meters. They have to pick up the load of gold which was run around today's prices, about ten grams, which is about one-third of an ounce, today's prices will be \$500, \$600 for ten grams. They bring it up to the surface, 150 pounds, on their back, from about 300, 400, 500 feet, on a slippery slope to the top. They have to make at least ten trips a day to get paid, and then on the surface, you see all kinds of contraptions, all based on gravity or water flow, sort of like a placer. Even doctors and professors who can't make enough money, they come to the mine and work as a miner, to make more money. The amazing thing is that these are little, like, ants moving around. In 20 years, 150 pounds on the back, 10 trips a day, 60,000, they have accumulated 40 million tons of waste material. Anything below grain size, sugar size, or salt, 48 mesh, is considered waste. So, today, the tailings are of tremendous value.



What they wanted to tell me is, “How do we improve the conditions where we won’t have to use that kind of labor?” They want to make it nice. I said, “You cannot make it nice unless your labor rate is incompatible. If you’re going to pay \$1 per hour, if it goes to \$3, you won’t have any workers. So, keep that in mind, and displace labor with knowledge and industrial work, what I call village industry – opportunities to make stone monuments, carvings, tourist items.”

03-01:00:36

Burnett:

Products.

03-01:00:37

Bhappu:

Pick up mineralized stones, and they sell pretty well. So, that was a beautiful experience, to see all these people working like ants. Then, I’ll just mention one more, that at one of the Ouro Preto, is an old mining town, but it’s also a university. The university school of mines is a small one. They have an archival library, and they have collected all the old manuscripts of all the old clergymen or *padres* who came there, and it was their custom to walk ten feet, look right, ten steps, look left, and make a drawing. What did they see, what plant did they see, what color of the rock did they see? It was a log of what they saw as they walked from one location to another, sometimes passing very mineralized [areas] —but they didn’t realize it. They were in the log, but these logs were stored unprotected by bugs and—

03-01:02:07

Burnett:

Bacteria? Worms?

03-01:02:09

Bhappu:

Worms, and all that. Beautiful books, 400, 500 years—you need help. So, I went to the Colorado School of Mines and they went to the industry and we raised about several million dollars to make a refrigeration library, so that these books and archival records could be kept for posterity. Otherwise, this heritage material would have been lost. So, that was one of the benefits of how brilliant those Spanish clergy were, that they saw and recorded these natural phenomena so many years ago. So we preserved this material and opened up a challenge for others to follow.

#### Audio File 4

04-00:00:00

Burnett:

This is Paul Burnett interviewing Dr. Roshan Bhappu. This is interview session two, tape four, March 5, 2014. So, we were talking about at the same time that you were in New Mexico Institute of Mining and Technology, you were also beginning as a consultant. The United Nations approached you, and you started working for UNESCO and the United Nations Development

Program. You described a couple of those processes. What's interesting, the story that I hear in the history of international development, especially in the 1950s and '60s, is that a lot of the pressure for development was coming from the non-aligned countries. It was coming from these countries often newly independent from colonial rule. The sentiment was that colonialism has retarded our development, and now that we've been released from that, we're going to hop forward with technology transfer. So, give us these techniques and technologies, and we will rocket ahead. They wanted the latest and the most industrial. They went, "Give us industry, forget agriculture, go industry, industry, industry." So, with that in mind, what's interesting is some of these projects tell a bit of a different story. They're not large industrial scale.

04-00:01:42

Bhappu:

They're not. The majority of the ore deposits, many of the larger ore deposits take years of exploration. However, a small prospect for one man using a pick, you can find it anywhere. So, in the old days, a miner or a family could make a good living outside of using hand labor and children and everybody else. In today's world, people became more modern and they wanted to be more sophisticated. Now, they are looking after bigger and bigger mines. So, in order to do the best for the developing countries, the United Nations started a program of discovery of challenging ore prospects. They had geologists running all over the world. For instance, they gave Mountain States [Dr. Bhappu's Company] a project to look at potential mining disasters, or environmentally unattractive operations, just in Arizona. We came up with 1,200 sites where little mining was done, and some of the rocks were on the surface, no way of disposing of it. Just leave it to the rain to wash it out. Many of our problems with mercury and all those started where people had excavated—hand-excavated—but had left the mine unprotected.

So, the United Nations, in our challenging seminars among ourselves, we suggested that in order to expedite the discovery and development of mineral deposits from all the new countries that were coming into play, that we would first look at what was done there. In the past, were there any mines operating? Were any mines operated by old Spaniards or Portuguese, or Arabians? Those became the active sites. If an exploration guy goes out, he looks at the formations, but if there is an operating mine, he doesn't have to go very far. If you look at a small mine, say, in Arizona, started as 5,000 tons, then went to 10,000, 50,000, 100,000, and one of the mines just mentioned, they're mining 500,000, half a million tons a day. He says, "We've got seventy more years," it was publicly announced. That's the kind of openings you get. You start small, and it just multiplies and multiplies. It's the same thing where instead of one miner, there is a whole village going after. So, once you see a village, it either grows with agriculture or some product, and a mine is one of the best ones. You see all copper mines, gold mines, it's always all the older cities in Arizona, Nevada, Colorado. They were all gold mines, or still were. You see, mineralization is a mechanism where ores tend to collect together, then you

will have a barren rock for miles and miles, and then suddenly, another prospect.

It's the same thing whether you are New Mexico Bureau of Mines, or you are UNDP. They get the same number of enquiries or more, saying, "I've got a prospect, what shall I do with it?" A developing country says, "Oh, in the last century the Spaniards were there and they took out gold and left, can't we start that?" They don't have the tools. So, we go in with the geology to look at the formation, that's the first team. The first year, we find out how many mines are available to be looked at, then we develop the program and say, "Well, how do we do that? Should we put up a little training seminar to train them how to spot that by coloration?" I pointed out that whenever you see a reddish color, you suspect metallic ore. Uranium ore, which can contain arsenic, was pinpointed by a cactus, a type of cactus that grew in the poisonous environment. That was identified, and that became a tracer to the uranium mine. In the old days, American Indians used to paint their faces, and they would use yellow as a paint. Little did they realize that that yellow came from uranium oxide, and they were blinded or they were injured, never realizing that they were using a uranium oxide yellow.

04-00:07:44  
Burnett:

Yellow cake.

04-00:07:48  
Bhappu:

In India, the ladies used to put beauty marks by way of putting black around their eyes, and it turned out to be that it was antimony was the culprit, and they went blind. But those are the kind of tracers that one was looking at, and you don't have to have a high satellite to look at it. You find all these sites very readily. So, when they come to us, we make a decision, is this worth prospecting? Should we put money into that, and time and effort? If it is a far-out location and no mining activities, these days, it's a shot in the dark. But if you are in the mining area, yes. Why do we do that? I said, "Why do we have to help small miners putting picks or shovel and produce one, two tons a day, then process it? Why can't all the villagers get together from their prospects, they're hundreds?" You put up and bring those lot to a central facility, that's where the United Nations can help, is to be a central facility that they don't have the money to pay for because that's going to be expensive. So, each one brings it and it is analyzed and then put through a central facility, and it's shared by everyone.

04-00:09:26  
Burnett:

So, a mining cooperative?

04-00:09:28  
Bhappu:

Cooperative, that's exactly what we are trying through the United Nations. They put up cooperatives.

04-00:09:35

Burnett: When was this?

04-00:09:36

Bhappu: This has been going on for a long time. People don't hear about this, but the United Nations has been doing that, and even us, when we are working in Mexico or in Peru, wherever we see proximity of mines, we always advise them. Don't put up a plant for yourself and do it. Mining yourself, your family will get some mechanized mining shovels, maybe some tractors and bulldozers. Bring the ore to a central facility. This was recommended five years ago, and everybody was happy because they didn't have to sell out their property. They wanted to hold back. They said, "This is my land, what am I getting out of it? A few dollars when I could be making more –"

04-00:10:30

Burnett: These are farmers, too?

04-00:10:33

Bhappu: These are farmers and villagers. They have been there for some purpose. They came as old miners, maybe they were displaced, each one found a little prospect. Let's combine them together. Not only that, but as I pointed out for the gem industry and others, anything that is left over as a tailing or waste, look what is in there to sew. Just handpick and make patterns out of it, or sometimes take a wool and put a nice little yellow stone, or blue, or red, and make a little artifact out of it. Any kind of a cottage industry is what they are looking for, so the whole family can work. So, those are kind of projects we would encourage, to go after those projects where you can get a quick payback and a minimum of investments. Once it is proven, then the big boys will come and pay you pretty good money to buy that off of you. You start on your own, small, and then grow on that one. So, there's a strategy that was very useful, and in all the developing countries—Afghanistan, Pakistan—all the minerals are located in central localities, where people can work together and make a good living.

04-00:12:12

Burnett: And retain value for the primary producers.

04-00:12:14

Bhappu: Yeah, because these people know each other. There are no enemies there. They are all friends and family, so that encourages them.

04-00:12:24

Burnett: Right, it encourages mutual cooperation, so capitalize on that, make that work for them.

04-00:12:28

Bhappu: That's right. So, I just wanted to tell that. That was a part of the strategy that was important, and our New Mexico Bureau of Mines and US Bureau did

exactly that. They said, “Well, you have this ore, you’ve got this value, this is the process.” Then, the project would go for bidding and so on. A little bit different than developing countries because people, you’re ready to go.

04-00:13:01

Burnett:

Right, they’re more ready to commercialize something.

04-00:13:05

Bhappu:

So, based on this background of education, research, testing, developing countries, I came to the idea that if you look at a mine, the progress of a mine, first comes the drilling, first identification of the ore, drilling, exploring, testing, feasibility, another feasibility, engineering, design, construction. Ten years, easily gone by. In the old days, it was ten years not because of permits, it was because people didn’t realize the importance of time. They were always looking at the tail end. Now, what we are saying is we have an option, we call it “exploration evaluation.” – you start your testing and evaluation, both technical and economic, from the first drill hole. Don’t wait until the end of the last drill because if you’re going to put 100 drill holes—[phone ringing].

04-00:14:21

Burnett:

So, the idea was to take processes which had been sequential and turn them into, as much as possible, concurrent processes?

04-00:14:31

Bhappu:

The time is very useful because the money spent today, next year, we may have to put 10 percent more, and these are \$100-million projects and above. So, one of my friends who was in the engineering practice, they used to design and construct at small scale. He worked for Parsons, which was a very big company. But his small company, he was a good friend, and we met together. I said, “Ed,” his name is Ed Frohling, “do you know mining companies spend millions and millions of dollars, and they lose a lot of time getting into production. You, as an engineering company, and we, as research, if we add a little exploration mining, we can form an enterprise where a prospect becomes a mine instead of ten years, five years. How can we do that?”

Well, once the drilling starts or assembling starts, they put it in a core shed, sometimes unprotected. Nowadays, we put nitrogen in the tubes so that it will not oxidize. In the old days, they didn’t do that, it just sat for six months or a year before it came to us, and by that time, oxidation has already occurred. So, what we are saying is you do not know if this particular deposit is going to be a bonanza or going to be a waste of money and time. So, you send us the first drill hole, you do the assay, we do our own assay, we determine the nature of the mineral—is it gold, is it copper, is it lead—what is the form of the mineral, what character, and based on that, what processes, preliminarily, are applicable? If it’s not magnetic, forget it, you’re not going to use magnetic. If it’s very disseminated, why do gravity? We’re not going to pick up very fine particles going to flotation. So, by a systematic approach of analysis from

project to project based on the geology and the chemistry and the mineralogy, we narrowed the options that are available. If it's physical separation, it's not possible, go to leaching. It's a green rock, it's obviously copper, why spend effort trying to upgrade it? Just leach it, and we'll use solvent extraction, known process and low risk. All you have to determine is how much do you have, so you can do the final feasibility.

So, the idea is if you evaluate each ore drill hole, you say, "All right, this is mineralized and this is mineralized," so you make a composite. The mineralogy is going to be more or less applicable to all the sites. You do that within a month after you receive the sample. Two weeks to one month per composite sample. So, if the drilling goes on for one year, around the thirteenth or fourteenth month after drilling, you have your flow sheet, at least a conceptual flow sheet.

04-00:18:15

Burnett:

It's revised and updated as the samples come in?

04-00:18:19

Bhappu:

Yeah, because that's how the project goes: it goes from discovery to pre-feasibility, to feasibility, and go. So, I'm telling you I'll give you pre-feasibility, I'll give you an idea of what process to use, and what is the approximate cost of it. You keep on drilling, now you are building up your reserves, and we keep on building up the records of how they behave. Soon after drilling, you have a project, no or yes. Otherwise, maybe it's a dog, throw it out, you have six prospects. Look at the other prospects, don't look at it. This, we call exploration evaluation, and putting a process description just preliminary. We haven't all got into pilot plant and all that, just preliminary, but as soon as we have the deposit and the drilling program, we say, "Okay, these things appear that it's a copper ore, and you must have a minimum of 1 percent copper to make this process work, it's open pit, so many tons a day, look at the economics." We'll run a pilot plant on a composite sample. That goes into the pilot plant stage.

So, this is what we do: we do the preliminary, if it looks encouraging, we go to detail engineering, if it looks good, we go to flow sheet development. Then, we do the final feasibility, which is plus or minus 15 percent of the cost. The first one is around 30 percent. Now, you are going to Wall Street to pick up the money, with your final feasibility, and you run the pilot plant. This could cost you \$10-50 million. Like, one in-situ leach pilot plant could cost \$30 million, we just costed it out, but you have to have that kind of money to prove that. Now, you have \$1 million in value, there.

04-00:20:33

Burnett:

Well, these are established companies who are clients, that's right?

04-00:20:37

Bhappu:

No, sometimes they are prospectors. They are unknown people who want to get into mining, so we lay the plan in front of them and say, "This is what you'll be spending. If you're going to spend \$100 in the final project, you will have to spend \$5 in exploration, another \$5 in metallurgical testing, another \$5 in feasibility, and another \$5 in going out public, and all that." So, 20 percent of the project is going to be your outlay before you get to the starting or no starting.

04-00:21:20

Burnett:

Construction and all of that.

04-00:21:21

Bhappu:

If any one of these things fails – One of the things we also do is what is going to be the waste product? Of course, we haven't had time to do a detailed analysis, but we do a mass balance and say, "You've got about ten pounds of copper in one ton. For every ton, you'll have about 1,990 pounds to be disposed of, of waste." – it's not necessarily the case because it's usually 30 percent copper and a sulfide mineral – so you are generating that much waste, where are you going to put it? Do you have a waste area? Should the waste be close or final will depend upon your liberation characteristics. All this little exercise goes into a planning guide to continue the project or stop the project. It would take maybe \$5,000, \$10,000, \$15,000 preliminary, about \$50,000 in some testing, maybe \$100,000, \$150,000, \$200,000 in pilot plant runs. That is our cost before the project will be ready, but the project could be over in \$5,000 if there's nothing to look at. Why spend the money and time? Just go to the next one. So, this is the kind of work we do to help the industry, and we help the developing countries as well as developed countries. Sometimes, it's the government that comes and says, "I have a prospect," like the one in Pakistan was called Saindak, it's a copper mine near the Iran border. They came to us, we did their feasibility, we did the testing, pilot run, everything here in Tucson, final report. They were able to raise the necessary funding from the World Bank, and it started the operation. They went to the Chinese to build the plant. We encouraged them very much to go to either Europe or America or Canada, Australia, but they were making friends. They did a bad job, and the plant, after ten years, just fell apart.

04-00:23:55

Burnett:

When was this?

04-00:23:57

Bhappu:

This was in 1960s, '70s.

04-00:24:05

Burnett:

The Chinese mining industry had been quite insular, they'd had Soviet advisors.

04-00:24:08  
Bhappu:

Oh, yeah, they were coming in and buying out projects, and they said, “That is a good project.” This was in time after Boutros, about at least thirty, thirty-five, forty years ago. If I go to the meetings, I always hear from the United Nations, “Chinese part of this project,” and it’s the biggest project of copper and gold in Afghanistan. We discovered it, we gave the money, seed funding, looked very promising, we were haggling in Afghanistan, who’s going to rule, and the Chinese came, bought up the whole project. They’ll go big, and Afghanistan will thank them, not us. One of my pet peeves is if we give aid, foreign aid to a country, what do they owe us? You’re giving to poor guy, a beggar, \$5, or—

04-00:25:22  
Burnett:

You don’t ask for anything, right.

04-00:25:24  
Bhappu:

But when you go into a foreign country, where the geology was done by us and the metallurgy was done by us, and it should be legitimate that an American company could come and build the plant. But the Chinese gave them concessions, not because there are cheaper – machinery, yes, but it’s materials of construction, how long it’s going to last that matters. Ball mills, crushers, they are terribly active, and too much wear and tear, and if you don’t have the right alloy, the machinery’s not going to last. So, those are the kind of decisions, and I always say, well, Dr. Colby, the Arizona Senator, he’s now out of office, but he says, “Well, we are there to help them, we’re not trying to make money from them.” I said, “Yes, but you’re also taking away jobs from the local market and giving it to a foreign market at a cutthroat rate, and who benefits? The company doesn’t benefit. Japan or Brazil, whoever provides the machinery, gained that because they are not involved anymore, unless there are some guarantees.

04-00:26:52  
Burnett:

Right, so you’re subsidizing some third party.

04-00:26:56  
Bhappu:

So, I still feel that we should be generous, but we should also be looking for our growth because if we don’t grow, then we are not going to find new deposits and new prospects to help other people.

04-00:27:11  
Burnett:

Right, right. I guess the rationale for development, it was very important that it not be seen as being in the interests of the United States or whichever country was the donor country.

04-00:27:24  
Bhappu:

The other concept that people have in mind is that if you have a deposit in a foreign country, they can throw the tailings wherever they want. There is no guarantee that there will not be pollution. This, in order to save money and



time, many projects, in order to save money and time, used to dump their tailings into the ocean, the river, the lake, or running streams. That caused a lot of heartaches. So, from the beginning, “thou shall mine, but thou shall not waste.”

04-00:28:05

Burnett: Pollute, right.

04-00:28:07

Bhappu: Not produce a waste product. That concept should be used, and now, World Bank and international banks, as well as World Bank and United Nations, will not consider a project unless it has the tailings part. We say that it’s the tail that wags the dog: if you don’t put the tail right, your dog’s going to fail. So, we include in our testing, we analyze all the products in the ICP multi-element scan, to see what the poisonous things are. Mercury, arsenic, bismuth, those are the toxic elements. Where are they? Where are they going? Are they going with the concentrate or the tail? Where is the tail going? Oh, it’s going on a dump, well, but then it’s going to leak. So, they said, “Well, now we are going to prepare the ground,” and that’s where the hydrology and waste managers and others come out. What kind of a bedding, what kind of a liner you should put? There is a lot of new research in liner preparation. Now, they have liner made from paper that is stronger than anything you can get. It’s a new development. It was reading in the news, it’s like a paper or a glass.

04-00:29:49

Burnett: Like a fiberglass or polymerized paper?

04-00:29:50

Bhappu: It’s better than plastic, yeah, stronger and more resistant. So, with that kind of thing, you can certainly discourage pollution. What you do is that you put a little channel around the tailing pond, so whatever seeps through is picked up. So, just in in-situ leaching, to assure ourselves that there is no migration of the acid or solution outside the parameter of the deposit, we put monitoring wells. So, monitoring wells tells me, “Oh, my pH has gone up or lower,” I said, “Something is escaping. Is it the solution?” So, we then changed the pumping pattern. This is all modeled now and can be computerized, but those drill holes, what we call—I just use the word “monitoring wells”—are very important. That controls your whole operation because once migration occurs, and I’m going to all these local mines and say, “Look, we have used organic, we have used bacteria in the past, now let’s become a little more modern and look at bacteria that will stop the pollution of underground water.” Some are on the verge; others are still living in the old age.

04-00:31:33

Burnett: Right, they’re skeptical, they equate environmental responsibility with cost.

04-00:31:36

Bhappu:

Well, it's like the global warming. They say some are totally false, others claim it's totally legitimate. One thing that I do want to encourage is that mining, today's mining, is not one man's domain. It's not one expertise. It's a multiple expertise, and we have to look as a team effort between the geologist, the miner, the metallurgist. But more importantly, let's look at the CEO or others, does he appreciate that? Or is he only after making profit at the expense of some other unfavorable contingency? Like treating water, recycling water. We have found in our flotation process, and Doug would collaborate, that when we go to more and more precise separation, the best reagent we have is fresh water. Fresh water—do not use the recycled water unless it is treated because that impurity, low-level impurity in the recycled water, could be the culprit. So, use fresh water, but don't use the fresh water on the whole plant. Do the stage processing, so you recover 10 percent of the weight, then 5 percent of the weight, and then the final weight. In the final process, use fresh water.

04-00:33:31

Burnett:

So, the water is treated on site?

04-00:33:33

Bhappu:

Oh, most of the time, yes. Or sometimes it is not—that water then goes to the next stage and the next stage. So, it's just recycled, but the last stage is with fresh water.

04-00:33:46

Burnett:

That's fascinating. Can we go back to, you've outlined for us the model of Mountain States, but can you tell us a bit more about the beginnings of Mountain States? Who are these people? It begins in 1972, this is when you're leaving New Mexico.

04-00:34:10

Bhappu:

At NMIT [New Mexico Institute of Mining and Technology], we made progress, changed the curriculum, brought in new activity and research. I decided I wanted to do a similar thing for the industry because I felt that there were good researchers like the Fuerstenaus and others who did a credible job. My contribution would be to operations—how do I use that basic knowledge to improve the process, reduce the cost, protect the environment?

04-00:34:47

Burnett:

The taxation of the environment, yeah.

04-00:34:50

Bhappu:

I called all of them together and I said, "Ed, let's form a company. You already have a small company, engineering. What you need is an R&D arm. Of your Mineral Enterprises, you have engineering, design, and construction, now we are going to have an R&D section. I will run the R&D section, you

run the engineering,” and that came under the umbrella of Mineral Enterprises.

04-00:35:25

Burnett:

This was Ed Frohling, is that it?

04-00:35:26

Bhappu:

Frohling, yeah. Ed was a good friend. He went to MIT, also, and he was a good friend of Gaudin. We arranged that I would leave Socorro, come into Tucson, and look around for about six months, and see what the opportunities were. Within a very short time, we started getting projects after projects. So, we worked out all the engineering, we had no problem, but now I wanted to run a lab and a pilot plant, so I needed a tailing dam and water treatment. So, we went twenty-five miles outside Tucson, at Vail. There was an old plant that was run by IMC, and that was vacant. It was far away from us, so I found out that nobody's going to come in to say hi unless they had a need to come. So, from a pollution point of view and all that, we kept away, and we had a very quick growth. Vail, in 1972, had about 300 people. Now, we are crossing around 30,000, and all homes around us. So, more!

Anyway, we went out there and started the lab. It was 12,000 square feet, and we still have 12,000-foot lab. We are making better use of space. We had a tailing dam that was the responsibility of the parent company. In 1987, Ed said he had enough, he wanted to quit, so he says, "I'll give you a chance to buy out." R&D division, not the engineering. Engineering went somewhere else. I said, "Fine, let's work it out." So, we worked it out, it was reasonable on both sides, and we started R&D International. It then became Mountain States Research and Development International. That was the new company. It was a continuation of '72 company, revitalized in '89 with a little better, you might say, plan of action, that we were going to be testing engineers. We will not go after feasibility, we will take it over to others who are more proficient than we are. We are a small organization, tight organization, at the maximum, I had fifty people at any one time. Today, I have ten. It depends on the amount of work that goes on.

We started giving our services to the international scene because with my mining connections, UNDP connection, Society of Mining, chairman of the group and all that, that encouraged people to come to us. If we couldn't do the job, we'd say, "Go there," or sometimes we'd say, "This is a little tricky. We are not that scientifically oriented, adept, and we don't have the facility. Go to Doug or somebody to get that part of the research, and then we'll take over the practical side of it." So, that's what we have been doing since '87, on our own. We have had good years and bad years. Last year was a bad year because the mining industry went down. This is because the majority of the mining discoveries are made by junior companies. They are one or two, father/son, or two or three geologists, finding a deposit, building up credible

assays, pre-feasibility, then they go out, raise \$20 million and \$50 million, and that's how they grow. So, this is what's going down. There is a lack of seed funding. My son is in that crowd, but they will research the project, and they are willing to put in millions of dollars because there could be a billion dollar payoff.

04-00:40:17

Burnett: Payoff, yeah.

04-00:40:20

Bhappu: So, mining is down right now. How do we revitalize it? What has happened, an interesting thing, is all the old tailings that were developed in 1940s, fifties, the twenties, thirties, forties, they were not as efficient. Many of the tailings still have railroads and other elements that were of no interest.

04-00:40:45

Burnett: Back then?

04-00:40:46

Bhappu: Back then, and the processes were not that efficient. So, the tailings have become new target areas for development, and this is what I tell my friends from poorer countries—go and find out an old mine with the tailings. That's where the money is. You don't have to mine, you don't have to start, at least that's the seed funding. Then, start at 100 tons a day, and grow with the money that you make. This way, you don't have to give up your share. I tried to do that in Mexico because there is too much hanky-panky going on in Mexico.

04-00:41:27

Burnett: Yes, yes, of many kinds.

04-00:41:30

Bhappu: The thing is that the poor miner is the guy who suffers. The guy who discovered the deposit.

04-00:41:35

Burnett: Right, absolutely, absolutely. Well, perhaps we should pause for the next tape.

04-00:41:45

Bhappu: Let's see what we want to cover next.

04-00:41:49

Burnett: We can focus on the next level.

[End Audio File 4]

Interview #2 March 6, 2014

Begin Audio File 5 bhappu\_roshan\_05\_03-06-14\_stereo.mp3

05-00:00:00

Burnett:

This is Paul Burnett of the Regional Oral History Office. I'm in Tucson, Arizona, interviewing Dr. Roshan Bhappu. This is session three, Thursday, March 6, 2014. This is tape five. So, Dr. Bhappu, in the news today, the Environmental Protection Agency has moved to block establishment of a mine in Bristol Bay, Alaska. On the other side, there's a coalition of fisheries, environmental activists, and aboriginal groups. I think that's a nice starting point, it's this stark contrast between state regulation, industry interests, and environmental groups and other economic groups. So, I wanted to ask you a little bit about how we got to this point in the United States, with respect to environmental regulation that impacts the mining industry. When did this first become an issue as far as you understood things?

05-00:01:29

Bhappu:

If you look at the history of mining in the United States, after the immigration and people coming from Europe, England, settling down, they were on the East Coast. So, although some of them were old Scotch miners, Welsh, Irish, they were all mining oriented. However, they couldn't find the kind of things they would like to do on the East Coast, so they started migrating, and the first thing they found was in Pittsburgh and elsewhere. They found coal, and so that became a big industry. Started there, and then people kept on moving west and west, for the Gold Rush, and somebody found gold. Boy, everybody wanted to migrate to California. In those days, we didn't have any regulations. However, our activities concerned with mining were not big activities. They were individual prospectors, and they couldn't do too much pollution.

Then, as the people began to appreciate the mining and miners became larger mining operations, they found not only gold in Colorado, and they found copper, lead, zinc. Utah, similar things. Of course, as Professor Gaudin used to tell me, "There is more gold than we think there is. It's more abundant. However, it's distributed widely." So, once one finds a nugget, everybody gets excited, and everybody jumps on to that. One area takes the burden. There are hundreds of miners working together, and now, we are beginning to see the effect of pollution, and especially all these are placer type operations. With the gold being heavy, they use gravity methods. Obviously, there was no cyanide or, you might say, any chemicals. Everything was with gold as a physically separable by typical jigs and tables and sluice boxes, and so on.

One problem was that in gravity, you require about three tons water as one ton of ore. Now, if you don't reclaim that water, and if that water carries all the dirt and silt, then it begins to become a problem. Of course, the miners always felt, "Well, I'm close to the mine, but the water is taking away that," but he

doesn't realize the guy upstream is polluting. But it's not chemicals; it's mostly physical particles, very fine clay, and so on. Then, as the mining industry got bigger and bigger, they established the schools of mines and all that, but nobody really took care of the environment because there were so few people, and the impact of whatever it was, was not felt and the general public never felt that.

05-00:05:18

Burnett:

So, most of the mining was taking place in areas of very low population density?

05-00:05:24

Bhappu:

Usually in the hills, some at the foothills, because that's how the ore from gold, from the original deposit, was being washed down. If you follow placer mining and follow the river that carries it, you find that there are ways the gold is being washed out, but being heavy, when the meandering occurs, there are spots that there is natural concentration. So, you see people with washers and different kinds of methods. Eventually, mining people came in about 1800s, 1900s, really, nobody really cared about it. There were a few people impacted, but people say, "Oh, well, the industry, jobs are created. Miners are bringing money, so the rest of the community is also flourishing, with motels and hotels and beer," so mining was a leading industry. They brought more people now as service people, and soon we found out that they are beginning to feel the impact. Of course, the government, in those days, didn't really care because they were taxing, they were getting something back.

It was not till larger mines began to appear, starting in California and especially Colorado, Utah, and Nevada, Wyoming, and then New Mexico, Arizona, then they began to realize that there is much more to a mining operation than just recovering the metals. You need to think about where you are going to put your tailings because if it is impacted, nobody can live on the banks of the river, and so on. So the government started taking an interest in regulating some of the mining operations. Of course, when the state came back, states were created, they had their own little environmental group, but it was mostly policing to see there are not fights and people squatting on somebody's land. Those were the kind of activities.

05-00:08:08

Burnett:

Land claims, mining claims, adjudicating those things, yes.

05-00:08:12

Bhappu:

So, they had to bring in some regulations, and the state started to register people's claims. He had the right to mine, and he could transfer it, but nobody can claim his land because he was first. Eighteen-ninety-two, and others, it became that the mining was allowed, once you claimed it, and that was your land, you can do with it what you want, unless somebody objected that he's making pollutions or I'm getting dust, anything. The biggest impact was that

now, we are beginning to see the incoming of cyanidation. That's more than 100 years old now—120 years old. That really started concern that cyanide is poisonous and they then started regulating that if you have a mining operation, you cannot let the cyanide go out.

If you look at the history, not many people have been killed by cyanide because the miners realized it, the people who worked with it realized it, and I used to go in the old days to the mine, and the miners were sitting around the water recovery system and eating sandwich for lunch. They didn't care because they said, "Oh, well, the cyanide is a small amount, I can't see it. It's in the water." So, hardly anybody, unless you drank it or wanted to commit suicide. Those was the only accidents reported, and sometimes, there was a spill, and the guys would go back and warn the people that the plume is coming, and things like that.

05-00:10:22

Burnett:

That was a different appreciation of risk at that time, and this notion that something might kill you thirty years from now, forty years, I have more things to worry about right now, tomorrow, than I do thirty years from now.

05-00:10:36

Bhappu:

The part of mining, bigger and bigger operations, they said, "Where should we put the tailings?" Obviously, they would find a place where they could put the tailing and it was not very far from the spot where they were mining. You see all the tailings and residues, the smelters came in, and the slag. Those became a nuisance and a problem area, and so, in the early nineteenth, twentieth century, the government became more regulatory. Even when I went to school, MIT, they said, "How do you dispose, if you're next to the coast, put it in the ocean." People still do that in Australia and others because they can show that there is no impact, there is no soluble residue. Except for the fish, they're not impacting anybody. It's mostly there are particles, sand.

05-00:11:41

Burnett:

So, the solution to pollution is dilution.

05-00:11:45

Bhappu:

Then, placer operations started on the beach sands. They started recovering titanium, and they also caused the black sand. Black sand in the beach, concentrated by nature, being heavy, you see the black band. People know that's where the metals are. So, most of the pollution went into the ocean. So, when I came to this country in 1948 and started looking at the mining, I was surprised that they didn't talk too much about environmental concerns in the classroom. I know there was concern and there were groups that specialized in abating, you might say, mitigating the problems of the mine waste, but as long as you kept the mine clean, inspector of mines came in, in Arizona, we had the Arizona Bureau of Mines come in, and they started monitoring. They started regulation. They started to help the prospector, and said, "Look, this is the

way to recover the gold and this is the way to stack, so it doesn't become a nuisance."

When you mine 40,000 tons a day and 100,000 tons a day, where are you going to put that? The ratio of mineable material to waste is about 1:3, so there is three times the waste that has to be stockpiled.

05-00:13:35

Burnett: Yeah, at least.

05-00:13:39

Bhappu: It wasn't that problem, but back East when it was raining and wet climate, they began to see that. From the coal mines, they began to see the acid mine drainage, the river running, the stream running red. They became concerned, and that's where the government came in and started doing regulation. They had Bureau of Mines, but they left the bureau to manage that part of the industry.

05-00:14:14

Burnett: And it remained at the state level.

05-00:14:15

Bhappu: Naturally, many of the stations at the Bureau of Mines were located with the mining schools, close to the mine or part of the mining premises of the college or the school of mines. So, they began to appreciate it. Like Colorado, the experimental mine and the bureau were working together. In Utah, the same thing. In Arizona, except that locally, the politicians said, "Oh, no, why should we stay in Tucson—let's move it to Phoenix." Naturally, the bureau was part of the mining premises, mining department, and the University of Arizona. Then, they said, "No, we are the leaders, we need to move close to where the central government."

05-00:15:16

Burnett: Where the legislature was.

05-00:15:19

Bhappu: Also, the Bureau of Mines was created by legislation, and it became a wonderful service for the miners, not only recovering what they were after, but also looking at why. They said, "Why is the stream running red? I'm only putting water there." They didn't have an idea of oxidation, or that the bacteria were oxidizing the pyrite and putting iron in solution. As soon as the iron went into solution with the basic pH, it put precipitate out, and that started the acid mine drainage. They began to feel the acidity on the crops. They found that around the streams and all, nothing was growing. So, that's where the concerns started, and the US Bureau of Mines was a great institution. I was sorry that it stopped about ten years, twelve years ago.



It was a shame and it shouldn't have been, but of course, by that time, people were now really concerned. Not because of the small miners as much as the bigger mines because they started the pollution problems, the acid mine drainage. Here in Arizona, we don't have continuous rain, but we have thunderstorms. Within one hour, you may have two to three inches of rainfall. They just wash everything out. Then, they began to find that some of the bigger mines, that the farmers began to complain that when they were pumping water, the water was acidic, it was eating away their pipes, and things like that. So, then they knew that some of the water that was used in the mine actually percolated down into the groundwater. Then, it became a big concern, and groundwater hydrology and all that came in. All the miners were at least not subject to very strict laws, but they were told not to pollute and to control. They had monitoring wells, for instance, all of our mines are about fifty miles, forty miles, twenty miles, and yet, they pump water for agriculture, especially pecan farmers. The water comes from the aquifer next to the mines, and some of the water is migrating towards the city.

So, the farmers were the first to complain, especially – I don't know why farming became that important in Arizona, because we don't have that kind of water. But it was shown that water use in mining was about a fraction of what the farmers were using, yet they complained. So, when I came in, in '48, '50, you say that Rachel Carson's *Silent Spring*, well that's '72.

05-00:18:56

Burnett:

Or '62.

05-00:18:57

Bhappu:

The fifties and sixties were relatively easy to work, but bigger companies realized that "I'm going to have a forty years' operation, what kind of an impact would that be on my surrounding community?" The people, the laborers, lived on that land. They realized, and then they started taking precautions to make sure that putting out berms and putting out artificial lakes where the tailing water, and then they also found out that the water they were using, now they are paying tax on it, water use fees. They said, "Oh, we can't afford that," so they started recycling. That meant that that they started with thickeners, large thickener. If you go to the mine, you'll see something like 200 feet deep, or sometimes like 400 feet, big thickeners. All the tailings go into the thickener. Usually, if you look at the flotation plant, which uses three times water, as a 3:1 ratio, the flotation is conducted at around one-third, or about 33 percent, 30 percent, 35, and that tailing goes into the big thickener, the sands settle out, and they have an overflow. It's a settling tank.

Your overflow now is around 50 percent of what goes into the tank, so they recover another 50 percent. That 50 percent is recycled. Then, the tailings underflow, the thickener discharge usually is around 50 percent solids, so they are made from 30 percent, now the slurry is 50 percent. That goes to the

tailing pond, settles out, and water appears on the surface. If you fly over it, you will see the tailings pond, big, big lakes like that. So, they recover that water. So, usually we recover 75 percent of the water, which is not bad. We still play for 25 percent. Researchers began to say, "How can I do a better job of settling?" So, they began to find out that there are flocculation aids, or reagents, that could be helpful. Also, the pH of flotation is usually level with lime. There is the pH to keep the pyrite down. That also helps with the settling. Then, they have flocculants and other reagents that they can use. So, in a traditional way, you say when I went to work for Miami Copper, [in the 1950s] we had tailing ponds and large tailing ponds. We recouped the water, about 70-75 percent, and we knew that with the evaporation, part of that went up. Some of it percolated, and what's happening, that when you do flotation at a finer size, 100 mesh, 200 mesh, there is a retention of water in the solids itself because it's not percolating out. If you leave a residue, you will find that the surface is dry, but five feet under, it is wet. Usually, 15-20 percent of the water is retained by the solids themselves because of the wide space.

05-00:23:04

Burnett:

Like a kind of clay, effectively.

05-00:23:06

Bhappu:

Well, clay is part of it, but nothing drains out because that is a big, tall stockpile. There is retained water in the tailing, so that's another 15 percent can be accounted. We want to account for 100 percent of the water, so we take the weather into consideration, we take the evaporation into consideration, and then, what is seeping through the tailings and going into the underground water, that's where the contamination occurs. So, the Environmental Protection Agency came in and says, "You cannot put a tailing pile for a pond or tailings unless you put plaster or something as a liner." So, the lining business became big, and now all the operations have a liner, some form or other. Those are some of the good regulations.

But let's go a little further. This water problem created new research activities at the university level. Of course, water, at least in the Southwest, is a very precious commodity. You need to recover as much of the water as possible, and make sure that what is discharged doesn't have any soluble problems that would affect people. That's why you have the waterworks and they have their what you call clean-up, "you need to clean up the water," that regulation came in. That started adding capital cost burden on the miners, and they wanted to get away. But with the regulations that came in, and especially after Clean Water Act of 1972, it became mandatory. But there was still a certain amount of grandfather clause, so they walked away, but they warned them rather than saying, "Now you have to clean up."

05-00:25:38

Burnett: Right, so existing operations that were going to be going for forty years or fifty years, they were okay, but any new mines?

05-00:25:46

Bhappu: All the new mines came in, they had to pass [regulatory standards]. The Water Service comes in to make sure it's not affecting the forest life.

05-00:26:02

Burnett: The Department of Fisheries?

05-00:26:04

Bhappu: Fisheries, of course. In one plant that we designed in New Mexico, I was there, we put the new operation into service and we took every precaution. We took every precaution that there would be no mine drainage and that the water would be clean. The mine was about ten miles away. The water, because it was hilly country, we couldn't put a pond. So, then, it came to the Red River, on the side of the Red River, there was a drainage line. A twelve-inch line with another liner inside, and it went into the tailings, ten miles away. When the operations started, the environmentalists thought, "We will punish them." So they took some of the fishes at the pond. They had a hatchery, so they took some of the fishes, dipped it in cyanide—because we were using a little bit of cyanide in the plant—it was a copper-moly separation, it was a molybdenum mine. They threw that in the river, and said, "Hey, look, we found that fish."

05-00:27:27

Burnett: There was sabotage?

05-00:27:28

Bhappu: Sabotage, exactly. This is where the big problem came in, as the environmentalists were the first ones to oppose it, and they did everything in their power to keep the mine from operating. That's what is happening to the Rosemont mine, right here, about twenty miles from here. They are putting one permit after another permit, getting to nearly 130 permits. The Forest Service comes and the Water Department comes, and the Agriculture comes in. The smaller cities say, "Hey, we don't want polluted water because that is our livelihood—we drink that." So, there has been some damage to the name of mining, that mining is dirty. Not because of the dust and all that, but they say, "Look, you are using reagents, and those reagents, whether they are for flotation or for leaching, usually cyanide or sulfuric acid for copper ore, is polluting." We tried to design the plant in such a way, and that's where our service came in. Every plant that we would look at and design, we wanted to put in extraordinary precautions not to pollute. We had science behind us.

People in the University of California and Arizona, they were big departments of chemistry and water. They'd cooperate with the Mining Department in coming out with solutions to prevent pollution. So, once they started putting limits on what you can do, that created a new energy for research and

development. The best way I can tell you is that the Rosemont mine, which is a 2012 vintage, you might say, I told you that there is 15-20 percent of the water that is not recovered. What they did is they took the tailings and rather than settle it, they put filters, at an expense of millions and millions of dollars, so all the tailing was filtered. So, only 8-10 percent retained water went to the dry tailing pond—quote, “dry.” It was not wet.

05-00:30:18

Burnett: But it's a paste?

05-00:30:20

Bhappu: At the last stage we got 10 percent more, so now, 75 percent is a common trend. They pick up another 10 percent, so now about it's 75, 85, 90 percent of the water is recovered, and nothing is overflowing. It's all retained. But someday, it will drain, we know that because of rainwater, there will be some drainage, but the drainage will be minimized.

05-00:30:49

Burnett: Right, and slow, over a long period of time.

05-00:30:55

Bhappu: We are going out of our way to design new plants without any pollution. I'm coming back to that mine in New Mexico—they put these fishes, went to the governor, and said, “Look, this is what the mining is doing. Are you going to allow that?”

05-00:31:12

Burnett: How did you know about this?

05-00:31:14

Bhappu: The Bureau of Mines, I was with the Bureau.

05-00:31:17

Burnett: But how did you know that they dipped it in cyanide?

05-00:31:19

Bhappu: I'm coming to that. So, the department office called us at the school of mines, said, “Please come on over, we need to resolve this situation.” They showed us, and I looked at the fishes, and I suspected something. Now, we were regulating the amount of cyanide in the flotation circuit to the minimum, so that when it's diluted with something like 20,000 gallons or flow, that it would be below the toxic limit, okay? That's what we had calculated. I couldn't figure out why they should be above the limit. So, we said, “Give me those fishes.” So, I sent it to Cincinnati, Ohio, to the Environmental Service, and I said, “Please tell us what these fishes died of, or what happened.” In about a week's time, they said, “These fishes were most probably dipped in a rich cyanide solution, which is, of course, toxic.” What happens, that the fish, you can look at the fins of the fish, it acts as a collector of impurities. So,

that's what they do. It's collected in the fins, and they said, "Look, this is not natural."

05-00:32:52

Burnett:

Oh, in the gills? In their respiration?

05-00:32:56

Bhappu:

Yeah, right. So, we knew now and went to the governor and told him, to the department, that these fishes, it's trying to spoil the name of the company and blame the Mining Department. They said, "Well, how can you mitigate that?" "Okay, well, what we are going to do is we are going to take the tailing that's ten miles away, we are going to take the overflow water from the tailing, some of that, and we are going to put our fish pond. If our fishes are alive, they cannot die upstream." So, this now becomes a—

05-00:33:35

Burnett:

Is that a practice, that now people do this?

05-00:33:37

Bhappu:

If you are using cyanide, that's one way to put up your own pond, in a tailings pond. If something happens or you examine it chemically, then you try to mitigate that. This gives you an assurance that the water is clean enough for the fishes to grow and actually, it's official, people cooperate with us.

05-00:34:07

Burnett:

So, instead of a canary in a coal mine, you have a fish in a fish pond.  
[laughter] A fish in a tailing pond.

05-00:34:16

Bhappu:

So, the environmental concern today is, as I said, it's the tail that wags the dog, and that's the first thing you think about, is what am I putting in that's going to come out at the other end? We try to control that by putting liners, taking the solution that flows from the liner into another pond, and put up a water treatment plant. The only problem is when the thunderstorm comes in, but now there are geoscientists, and now hydrologists have now worked out a new peripheral berm underneath the tailing pond, putting in absorbants.

05-00:35:08

Burnett:

So, a kind of multiple redundancy, I guess, so that if something fails, there's another tier that will catch it.

05-00:35:17

Bhappu:

This became a very beautiful research area, and at the New Mexico School of Mines, and I suggested to the regents that they put in an environmental—not a big department, but sufficient, a few people that would maybe offer two or three classes.

05-00:35:37

Burnett:

This was what year?

05-00:35:39  
Bhappu:

This was 1968, '66 in that time. We would offer an environmental option in metallurgy. If somebody wanted to specialize in them, he could get the degree and then he would do advance work with our experimental plant and the research facility, as a graduate-student assistant. So, that developed into a good event, then everybody else started following and putting in environmental-science programs because it's expensive and it prolongs—you need more graduating hours, semester hours, and people didn't like it. But some of the students really are very conscious about this thing, and they want to do it. There are about ninety students out there in the mining department at the university, and if you tell them what's a concern, they're thinking, well, half of them will say, "I want to specialize some way in mitigating this challenge." So, there is a lot of activity, and this is when a lot of research and mining companies themselves are putting in money. It was a shame that US Bureau of Mines was taken out. Their duties were taken over by USGS, Geological Survey, but they're not doing the job they had done.

Every state has its own Department of Mines and a Water Department, and they work very closely with the industry. They go and check out the plant, and they will allow you a certain limit of leeway, but if you exceed that, they really tax you. They really penalize you, hundreds and thousands of dollars for one fault, or if something spills. That's another big thing, is most of our chemicals and our supplies and all those come by trucks. If there's an accident, there is a spill, that's another big area that people are concerned about. If the pilot plant breaks, that's another area of concern.

05-00:38:05  
Burnett:

Many of the controversies surrounding pollution of mines are about spills. It's not so much that they say, "I don't like this berm system," it's more like sometimes it fails, sometimes there's an extraordinary event like a thunderstorm.

05-00:38:28  
Bhappu:

It's something that happens here. Agriculture people use acid to condition the soil. The trucks carry acid. In one of the towns, I won't mention it, there is a proposed in-situ mining site being considered. They asked for a permit, and they said, "You are bringing trucks full of acid for your leaching operation. That's not allowed." "Hey, but you're allowing the farmer to do the same thing. How come?" "Oh, they come under the grandfather clause." So, this is the kind of problem we are having—little jabs, this is not allowed, that is not allowed. So, suddenly, we are faced with a new challenge.

05-00:39:26  
Burnett:

I hadn't thought about grandfathering before.

05-00:39:31  
Bhappu:

The thing is that because they have been using it for a long time, it should be allowed, but you are a newcomer, you are penalized. So, that's an issue that came up just recently. The mine was being prepared, all the permits were obtained, and then this is a new permit. So, now what they have to do is to bring sulfur, that's another alternative, is to bring instead of sulfuric acid, which is now recovered in the smelter as an environmental protection—so that the acid won't be out. So, all the smelters have acid plants, they recover the acid from the sulfur, and then they use that in their own mine and also ship it to others who don't have a smelter. So, we are using all the acid that is created by the smelters. Now, we have to bring in natural sulfur from the mine and burn it, recover the sulfur dioxide, and make acid. So, you see, that increases the cost of your operation. So, those are the things that the new mine is facing. The government agencies, I think, they are all right. They have to do their job. But a guy from the Arizona Department of Forestry or somebody, he says, "You know, I found out that this little chemical will kill or destroy the cactus of this kind," which is random. Cactus are very—

05-00:41:26  
Burnett:

Hardy.

05-00:41:29  
Bhappu:

They can take a lot of hardship. They say this particular cactus is not going to survive. So, now, there is a big research, and should we allow that to happen? Well, some of them say that rabbits and snakes, you are taking away all their habitat. They should be regulated. So, once you start doing this, every biologist who is not in favor of mining will say, "Oh, have you considered?" and this keeps on going.

05-00:42:12  
Burnett:

If the argument is taken to its conclusion, there's no safe place because every ecosystem is going to be affected if it comes into contact with mining operations.

05-00:42:24  
Bhappu:

The question is, you go to the Forest Service, you go to the Water Department, and say, "What are your tolerances? What can you accept?" Of course, they say, "Zero." I said, "Fine, but what can you accept in a drinking water? Would that qualify as a standard?" They said yes. So, now, it will come to a time in the next few years where all the water will have to be put through a water treatment and supply the water to the city. But if they find out that you are treating the mine water, they won't accept that, either. What is the remedy? So, the government has to come in, and sure, the miner has a right to mine, he's taken all the precautions, so give him an operating permit. Monitor him, in the first few years. See if he meets all the tolerances. If not, give him a chance to correct the situation, and if it happens again, make a warning, and third warning, you close down the mine. So, I think we can live with that.

It's going to increase the cost, and who is going to pay for it? It's the consumer. To the same people who are objecting, do not then object to a higher price for an automobile, or pipeline, or a refrigerator. After all, the consumer is the user of the metals, and the price of metal, when I went to Miami Copper Company, the price of copper was \$0.50, \$0.56. It went down to \$0.26 because there was not much demand for that. The mines could hardly operate. Today, the cost of copper is \$3.20, miners are doing well. But most of that profit goes into environmental control. So, the miners are making money not per pound of copper, but how many pounds they can create.

05-00:44:57

Burnett:

They have to go for volume.

05-00:45:00

Bhappu:

That becomes a challenge. So, the mines that were 5,000, 10,000 tons a day are now processing 100,000 tons a day because it takes the same number of people. It just has bigger machinery, you take a mine truck, they used to have a twenty-five ton burden. Now, they have trucks that will haul 400 tons. The wheel is about eight feet.

05-00:45:31

Burnett:

So, there are economies of scale.

05-00:45:33

Bhappu:

Economy of scale, and that's why they compete with Chile. If you put more burden on them, then the mining will suffer.

05-00:45:45

Burnett:

Are there economies of scale in environmental protection? So, in other words, for the very large mines, they're making money from reducing their costs, but is it also more efficient because it's a single plant or it's a single operation, and they have better technology, better controls for that?

05-00:46:13

Bhappu:

Well, the thing is that one of these came up in one of our discussions, and I said, "Okay, if that's going to be the problem, let's clean up and say, 'We are using clean waters, I'm going to tax you.'" Because you were using ordinary water from the well, our water is cleaner than that water. If you're going to use agriculture, garden, let's make a bypass so you can use that water for non-consumption. So, as I pointed out, the agriculture uses a lot of water, and the amount of water they use in mining is a fraction of what they use. It's more useful, that water, for the mine than for the public, in the farms, especially cotton that you see between here and Phoenix. So, I think that there is a limit, and what we need to do is to have an open discussion.

First of all, what should you be doing as a miner? Old people who have opposition to mining, they are not going to change. However, if you take a younger generation in the schools, high schools and grade schools, and say,



“This is how mining uses your water. Look at my quality of water, and this is what you are pumping from the well. They are both equal. Would you accept that?” So, it’s public information gathering that all the mining societies and our Mining Foundation of the Southwest is putting a lot of money in one or two or more mentors who go to schools—grade schools, especially—and give lectures. Many years ago, I used to do that, I went to a grade school and talked about the copper mine and the impact of it. After I finished the talk, in about forty minutes, the teacher come in and said, “I didn’t know you had so much copper being produced here.” So, now we have summer schools where the teachers can go to the mine and spend one, two weeks. We go to all the mines and they see what’s happening. This economy of size is wonderful because it allows us to do more for less money, but investment becomes high. The capital cost goes up, but the operating cost comes down.

So, mining has gone away. In short, in the beginning, they didn’t have any regulations. In the seventies to 2000, they had more regulations. Since 2000 to 2014, we have much more regulation.

05-00:49:37

Burnett:

More regulation since 2000?

05-00:49:39

Bhappu:

Yes. Last ten years have been horrendous to the mining industry. No new mines have come on stream. Both in Canada, the United States, and I told you that when you work for World Bank and international bank and UN, although it may be Bangladesh, you have to meet the US standard in the new operation. So, they’re not getting away, and this is where only people who can do that are big operations, big mining companies. They have the kind of money to invest in developing country. The local money, like Pakistan, India is much better because they have resource, Saudi Arabia, they can put the money for mitigation of pollution, but in Ghana or another country, they don’t have that kind of money. So, then somebody has to help them, but then they have to meet the challenge. So, if there is a World Bank Project of \$100 million, now it’s going to be \$150 million, that last bit being environmental regulatory control. Many of the diamond mines in South Africa and Central America, Colombia, Brazil, you go to the jungle, nobody cares.

05-00:51:22

Burnett:

There seems to be an opposite narrative out there about the World Trade Organization, for example. One of the complaints about accession to the WTO was that there’s this, what is it called, downward harmonization. So, essentially, the environmental regulations, when you join the WTO, in order for people to be able to compete in open, free trade, it’s not fair for one country to have low environmental standards and have a natural advantage. So, rather than raising the environmental standards all to one level, the accusation or the narrative is that there’s downward pressure on

environmental regulation in developed and industrial countries. So, that's not happening?

05-00:52:18

Bhappu:

That's not really happening, but it depends on the size of the operation of the government. Not all the governments can regulate everything in all the mines, and so, some people get away with it, and some of the miners, the government said, "Okay, you don't have to meet the US water standard. We have our own where we can tolerate a little impurity, as long as it's physically possible to ingest that. The doctor says, "Yeah, you can tolerate ten parts per million, let's put that, not two parts per million." Then, this happens, but they have to live, too. They have been living like this for years, so they said, "Well, why are you putting the penalty on me? I've been drinking this water."

05-00:53:16

Burnett:

Developing countries, you mean?

05-00:53:19

Bhappu:

Yeah.

05-00:53:20

Burnett:

Yeah, and I think they have a window, they have a time, ten years or fifteen years, in order to raise their standards.

05-00:53:31

Bhappu:

Good governments realize that, and things like in Australia, it's a very small population, good mines. In mining, there is a tolerance, and I said, "Well, just get into operation, but in ten years, you'll meet that standard that everybody else has to."

05-00:53:53

Burnett:

This is a narrative, too, for in the 1970s, in other interviews with mining executives and the Homestake Mine in South Dakota, they had to have a conversation with the Environmental Protection Agency. The EPA would come in and say, "We have a zero tolerance for this," as you said. They said, "Well, we can't, so what can you live with?" as you said.

05-00:54:25

Bhappu:

An open dialogue is what's needed. I think that the environmental peoples who work in the Environmental Department are really conscientious people, and they want to do their best. People who are in the government, you say, "I can go for zero." Well, that's not humanly possible, so let's settle on something that people can live with. Now, you say, my grandfather lived on the farm, my water was contaminated, he didn't worry about it—yeah, but he died at fifty or so, so you know? You say, "All right. You can live on it, but let's see if you can clean up that water." How much pollution are the farms producing? How much pollution is the cattle industry putting up? They have

regulations, too. Why put that burden on mining? Because mining has always been associated with pollution.

This is where in-situ leach comes in, is you don't see any disturbance of the surface. Then, they blame us and say, "Hey, guys, you are not disturbing the surface, it's clean, but you are disturbing the underground," We say, "okay, here are my wells around the property. You regulate it and tell me if it has any pollution, poisonous material, or if it doesn't meet the tolerance level." So, this is where new technology and the question has come up, if the tolerances are so strict, there will be no mining. That is why many of the big mines are going out [of the country]. Nobody's putting big new mines in the country because of this. Not because it takes years to get a permit; and there are always protestors standing out the mine gate and saying, "No, we will not let you mine." I think the United States government and states' governments and the people who control our economy and the future need to sit down and come out and say, "What can we tolerate?"

People have always adjusted to tolerance from the beginning of the world, and tolerance is something that we need to teach the little kids. You can't have everything, you know? Our education has to change. What our societies, mining societies, are good at, is we are great at talking to our own people. You go to a seminar and there are about 50 people, 100, sometimes 500, listening to your quest, and you are this clean and that clean. But who's telling your neighbor that? So, the neighbor doesn't know anything about it, and who complains? It's the neighbor. Even people who are educated, biologists and others, come out with new tolerances, saying, "Well, this cactus or this flower or this little lizard or something is going to be affected." So, communication between the mining industry and the public is a must. Government is not going to try to help you there—you help yourself. That's why we have open gatherings, and people like EPA and others opened up. The whole school conference room or the auditorium is full, overflowing, everybody raising questions. We are there on the stand saying, "Yeah, we are doing this, we are doing that." But that happens maybe three, four times a year.

We need to have the public, and the city, and the state, and the government, all get together. Otherwise, our mining will suffer, and what's going to happen? China. Chile. Brazil. They're growing countries, and sometimes they look behind. They'll go ahead and pollute. I'll give you ten years—by ten years, eventually what happens is the price of metal will go up, the price of refrigeration will go up, price of automobiles will go up. The consumer is going to pay for it, and even coal mines, there are new coal mines, some new coal mines, but they have to be regulated in Arizona. Some of the older mines – when do you hear about the mining? When there is an accident. Thirty people killed because of the underground slippage, or the spill, and so many people were affected. Day to day news doesn't tell you that all the mines in

the United States didn't have one accident today, but one simple incident is publicized.

The kids say, "Hey," when we go to the school to talk to them, "you are a dirty guy. Yeah, you are a miner." I said, "Where did you hear that?" "Oh, my parents told me. I see that in the news, that there was an accident." I said, "How many air flights, millions of miles are used up, without accident. But one little accident, one plane, and it's in the news." So, I think public relations and the press, I'm very glad to see that the *Tucson Daily*, every day they put up a little mining narrative with a picture of the old mine and how that got started, and how Morenci started, how the old people lived. I applaud them because it's a historical fact, and the history department in the University of Arizona has done a marvelous job of introducing mining to the public. It's a combined effort with the miner, the public, the government, all working together if we want to succeed. Not me, but the whole country.

05-01:02:18

Burnett:

Right, exactly. We'll stop the tape there.

#### Audio File 6

06-00:00:00

Burnett:

This is Paul Burnett for the Regional Oral History Office, interviewing Dr. Roshan Bhappu. This is session three, tape six, March 6, 2014. So, the first hour, we talked about the context of greater environmental regulation. Initially, it was local and state regulation that would adjudicate claims—someone, a neighbor, is polluted by a neighboring mine. But something else happens in the 1970s, especially with federal regulation, the Environmental Protection Act, the 1977 Surface Mining Control and Reclamation Act. There were upfront taxes, in some cases, on minerals, on ore, to fund protection and reclamation measures.

06-00:01:04

Bhappu:

Put up a bond, yes.

06-00:01:08

Burnett:

That's a big change in the industry, and earlier sessions, we talked about your technological solutions to these kinds of challenges. Could you talk a little bit more about and update us, so we're getting into the seventies and eighties, what did your company and you do?

06-00:01:31

Bhappu:

All right. When I started my practical experience at Miami Copper Company in 1954, we were an underground mine, and we had waste coming out from underground. We also had open pit areas. All the dumps were placed on one side and the tailings on the other side, next to that. As I pointed out, this waste product still has some economic value. Maybe not immediately, but in the

future, and so does the tailings. Now, how did we try to operate under those conditions? We felt that in order to extract what was left in the tailings or especially in the low grade material, that the copper minerals will oxidize. So, we would just sprinkle an acid solution, mild acid solution, and let it migrate. Since we had an underground mining area, the waste material was on top of that, so it will percolate down to the lower level and we would recover it and recycle it. So, that became important to us for two reasons: not only for the metals that we picked up, but then we can now re-use the water for the flotation process.

So, we took advantage, although we were not required to, it was just economics told us that we should do that. When I faced the challenge of leaving 150 million tons in a block cave area, which was still mineralized because they had a cutoff grade of maybe close to 0.3, or 0.5, that's six, ten pounds of copper per ton.

06-00:03:55

Burnett:

Underground in the block caved area?

06-00:03:57

Bhappu:

Yeah, but they could not mine it because it was very expensive to mine it and bring it to the surface. So, we said, "Well, we are going to leave it anyway, so what can we do?" We have a broken rock because of the block cave, it is broken. We have underground openings, we have the lowest level open, we have drainage underneath it, we have shafts operating. So, we said, "Let's start this in-situ leaching. We are not going to mine any new ore, so we have no waste. We are not going to treat any ore, so there are no tailing ponds requires, only solution. So, in-situ mining is also called solution mining, and copper, zinc, gold, silver, even uranium, vanadium, all can be mined by the in-situ process as long as you have the right solution, leachant, or leaching agent, which would be acid or a base or it could even be cyanide. It could be organic, inorganic, so this opened up, of course, a new area of research.

I had in that experience, I had come fresh, and I know that some mines were experimenting with this. So, it's not a new idea, it's just that the life of the mine didn't depend upon that. But in the case of Miami Copper Company, they were going to close the mine, so they have nothing to lose, you might say.

06-00:05:42

Burnett:

So, this is effectively advanced erosion? There's regular water erosion, but you're using a 5 percent solution of sulfuric acid?

06-00:05:53

Bhappu:

Right.

06-00:05:54

Burnett:

So, it's getting a little acidic help. It, in contact with the rock, liberates the minerals you want and it carries it out.

06-00:06:03

Bhappu:

So, some of it, the work is done by the reagent, or the lixiviant, which is the reagent that dissolves. Some of it is where this biological phenomenon came in. We never recognized it, but by experimenting, we found out that yes, biology is helping the mining, but not all of it. Certainly, it has a major contribution, and so, when I joined New Mexico Bureau of Mines, I took that as a challenge, of bacterial leaching. I took that in-situ experience to New Mexico Tech, and created, I asked the National Science Foundation for a grant to look at bacteria. I made a research foundation, the In-Situ Research Institute, to draw new money for in-situ research because New Mexico had a lot of uranium, copper, everything. Arizona was mostly copper. There were not too many new uranium mines as such. So, most of our applications of the future are going to be in-situ mining of broken rock or ore left in place. Many of these mines are going to operate for the next forty, fifty years, so that can be way out. Only those old mines that were abundant, and if that gives you an opportunity, you can do that.

06-00:07:47

Burnett:

This is going to have massive future applications because I think you said that the one that you started working on in Arizona—

06-00:07:55

Bhappu:

It's still up operating.

06-00:07:57

Burnett:

It's been fifty years now, and they've recovered two-thirds of the mineable element in there.

06-00:08:05

Bhappu:

The total reserve. That's the question, was it 150 million or 200 million or maybe 500? We don't know that. It was just estimated, what was left in the ground. I think that mining companies are now beginning to take a second look at what they see at first, "Oh, it doesn't look very attractive." But when you start looking into deeper, and looking at models and modeling it, you begin to find out that there is really a challenge and an opportunity to take advantage of either new or past operations. They have left that legacy to you, especially regarding tailings. In South America, tailings are the biggest thing. Peru and Bolivia and all, tailings were left because in the old days, they were only doing gravity methods. They couldn't pick up – they didn't know much about flotation. They knew copper, but when copper, lead, and zinc occurred together, didn't know how to separate them. So, much of the wealth of the mine was left, and today, there is a big, not a rush, like, but an eagerness to

acquire those old mines so that they can be reworked. They have the people, and the problem is that if you do not work that, the people will suffer.

06-00:09:42

Burnett:

There are so many, I guess, sunk costs that are there. They've built a road, they have buildings, they have infrastructure.

06-00:09:56

Bhappu:

All the population of the town grew around the mine. If there is any pollution there, it's going to come back to the people. So, both the government of Peru and some of the investors in mines are now looking at trying to get to the mines that are accessible, so they can recover the residual values, whether it's copper or gold or whatever. In doing so, the mining cost is already done. Tailings are already fine. But what they left is residual rare earths. They never looked for rare earths, but you find that every mine has a little rare earth. They look for niobium and tantalum, and the biggest one is, of course, the uranium. Now, in New Mexico, they had a big uranium rush, and they had open pit mines, underground mines. All the tailings and all the waste went into an open pit dump yard. That dump yard is now leaking, and uranium and vanadium especially are leaking towards groundwater, Indian—

06-00:11:22

Burnett:

Reservations.

06-00:11:25

Bhappu:

Indian settlements, and even Flagstaff and other communities. So, the Atomic Energy Commission and the EPA got together to say, "We give you a challenge: how do you recover what is left in that, unless you mine it out and go through?" We bid on it, we got a contract. We said, "Look, it's already broken rock, okay? What we are going to do is we are going to use solution mining. What we are also going to do is mining in such a way that the material will stay in there, but most of the uranium will be brought down to the water quality level [standard for safety]. This is not one of economics; it's a question of public safety, and so, there is a certain amount of funding and government support.

06-00:12:39

Burnett:

Which renders it economic.

06-00:12:41

Bhappu:

These are the superfunds, that's what I'm coming to. These are the challenges to us because, as I pointed out, one little survey in Arizona, we saw 1,200 sites that needed some remediation. If you put all through the world that there are 14,000, the maybe not high enough, you know? [Ed. Note. Here, Dr. Bhappu is referring to a quoted figure of 14,000 Superfund sites across the United States] Those are, especially in Colorado, Arizona, in the hilly countries, the miners came in, dug it out, left it underground.

06-00:13:13

Burnett:

Okay, so many of these are small sites?

06-00:13:15

Bhappu:

Comparatively small. The big sites are uranium and pollution from copper mine and coal mine, especially, coal mine drainage, which is a big challenge. So, that takes care of that, and this opened up a lot of challenges. Now, when I went to school, we didn't think about all that waste. We were told, "This is the way to extract. Tailings?" "Yeah, put it on the side." We never talked about that. Even at MIT, there was a sense of, "Yeah, why worry about that? Let's let this next generation worry about it." When you start operating and you're living in a community and you see this pollution, my question is that maybe when I started in-situ mining, I might have started a pollution problem, although it has been going on for 100 years. So, I feel responsible, and I hope that no mines that we work on will have that problem.

So, it started a new research area, mining departments came in, environmental departments came in. The problem was the environmental regulation was concerned only with agriculture. It was concerned with farmers and groundwater, but nothing was talked about in the mining, till we started facing new challenges and a mine being closed because they polluted or the mine not being given a permit because they didn't show on their feasibility study how they're going to take care of the tailings. So, all the engineering companies, all the construction companies, all got together and say, "Well, we have to have an environmental department." We will work closely with the state, and also, why not use the college, universities, as a center of excellence? Tucson's residents become miners, and if you go to Phoenix, to Arizona State, it's a university. There is no mining; it's mostly agriculture research. That's how it went. So, I think that's a good thing. The environment concern brought a new thinking in the mining community. We started creating environmental committees, and you might say, sections. We used to have, mining, metallurgy, hydrology, and now we are saying, let's go into environmental sessions. So, we have presentations on environmental problems.

Who are the best people for environment? It's the metallurgist. He understands the chemistry, he understands the physical and chemical nature, flotation, and as I pointed out, if there is a discharge of, say, some reagent, all I'm going to do is add a frother and a little bit of that collector, and foam it off. So, foam flotation is becoming a big thing, for clean up, because some of those ions are sulfates, and ion exchange has become a big thing, now. So, we use ion exchange as a water treatment facility method because it will pick up both the anion and the cation, because there are two kinds. The solvent extraction became more prevalent because many of these environmental problems are associated with soluble impurities, not insoluble. Insoluble is pretty stable.



So, for metallurgists, surface chemistry was great for doing work on flotation. But now, our emphasis is on ion exchange, solvent extraction, electrolytic migration, precipitation, and even bacterial activity. Once I appreciated the fact that oxidizing bacteria were helpful to me in the leaching process, when I went to New Mexico Tech, one of the challenges that came in is, now, how am I going to take care of the solutions? If the bacteria were helpful to me in dissolving the metal, shouldn't it be opposite? It's like ion exchange, plus or minus. It should be an opposite-charged reagent or bacteria that will clean up the solution. Not the solid, but the source.

06-00:19:01

Burnett:

Right, if you could reverse the process.

06-00:19:02

Bhappu:

Reverse the process. It was felt that most of our impurity is sulfate-oriented because we use a lot of acid for leaching and so on, it's  $\text{SO}_2$ . So, we want to find that bacteria that thrives on sulfur as a source of energy. Thiobacillus, opposite to ferroxidants are ferroreductants, or reducing bacteria. That will break the sulfate bond and create hydrogen sulfide. Hydrogen sulfide will then contact the ion—copper, lead, zinc, mercury—and make them into sulfides. Since these are very, very small impurities, parts per million, it's not easy to take them out on the surface and process them, although it can be done. Why can't we just do in-situ leaching? So, we'll cultivate the sulfur oxidizing bacteria. Sulfur oxidizing bacteria occur in nature, they're not a new species. It's already there. Let's create them.

The only problem is there's a million count, but you need a billion before they become very active. So, we'll take the water, we'll condition it, neutralize it, and build up the high concentration of bacteria, and then pump it in. They will clean up the copper, lead, zinc, and the cations. They'll form sulfides and they settle down in soil, underground. It's a small amount, it's not going to hinder the groundwater flow.

06-00:21:22

Burnett:

They then become insoluble, at that point?

06-00:21:25

Bhappu:

That's right. Now, there is no more sulfate.

06-00:21:28

Burnett:

Right, and there's nothing to migrate. If water comes down and settles?

06-00:21:34

Bhappu:

They will lose their activity as soon as the sulfate runs out. So, it's a self-governing thing. On one side you create oxidizing bacteria, and then you use the opposite, sulfur-reducing bacteria to clean up the water. If you don't do that, that plume is going to come to Tucson. Some of this thing is traveling at one foot per day, or something like that. So, to control the plume, all you have

to do is to start with the bacteria. Once the bacterial energy and usefulness is used up, it becomes inert. So, it's not a problem anymore, so it's self-governing. Now, when we went with that concept to the EPA, both the local and US, they said, "If this is the kind of mechanism you are proposing, why don't you let nature do it?" I said, "Yes, nature will do it, but it'll take a million years, a thousand years." [laughter] No, but this can be done within ten years.

06-00:22:54

Burnett:

I wanted to go back, when you said that the metallurgist was best positioned to handle these environmental because they understand the chemistry?

06-00:23:02

Bhappu:

Chemistry, it's a chemical engineer. Yeah, and then the chemical engineer, of course.

06-00:23:08

Burnett:

What I'm thinking in this history of the growth of environmental protection, environmental regulation, is that there's a kind of new kid on the block. The science of ecology, right? So, ecologists are coming at this and thinking about so, for example, if you have this pollution and then there's some kind of remedial solution, an ecologist might think, "Well, what are the potential downstream unintended consequences?" What we need to do is test the ecosystem to find out, even if in principle, this chemical reaction might result in this, ecologists might say, "We don't know for certain."

06-00:23:55

Bhappu:

Yeah, you confirm it, and that's where the research comes in. You try all these new reagents, you can try liquid ion exchanges, for instance. You can pump it in, now, ion exchangers are organic compounds and charged. You can pump it into the aquifer, but you know, it's costly to do that. But if you can find a naturally occurring bacterium, why not use that?

06-00:24:30

Burnett:

So, what you're saying is that this chemical engineering work, it is ecology?

06-00:24:36

Bhappu:

That is right. The thing is that the typical miner, in the old days, and the metallurgist, was working with ores—solid material. Now, what we want to start is people working with solutions, with water, with seawater, and all kinds of streams, to see how you can take advantage, and even water treatment. Municipal water treatment, because of mercury in some of the lakes in New Mexico, they say, "Well, it came from accumulation of mercury by fish and other natural means." There are no mercury minerals there, so it didn't come from that. It came from plants. Why plants? Because plants are absorbent of impurities. This is like an ion exchanger, so I think that this becomes a new field, part a co-mining operation or education. Using mining solutions and such as a base to embark on solving problems with solutions more broadly.

06-00:26:02

Burnett: Right, in both senses.

06-00:26:03

Bhappu: We called it solution mining, and it's a good term. It doesn't destroy the surface. You have to make sure that you are not encouraging something else to grow.

06-00:26:17

Burnett: Right, this is the problem, right?

06-00:26:19

Bhappu: So, it's always an antidote, or also the encouragement to something else. This is where the university research comes. Mining companies can't do that. It has to be supported by the university through the state and through the federal government. Whatever you say, the amount of monies that were set aside for education, has been reduced 30 percent. This is the wrong thing. What happens when the strike occurs or there is a problem of the cost reduction? Who goes first? It's the research department. That's the lifeblood. They are the first ones to go. Big mining companies at the big shows in Salt Lake City, a conference on Society of Mining Engineers last week, there were hundreds of kids, younger people looking for jobs, because they had been laid off by big, big mining companies who had their own research. Big mining companies can't put up research. Anaconda Mining Companies built a research center here, when I came here, I would say, about 1970s and '80s. Forty million dollars in those dollars, and today, there is nothing. It's empty.

So, the research departments are the first to go, so somebody has to take the burden, and that's the government. State or federal, you're getting taxes, and the question is should you tax the mining company? Well, people say that the mining companies make billions of dollars. They do, but they also take the risk. They also invest billions of dollars in plant capital investment, community, churches, schools, in their own community. In South America, all the countries, the big mines support the church, the school.

06-00:28:53

Burnett: And the government.

06-00:28:56

Bhappu: I think that it has been a hindrance, but it also has been a challenge. Working with the tools that we have and with the new inventions and new development, new especially monitoring devices, on-stream analysis, that you can see what's happening. You don't have to take the sample and take it to the lab.

06-00:29:32

Burnett: Right, it's real-time analysis.

06-00:29:35

Bhappu:

So, if there is a problem, if there is a minimum deviation from the standard, you have a remedy. In the old days, we used to have mercury and lead, although in chloride solution, lead sulfate is very insoluble. Mercury is soluble in acid, and the way to do that was to add a little bit of sodium sulfide. So, mercury, you make cinnabar and then you float it off. So, flotation is still going to be there. All you are going to do in solution chemistry is to contain it, but now you may want to float it off.

06-00:30:32

Burnett:

So, you can do two things, you can trap impurities or you can liberate them? Either way.

06-00:30:38

Bhappu:

Yeah. If you're on the surface, you will trap it and remove it. If it's underground, it'll stay underground, it's when it comes to the surface because of the fluid flow through porous media. It's going to stick there.

06-00:30:54

Burnett:

Well, speaking of education, you've talked about educating schoolchildren and the next generation. You've said that it's too late for some people.

06-00:31:01

Bhappu:

Yeah, I think that that is true, but that has been confirmed, that the best formative years are between seven and ten. It's a grade school. High school is too late, people have, "Oh, I'm going to be this." But you ask a kindergartener, "Oh, I'm going to be a pilot," anything that is exciting. Then, when he gets into reasoning age, seven, ten years, then he begins to say, "Oh, should I become a doctor, should I go into medicine, should I go into engineering? Should I become a bean-counter, should I go into economics?" He starts thinking about that.

Most probably by the time he's in high school, he has already made a decision. "I'm going to go to this college or that college," or, "I'm going to go into practice," in the sense, "I'm going to be a carpenter or welder." There is a big demand for those guys. They make good money. Every engineer needs five technicians, and I preached that to the United Nations. I said, "Don't start a college. You're going to spend millions and billions of dollars, and you are not going to have a good college, it takes a reputation. It takes years of cultivation. But start a two-year college or a trade school, where you can take a kid who has an interest in chemistry, mathematics, and all that. Take him and get into welding, then go to soldering, welding, carpentry, plumbing. There are more people in the service group than engineers. Why? Because you can only have so many engineers, and not all the children are equal in aptitude.

06-00:32:56

Burnett:

It's also that, I mean, we have a fetish for the college education. It is the end point in the industrialized world. But when you look at highly productive nations such as Germany, there is no shame in learning a highly technical trade.

06-00:33:15

Bhappu:

A trade school. My grandfather was the first one. He went to, because we had our own schools, Zoroastrian schools, he told the governing body, "Not all your students are going to be going to college, although you hope. Why don't we start a trade school in the high school?" So, you can pick up some guys and say, "Hey, you are not good at mathematics, but you're good with your hands." So, in the last two years of high school, give him a trade training, rather than college-type training. If he becomes proficient and he wants to go back to the academics and go to college, give him the chance. But show him another path of education. We've got schools of mines, but we don't have mine trade schools. Mexico has that.

Developing countries, they know they can't afford higher education, but they can afford to train a guy out of school or on the street, give him a couple of years of education. In the morning, you give them a little theoretical, get them into looking at scientific publications and get him oriented to what he wants to do. Then, in the afternoon, give him a practical training class. Those are the kind of educational opportunities that we in the mining industry have to look forward to, is that it's not only the students that we have to worry about, but they have selected it, what about the people in the street? People who live in Safford, or in a mining community, Miami Globe, none of the students there want to go to mining school. Everybody locally works in the mine, but as a technician, not as an engineer.

06-00:35:31

Burnett:

Right. Well, I think in terms of education ramping up the appeal of mining, I think that one of the big challenges is that it doesn't have a romantic side to it. Young people want – so if anyone thinks of engineering, they think, "I want to build the new car," or, "I want to build a new high-tech device that fits in my pocket." They don't think about the fundamental side of that, like, what goes into making that element? The reason I asked you about education was I wanted to direct a question to there's all of this great stuff that you have done and your colleagues have done to get environmental solutions, in many senses, to these problems. What education or what communication is happening to the EPA? What does the EPA think of all of this?

06-00:36:23

Bhappu:

EPA thinks highly of it, and they encourage scholarships, and they have their own programs. The thing is, that I haven't seen them coming to the schools and colleges to talk about EPA regulation. They again are talking to each other. Once you use a derogatory word, "dirty," it sticks in the mind of the

people. Mining is dirty—it's not dirty. It's what you thought about it, and called it dirty. Mining is dangerous, yeah. You hear about an accident once a year, and yes, pilots are there, they take a risk. Sailors take a risk. Navy people, all the disciplines have a risk factor. What I'm trying to impress, that suddenly making people aware of mining and minerals and water treatment and all that doesn't come overnight. You have to be trained and a little dose has to be spilled in, every day.

Now, what does mining do? Before the shift starts, the shift foreman, woman, comes as one word—safety. Practice safety; I don't want an accident on my shift. That's the first thing. If you look at Phelps-Dodge or Freeport, any of the big mining companies when their presenter, he presents a paper, his first paragraph is on safety. This is what we do, I hope you will be safe. That's his beginning.

06-00:38:29

Burnett: That's the spirit.

06-00:38:30

Bhappu: That's important. If every classroom was in a grade school, we'd say, "Be careful, walk carefully, walk on your side so you won't get run over." Some kind of a safety key sentence. It's a great help. Or, "Help your mother," something. Good schools do that. So, I think that mining is faced with this problem. Like every other problem, they're going to solve it. It's going to take time, it's going to take government—local and federal—it's going to take teachers, the college teachers, and the community, as a whole, to make a big impact. The question is, can mining survive under all these conditions?

06-00:39:30

Burnett: No.

06-00:39:31

Bhappu: If they have to look at all the restrictions and capital cost and operating cost, yes, eventually it's the consumer. Or are you ready to give up and say, "I'm going to go to China." How many are picking, taking Chinese as a second language? Many colleges offer that because they think that their next job is going to be in China. And yet, the Chinese mining industry is in a terrible shape. I've seen it. You go through the coal mines, you drive all night, and you are still in the desert. It is cold environment of gases and cloudy train ride, all through the day, all through the night, as you go through the coal fields. You go to the mine, in a small mine—because "small" is 2,000 tons a day—they will have 100 engineers. We have five. They're overspending, and when I told them simple little things, they say, "Oh, I didn't hear that in the classroom."

06-00:40:50

Burnett:

I guess the emphasis, as we all know in China, is industrial development. There is environmental research going on in China to a large degree, but in some areas, safety is less of a consideration, environmental health, that's why they have pollution problems they do.

06-00:41:09

Bhappu:

I probably said it's not China universities in the metallurgy. They do a beautiful job, just as good as Fuerstenau at Berkeley, because that's where they have been trained, so they practice that. Even in Turkey or Iran, you should see the technical people that come out of Iran on metallurgy—excellent, but they were trained in Colorado or MIT or Columbia University. So, that's going to happen, and the bad thing is, I'm saying, it's not a good idea to say, "I'm going to stop mining here, but I'm going to let Bangladesh do the mining. I'm just going to go get the metal, and I'm going to use it." No, you are going to lose the balance of economy. You're going to lose the balance in education and invention and challenges. There are no challenges if you let everything go out to other people.

06-00:42:12

Burnett:

Also, if the impetus is environmental justice, what are you doing if you're just sending off shore the toxins and the poisons, so that somebody else suffers?

06-00:42:23

Bhappu:

That's the other soul-searching question, is if you have pollution, if you mine in a developing country, they will have pollution, too, unless you tell them what to do.

06-00:42:36

Burnett:

And give them the incentives, right? In the United States, there's a state that can force, but we've seen in the BRIC countries, they are accusing the industrialized nations, saying, "If you want us to take environmental care, pay for it, because we have work to do." That's their answer.

06-00:42:59

Bhappu:

Well, look at the dogma in medicine. They take a doctor and say, "If you want to get the best doctor after your degree, go to a village and treat the people there, go to Nigeria and look at their conditions." Doctors Without Borders and things like that, well, one or two years of that will really renovate you to come up, and then you can come and say, "Here, I've got some solutions to my pollutions." So, I think that's one thing I didn't mention, and I'll mention it in the next session, is the cooperation between different countries. Especially in mining, what's happening—are we exchanging information, are we exchanging our students? Mining is not local. Mining is universal. It's a universal country, and every time I travel, I go to Tokyo or Sidney, I see mining engineers, you know? "What are you doing?" "I'm on assignment."

06-00:44:11

Burnett:

So, it's a small world, the mining community?

06-00:44:15

Bhappu:

The mining community is a small world. The one thing that we didn't talk about is maybe gemstones—why are gemstones so important? The thing is that developing countries, and since centuries, have always found gold. Peru was a gold-using nation. Their doctors, their skirts, everything was made from spun gold. If you see the Ouro Museum in Lima, oh, it's something out of this world. These implements, everything was made from gold. Gold was soft, so they would add some other metal to make it stronger. So, anyway, I feel that the gemstones are the big incentive and resource of a country, especially of a developing country. Why? Because gemstones are visible. Your eye is an electronic instrument. It picks up the emerald. This is a ruby, this is a sapphire. So, day one to 2,000 years, everything has been handpicked, and that's why jewelry is so expensive. They are hard to come by; you can't process this in a large tonnage till De Beers and others came out and used the metallurgy. Diamond being 3.3, all the kimberlites and gangue being 2.8, 2.9. modern in specific, heavy media at 3.0, all the diamonds would sink and everything else would go up. So, it was a mass production by one single method of metallurgy.

Now, they are getting more sophisticated. An electronic beam can pick out a diamond on a conveyor as the diamond's surface makes a bigger reflection. This is called electronic sorting. All the minerals of the world that are gemstones are all heavy. All have their own identity, physical identity.

The following section was recreated during editing due to technical difficulties: So, you take advantage of the unique physical properties of the gemstones such as density, magnetic and electrostatic responses, radio-activity, reflection of the beam of light, etc. Use of modern detection machines, allows us to separate gemstones from the worthless ground components effectively. These advances have opened up new research opportunities and mining activities for helping developing countries to recover gemstone resources by using modern technologies. My work in this area involved helping developing countries to improve their methods of gemstones extraction at a low cost through United Nations who wants to help these countries.

Because what happens is that they collect a handful of rubies, worth thousands of dollars, a German comes in and buys that whole lot for \$100. That was not fair. This trade should be regulated, reasonably. Nowadays, in Brazilian universities, in Canada, they are training people to look at electronic sorting as an aid to mining by hand. These activities by UNDP, local universities and educational foundations are most worthy efforts deserving of our support.



If miners in developing countries could increase their throughput with some of these new technologies, they could receive a greater share of the final sale value of the gemstones. Then, the miner could put up a jewelry store. These peoples are very artistic, and can create finished products with emeralds, sapphires, such as jewelry. They are wonderful at it. They are very artistic, and they will make implements, a brooch, a ring, and gradually build up a cottage industry.

Now, the miner can afford to put up a bulldozer, and instead of mining 100 pounds a day, he'll be mining 100 tons a day. He will have a mechanized separator. He will recover rough stones. Some of them will go to jewelry, some of them will go to market, to a regulated market, as the Brazilians have.

06-00:49:20

Burnett:

To retain the value?

06-00:49:22

Bhappu:

The value. So, I think that the gemstone is one area that mining can benefit because you are developing the country on its natural resources. So, that's why I imagine that scientific extraction, getting away from handpicking and thievery, to pick up more stones, cheaper stones, and maybe someday the price will come down. People can afford a diamond or a ruby. You go to India, and you see all gold. The whole wealth of the family is on mothers' or daughters' hands or necklace, because it's there. They can afford it. In India, to marry a daughter, you have to give a dowry, and it's usually in gold and jewelry.

06-00:50:26

Burnett:

So, there's a couple of issues. One is this artificial scarcity, right? That they're relying on this incredibly antiquated and labor-intensive practice. That is, it's cultural, it's economic, so this traditional way of doing it, unless it's disrupted by some technology transfer, it's not going to happen.

06-00:50:48

Bhappu:

Yeah. But there is also deception because you can create a gold powder, and the rest of it is lead because it's heavy. There's a lot of things—diamonds—are saleable, and some of it, you see that in magazines, naturally costing \$7,000 will sell it for \$70. It's a synthetic. In New Mexico Tech, we made synthetic diamonds to prove that it can be done. Is it a true gem or are you dealing with a substituted material? Zirconia is one of them. They look like diamonds, they act like diamonds.

06-00:51:42

Burnett:

In many ways they're just as beautiful, right?

06-00:51:43

Bhappu:

Yeah, just as beautiful, so how else would you know? Anyway, the thing you can do to help the developing countries is to take care of their natural

resources. I find that everywhere I travel, any country, there is always a local jewelry, a little diamond bazaar, or something like that. Many of them are illegal, or gold bazaar. And I told you that Brazil stops it by paying extra to the miners, so that he doesn't have to go to the black market. That's the whole idea. So, gemstones are a new scientific endeavor, and should be introduced as a part of mining and processing. When I went to Afghanistan, I had a miner with me and geologist and a metallurgist, and a gemstone dealer. So, we brought them the whole way. My friend, mining engineer, says, "Now, I'm going to talk about explosives." Everybody raised their hand, "Sir, we know everything about explosives. You can't teach us anything." [laughter]

06-00:52:55

Burnett:

I bet they do! That's right. Well, I think I saw on a website the conference proceedings for that conference. You were speaking and another mining engineer was speaking, and then there were two chiefs of tribes speaking from Afghanistan and they were talking about local governance and customs.

06-00:53:12

Bhappu:

Yeah, so anyway, I thought, "That's one thing I wanted to procure," and as far as remediation, I said bio-oxidation is playing a very important role and will play important roles in the future. Environmental concerns would be stressed during the class hours, and students will have an opportunity to see where the problems are and what method is being used. If it's a four-year course and a student was strictly limited to core courses in chemistry, physics, biology, geology, well, let him graduate and give him an option at the master's level to specialize. Metallurgy with biology, metallurgy with electronics, so he becomes an expert in the thing.

06-00:54:12

Burnett:

An interdisciplinary expert.

06-00:54:13

Bhappu:

Interdisciplinary. You've got to go interdisciplinary, I think. Sure, in your growing years, you should take physics and chemistry and math, I think that's great. But when getting into the senior class, bring them some sense of what happens, a little bit of business, a little bit of how to file a patent, and how Wall Street and the mining industry associates. Today, this week, in Toronto, there is a big mining get-together, 40,000 miners are there today. They're exchanging information. They say, "I got this property, are you going to be interested?" Making deals. So, that's the kind of education, real-world education people need. You diversify their thought—it's not just mining, digging, digging. It's more than that. Think about what's going to happen. One day, these professionals might be the manager. We are not giving them the managerial training, or interdisciplinary training. My son, Ross, took an MBA degree, a doctorate in MBA, that's fine. But once you're in mining for sixty years, you always consider – what's the new horizon? What's the new technology?

06-00:56:06

Burnett: Well, that's something that we'll pick up as we talk. That sounds great.

### Audio File 7

07-00:00:00

Burnett: This is Paul Burnett, of the Regional Oral History Office, interviewing Dr. Roshan Bhappu, in session four, tape seven. So, we left off talking about new horizons in technological development and this larger political-economic context of globalization and environmental regulation. Can you tell us more about the kinds of innovations that were taking place in mining, in which you participated?

07-00:00:46

Bhappu: Okay. One of the things that I should tell you about is the life during those years, sixties and seventies. When I came to this country, I came from Karachi, came directly to Denver, went to Golden, and stayed there. Golden is a small town. It's a very good environment, has no distractions, except unless you have to go to Denver, which is expensive for a young engineer student. The life has been very well received. When I moved from Colorado to Arizona, at Miami Copper, now you are living in a mining town. The mining town doesn't offer much as far as recreation—concerts. So, life in a mining town is quite different.

Now, those people who go to college in Columbia University in New York, or at Berkeley, they are next to the big city, and they enjoy the life. But you talk about the life of a miner living in a remote location. The mining life of a miner is that he works, he comes home, he goes to sleep, next day – The only time he gets off is on vacation, and usually he selects somewhere on the coast, or goes to a big city. So, the life of a miner is not full of activities. It's only recently that mining companies have come to realize that. Although they have a golf course and a tennis club, or things like that that they provide, they are now providing much more than just—it's important to keep the person happy, satisfied, and to not cater to all his needs, but at least the essential needs.

At Miami, we were close to Phoenix, so every weekend, we went to Phoenix. In Socorro, we were close to Albuquerque; it's only seventy miles away. We used to go to Albuquerque for weekends. So, that's the way our life went, but most of the time, it was remote. You didn't travel except on assignments, and you tried to encourage fellowship by joining the youth club or YMCA or a mentors club, or teachers association. SME, [Society of Mining Engineers] subchapter of WAIME, which is the Women's Auxiliary of Mining. So, at least we tried to take more part in local activities. Not necessarily church because we didn't have a church preference, but we used to go to Catholic church and other churches, and talk about our religion. They wanted to find out more about us.

07-00:04:27

Burnett:

When you talk about “we,” could you tell us about the “we?”

07-00:04:29

Bhappu:

About my wife? Yeah. As I say, my first wife was Carmen Macintosh. His father came from Mexico, is a mining engineer. I met her in Denver, when I went to the school of mines there, and she was at the women’s college. We met at a dance. I liked her because she was more cosmopolitan. She didn’t expect that I was a maharaja or something, so expect a life of luxury, but at least she was interested in our religion and she was a Catholic, so she was pretty strict. But at the same time, she was quite flexible, and our son, as he grew up, I wanted to initiate him, like a christening.

07-00:05:25

Burnett:

Yeah, like a Confirmation.

07-00:05:26

Bhappu:

So, she agreed to his being christened as a Zoroastrian, and we have a ceremony that we go through. So, she was a wonderful lady. She took active part in the Mining Women’s Society, and the students, and most of the time, it was working with the family because there was no distraction. Oh, we had a theater or something, but realizing this, I said, “Phoenix has all the concerts and very good artists who come there.” In those days, we had \$5,000 fees. Today, Tucson, they will pay about \$100,000 to \$500,000 for an appearance in the concert. So, I talked to the mining company and I said, “Look, we need to start something like a concert series, and maybe have two or three concerts in the fall. We can invite the United Artists. It’ll cost us maybe \$5,000 for travel because they’re already in Phoenix—they usually come on trucks, we pick them up.” So, we started a little concert series.

07-00:06:41

Burnett:

Classical music?

07-00:06:42

Bhappu:

Classical music, and also pop. The sense is it’s not all high classical—something that people can enjoy. Maybe we would have a piano recital, maybe a trio, and maybe a lady soprano. Small concerts at the high school, so the kids could join in. The company, Miami Copper, supported that. When we went to Socorro, which is also a small town, about 10,000 people, about 5,000 of them directly related to the college, school, we had Dr. Colgate, of the Colgate fortune, who was one of our presidents. Mrs. Colgate says, “Roshan, that’s a good idea, let’s start a concert series, and people come to Albuquerque, so we’ll invite them.” They put in their personal funding to bring those people to Socorro, to the students, to the community. So, a miner is very isolated, but with proper arrangements, he can enjoy a decent life. This is where the mining companies come in. This is a fringe benefit. He’s away in

a village, nowhere to go, no recreation, except pubs, where there are lots of beer joints and all that.

But everybody didn't want to drink beer every night. We want to enjoy ourselves, so they usually have a golf course, they have a little gymkhana-type arrangement, where you can play tennis. So, all the mining camps, the bigger mining camps, they, of course, if there are regional miners, they invite them to become members. Mining life is not as enjoyable, but you can make it so, if you start something, you enjoy something. I used to join a Y's Men Club. It was young people, all Y's Men, we'd meet together, we'd talk to each other, and say, "What should we do for the kids next summer?" We made plans for the community, that's why we were called "Y's Men." It was a part of the YMCA group. So, I just wanted to mention that there are fringe benefits, and a good mining company usually provides some recreational activities. All work and no play is not good, so they realized that. They also organized tours around the neighborhood, or Saturday, Sunday, we go on picnics and things like that. Like in Arizona and New Mexico, there are always old American Indian sites to visit, camps, the old ruins. So, in the personal life, in the 1960s and '70s, when I was in smaller towns, that's how we enjoyed ourselves. Vacation-wise, we always went to the ocean, or somewhere where we could have some fun.

Our next area, that research innovation and entrepreneurship. When I selected mining as an option, I was influenced by my mentors, my high priest, my parents, family. When I came to the United States, I really enjoyed that. I had never seen a television, and I saw television for the first time. We went to concerts, and Denver was not that far off, Albuquerque, so we went to things like that. As far as the mining, we had a lot of time to think. We had a good library. So, I was thinking in those terms, of being a good metallurgist, a good researcher, that was my idea. Then, I thought that surely a good researcher could also become a good teacher, but you could not do that unless you had practical experience. So, that's why I selected to come to Miami. I wouldn't have had the opportunity to look at in-situ leaching as my main field of research and operation, till I was in a small city and a challenging assignment was right in front of me.

So, to budding engineers, they have a lot of challenges. They're looking around their own campsite and find lots of ways. There are slag piles, there are tailings, and each of them has some metal value. So, to help your company, in the mining community, research was of two kinds: one was just a guy who is a practical guy, he wants to manage, he wants to maintain the operation. The other guy in the metallurgical lab is a researcher or a tester. He tests ore, but he has to find a standard to which new ores [will be compared], and then that guy will say, "Look, I got the next five-year plan, and this is the kind of material you're going to get for the next five years. Are you ready, or

is our mill, our plant, ready to accept that material? Or do we have to make some changes?”

So, every few years, we get a five-year and a ten-year mine plan. We use the standard procedure, and if the standard procedure doesn't give us the expected recoveries, then we have to make some alterations, minor alterations, or sometimes even major. You know that once you have a new concept, you go through research and development and feasibility, engineering study, construction, you're talking about five years. So, you have to be ready five years from now, and it gives enough time to be ready because you have an operating mine. So, research innovations come from experience and sometimes by luck. We're working in an environment where you have to come up with that because if you don't, you are out of a job. Like at Miami Copper, they told me, "We'll leave you off in four years, let you go. If there's no solution, we have to shut the mine." So, that gives you another incentive to come up with a novel idea that could be implemented, taking advantage of the facilities and the process and the people that are already in the camp.

So, that kind of research is day-to-day research, and what I call short-range. You don't want to come up with new flotation reagents that revolutionize the mining. That's what Doug would do, in University of—

07-00:14:26

Burnett:

In a research laboratory in a university, yeah.

07-00:14:28

Bhappu:

So, it's more like practical research, trying to find a quick solution.

07-00:14:33

Burnett:

Incremental, perhaps.

07-00:14:39

Bhappu:

Research innovations come from that kind of a challenge that faces you. Sometimes, you'll come and see that your exploration department of your company knows that you have a limited life of the mine. He says, "I've found another deposit. I'd like to get that ready. Is it worth putting the new investment?" So, we have a meeting and say, "The research department of the mine gets samples." In the old days, people like Anaconda and Cyprus, they had big research organizations, and they would take care of all their local developments, research locally and the future. But many small mining companies wouldn't have that chance. So, that gave me the idea that if I wanted to go further, in the future, catering to new projects—not necessarily going with the big mines, but small mines—but at the same time, I was looking for opportunities like bio-leaching and others that could be applied by big mines as well as small miners.

So, in the research that we did at Miami, was practical research. When I moved to Socorro, New Mexico, it was basic research to a certain extent, but being a Bureau of Mines and also professor, my job was to make sure that today's technology is pretty well understood, and also look for future technology. At Socorro we had a biology department at the School of Mines<sup>1</sup>. So, we used them and we started a biological research in the experimental mine, or the New Mexico Bureau of Mines, which was a public service, coming up with old ideas for old mines and new ideas for new mines. We were very well supported.

I'll give you a good example. When I went to Socorro, I met Dr. Workman, he was the president in 1960. He said, "Bhappu, who are you?" I said, "I am a metallurgist." He said, "Oh, you work with dirt and minerals and all that. No, no, no—in ten years, we'll have everything synthetic, all plastics, and you metallurgists will be out of a job."

07-00:17:23  
Burnett:

And this is in the sixties?

07-00:17:25  
Bhappu:

He said, "So, I don't know why we support New Mexico Bureau of Mines." I said, "Well, so that weekend, on Friday, we had a seminar by most of the faculty." Workman, he was interested in micrometeorites that fall to the earth. He wanted to know more about the world, how was it formed, composition of asteroids, what is happening on the moon. So, I said, "How do you recover this?" "Oh, well, we have a big catcher. We have a big receptacle where all these things fall over the year, and then we collect, it's like a funnel, and it goes into the well. Every year, we clean it up, and we are lucky if we find ten, fifteen micrometeorites that we can handpick." "Okay," I said, "there must be an easier way to do that." So, since these are mostly iron and nickel and some silicates, I say, "Let me try some iron-ore beneficiation, or iron-ore concentration." So, I tried a magnetic separation, and I can pick up some. The thing is that only a few of the micrometeorites go into that twelve-inch diameter receiver, but these things shower the earth all around you.

So, I went to the same site where they had that catcher, and I took the soil around that, composited it, brought to the lab, and floated the micrometeorites using standard iron-ore beneficiation, which was used in Minnesota and all that. So, in the first crop of concentrate, I picked up 150 of them, and the next time, modified that, and I had all the concentrates was mostly micrometeorites. They were taken from an area where they had concentrated over millions of years. So, I went to Dr. Workman, up to about a month, when I was sure. I said, "Dr. Workman, I would like you to come to my lab, and bring your scientists with you." He never came to my lab, but it's dirt, you

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<sup>1</sup> renamed New Mexico Institute of Mining and Technology or "New Mexico Tech" in 1960.

know [according to Workman]? He wants high scientific research, okay. They came to that and I said, “You are interested in micrometeorites that shower the earth—you pick up about a dozen of them a year and you work on them. How would you like to have hundreds of them to work with?”

“Oh!” he says, “You would be a genius.” I said, “No, it doesn’t take a genius.” So, I picked up them and put it in the flotation cell, and of course, a nice little size, just perfect for flotation. So, I put in the reagent, and up came this micro-meteorite, coming on the top in the froth. I picked it up in a little pan. I showed them. “My goodness,” he says, “you *are* a genius! You can do anything you want!” From then, I had a free hand at the New Mexico Tech.

07-00:20:45

Burnett:

Wow, so you demonstrated your talent?

07-00:20:49

Bhappu:

Yeah, I showed that mining can be a beneficial thing, and in the future, you are going to use mineral-processing technology to separate copper, iron scraps, recycle processes.

07-00:21:05

Burnett:

Recycling, yeah.

07-00:21:07

Bhappu:

You can recycle anything you want. Ink, for instance, we went to the local printer and we got all this pulp, and we floated the ink out so we could recycle the pulp and make new, fresh, recycled paper. So, I have flotation, I can separate. So, this is what I wanted to impress on them, and from then, they elected me—that was about a year after I joined the group—a vice president of research for the whole institute. Then, we started the in-situ research because as soon as I came there, I said, “Look, guys, I have a challenge for you, and I want you to help me come up with new processes. The process that we are looking for is leaching underground.” People are against mining, we know that. They are afraid of accidents; they are afraid of going down the shaft; they are afraid of big excavators. We need to come out with an idea that, in the future, you may not need excavations and open pit mines. That even a deep-seated mine, you don’t have to go underground and start exploring. You can determine geologically the zone that you want to extract, make sure that it is porous enough so that your permeability or darcy is enough to migrate solutions, and then the hydrologist will help me make a well pattern, so that I will have an injection hole and four recovery wells, so that the solution will move. We worked on that, and in two years, we went to Grants, New Mexico, and ran the first experiment of an in-situ leach, with Anaconda, mining for extracting uranium.



07-00:23:17

Burnett:

So, just to be clear, you became VP Research in '64, and then two years later, '66, you go to Grants?

07-00:023:26

Bhappu:

Right, because I told them that we need to demonstrate that in a simple way. They had a shallow deposit, so we didn't have to go too deep, but I just wanted to give them the concept of what's to be followed in the future. They liked that very much because working in a uranium mine underground, there's too much radiation. So, for safety's sake, I thought the administration and the board of regents, the governor of New Mexico, they all felt that that was the way to go, so they supported it. We went to different mining companies, Cyprus and Anaconda, old mines. ASARCO had a lot of old mines that were block caved. They have a big resource in the Casa Grande, not about sixty miles from here, but you can't make a big open pit out of it, obviously. What was important is that developing a process at the school-of-mines level, we would have workshops and we invited the public to demonstrate or show them what we have learned.

So, as a research professor and as a director of research, I would have a research seminar every year. Five days. I would have one guy like Professor Gaudin or Fuerstenau or whoever I could get to have a guest lecture, followed by staff, to explain what biological research is. It was very well attended. We began to make a good name. People came to us, gave us endowment funds. So, the fifteen years spent were basic research with applied applications, so that in-situ leach, bio leach, became a standard word. AIME and all the mining societies had a program, and every year, they had a whole session on bio-extraction, bioremediation, which came later. Bioremediation came when I was working for Mountain States, but up till then, I knew ion exchange, and we knew that ion exchange was useful for uranium. So, it became a very simple process to inject, take the solution, put it through ion exchange, recover, wash it out, and make uranium yellow cake. People liked that idea, and it spread very quickly, and especially in Texas, which got several new operations. Wyoming was another operation.

So, besides the in-situ leach and the bio leaching, what else did we learn from local research? We came across molybdenum. We had a big molybdenum mine. But Molybdenum mines and mineral always carries rhenium as a byproduct, and people couldn't recover rhenium. So, I told them that once we have a molly concentrate, we make the molybdenite. When in the roaster, the first roasting step is to convert, but before about 200 degrees centigrade, when the molybdenite mineral disintegrates, rhenium comes out first. So, we catch that in dust collectors. So, usually we have only one dust collector for all the dust in the roasting. Here, I said, "Let's put five different dust collectors, and what comes out first, second, third." We looked at it, and rhenium came out very quickly. Professor Malveren in the University of Kentucky wanted to

recover rhenium, so in a seminar, he met me and I said, "I would like you to try that on an experimental scale."

What he had was some material that had rhenium. He set up a small pilot plant, and everything went well. We got a \$90,000 check from him, from the university, saying that this was our portion of the research, that they are giving it back so we could come out with some more. Those are the byproducts of research. So, one of the big things was that we had a lot of arsenic, and arsenopyrite is a gold carrier. Everybody knows that arsenopyrite does not dissolve in cyanide. But we found that once we break it down, then it's easy to do that. Many of the gold ores in Nevada, all over the world, Australia, they called it refractory gold. That means that it is not soluble in cyanide. It's not metallic-type material, but it's embedded in arsenopyrite, which has arsenic. So, there was a lot of research done and all that.

07-00:29:36

Burnett:

How to liberate the gold from that.

07-00:29:38

Bhappu:

One of the things was to use biological products to break down arsenopyrite artificially, and then go through cyanidation as the next step. Arsenopyrite is just like pyrite, it'll oxidize. There was a company who invested \$40 million, and an Australian company built a plant in Nevada. It didn't work because they hadn't taken it through a pilot plant. They had taken it to the pilot plant scale, up to about a two-foot diameter reactor, for biology. They jumped to forty-foot diameter reactors, with oxygen pressure, and it didn't work because the scale of it was not right, the reaction time and all that. So, the company called us and said, "You people are in bio, what do you recommend?" I said, "It's not going through these reactors first. Just put the material on a heap and let's just put some bacteria, and let the bacteria destroy arsenopyrite, rather than chlorine or heavy in a pressure vessel. It will do that on a little heap, and then after one month of leaching, arsenic cyanide will be out, and we'll take that reactive product and put it through your agitation for gold extraction. So, all you have to do is to add a little heap-leaching operation.

07-00:31:16

Burnett:

So, that's more energy efficient?

07-00:31:19

Bhappu:

That's right, but this is the first instance when biology became, "Let's always use bacteria to oxidize. Why should we go through pressure reactors?"

07-00:31:31

Burnett:

What year was this?

07-00:31:33

Bhappu:

This was just before I left there, about '69-'70. Then, I joined Mountain States. I told the company that I had just come from New Mexico Tech, we

had this research. I would like to do more work on it as a Mountain States organization, and not only would we do the research, but we'll give you the whole plant design and construction. So, they liked that idea, and we went and proved that thing. So, that was a byproduct. Now, today, all the new gold plants are looking at bio as an alternate for decomposing non-soluble—when they say “non-soluble,” it's non-cyanide-soluble gold.

07-00:32:37

Burnett:

What are the bacteria eating? They're phages, they eat?

07-00:32:44

Bhappu:

This was a reducing bacteria, yeah. They were taken from the surrounding soil, and built up their concentration and inject them. Of course, in a heap, you don't inject, you just sprayed. They do their work, and the solution that comes out is full of arsenic because it breaks down now the arsenic. So, the arsenic is combined, treated with lime, to make calcium arsenate, which is very highly insoluble. So, there is a solution for another pollution.

07-00:33:21

Burnett:

Right, so it liberates the arsenic and then traps it in an insoluble form.

07-00:33:24

Bhappu:

So, people who complain about arsenic, I said, “Don't worry, I've got it. All you have to do is put a little lime trap.” One thing leads to another, and research is one of them, that when you solve one problem, then you face another one, and then there's a simpler solution. You can't break down the arsenic, but once you have it in solution, you can pick it up. You just put it through a ground lime, and when you see the arsenic coming out of the column, you see the thing is loaded, take it out, put a new lime column ready, and just keep on circulating till the water is clean. That lime-containing arsenic is so highly insoluble, nothing will break it down, so you can bury that where you are.

07-00:34:21

Burnett:

Just as it is, yeah.

07-00:34:22

Bhappu:

It'll be acceptable to EPA. So, those are the kind of things, research innovations. When I was at Socorro, New Mexico Tech, I said, “Why am I doing this? Why can't I make it into a business?” This is an artificial environment, it's a school. We can't go out and peddle, and so on. So, I said that I would like to start an R&D group, but that requires money. None of the engineering companies have an R&D group. They take the flow sheet that is developed by the company or by the university, or US Bureau of Mines, in the old days, and then build the plant around it. I told my friend Ed who was working, who already had a small mining engineering company, I said, “Ed, I'm willing to help you. My contribution would be my help. You keep me alive for a few years, and I think we'll get this ore, we will do the research,

we'll get the flow sheet, we'll let you analyze it." If it feasibility looks good, you do the detail engineering design. At that time, he didn't have construction, but then he added construction.

So, when we moved to Tucson, where Mountain States Enterprises was, we started the R&D. We added a wing to the big building, and we called it the R&D division. There were big signs that say, "Roshan's bug house," because we were using bacteria. We were also using things like ferrocyanide for depressing and recovering molybdenum selectively. So, there was a sign put up, "Roshan's gas house," "gas chambers." That's how we got into it. The entrepreneurship came, because I felt comfortable that I can solve that problem. I felt comfortable that I don't have the money, but by working with an engineering company, that would be a good incentive to start an R&D group, sustain it for a few years, and then R&D becomes self-sufficient.

07-00:37:03

Burnett:

I know you said later, in an article you wrote, you said something about you were describing the family of companies that had emerged by the 1980s, and yours was one of them, that these are contract research organizations. Their market was on both ends—companies that were too small to afford their own research, and companies that were too large, that had spun off their research. They used to do research, but they don't. Is that what was happening, too?

07-00:37:35

Bhappu:

There were few institutions in the world, at the time. In the United States, we had Lakefield, in Ontario, Canada. Not far from Toronto. We had Hazen Research, which actually started – Mr. Hazen was a good friend of mine and I helped him start that operation at the Colorado School of Mines. It's an old institution. Then, there was the Bechtel Institute. Then, research at local universities. That was all. In Australia, it was mostly CSIRO<sup>2</sup>. They did all the work commercially, and also at the Bureau of Mines. In England, they had school of mines, London School, they were there, and they did contractual research. Then, there were big equipment manufacturers, for Denver Equipment Company, which made all the machinery for processing, Outokumpu was a big smelter group, and the German Krupp, they had research. But it was not done universally. It was a few selected organizations, and I said, "I have a good chance to succeed because there are not too many operations." I'll be in competition, but being a small group, I'll have a more competitive price. More importantly, I would be in an area—Arizona—where there were lots of operating mines, and Mexico, operating mines. Internationally, I was also very active in the international mining, so we would have our conferences in different parts of the world, and spreading the word that Mountain States is available for research.

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<sup>2</sup> Commonwealth Scientific and Industrial Research Organization.

07-00:39:41

Burnett:

And your benefit of being in Arizona is that you have these existing mines in operation that need to get that extra return out of their otherwise exhausted deposits—right.

07-00:39:49

Bhappu:

Had continuously, because none of the big mines had that central research. They got out of that business because they thought that there were others that can help them, usually at the cheaper option.

07-00:40:02

Burnett:

It's an interesting shift because there's this pattern that we all hear in the history of business, that there's vertical integration, that the large, sort of oligopolistic companies emerge by acquiring these different arms. So, mines would be a division of some larger steel manufacturing company.

07-00:40:27

Bhappu:

Right, right. Well, like Anaconda was a big company, there are lots of plants, and they put up a central facility for catering to all the Anaconda operations. They wouldn't go out to ASARCO because that was a competitor. So, ASARCO had to start.

07-00:40:45

Burnett:

Right, so research had to be in-house?

07-00:40:47

Bhappu:

But eventually, independent researchers came in, and there were two reasons. One is that if you do the work locally in your lab, and if you go out for capital, for an investment corporation, who did the work? Oh, our research department. How do you know it's not slanted? So independent –

07-00:41:12

Burnett:

- is objective.

07-00:41:12

Bhappu:

It says, "Look, we have a process, all we want you to do is just confirm it, put your stamp on it." So, we would be honest, we would research it. If it was good, we would put a stamp on it. So, that became entrepreneurial, and because of my father and grandfather, all the Parsi Zoroastrians were entrepreneurial. They started their own business, and family after family followed that. So, that concept was always fresh in my mind. I was looking for opportunity, which I got. I went to Colorado School of Mines, they gave me the opportunity for future. Went to Miami Copper Company, it was only four years, but it gave me a lot of ideas as to what mining companies would want in the future. I went to Socorro, which was partly teaching, but mostly research, practical research. Many of the theses will be basic research, but all the work done by the experimental and the research foundation would all be practical-oriented, based on the theoretical data collected in the college. So, it

was a good match. We made a lot of money by research foundation because we would patent it out. We didn't want to patent too much, we didn't want to get involved in it because every time you have a patent, somebody says, "Oh, I invented it," you know?

07-00:42:48

Burnett: Then there's lawyers.

07-00:42:49

Bhappu: You spend more money with the lawyers than getting the patent. It's not worth it. One thing that I did that was very helpful later on is I wanted to put all those ideas of new technology, innovative technology, in a textbook. Being a text teacher, I said, "People want to hear this more practical side. Although we want to introduce some scientific facts, those are not available," and you will find I and my colleague from the University of British Columbia, Andy Mular, put out a handbook on mineral processing<sup>3</sup>. We translated that into Spanish, so everywhere I go in the world, I find our book there. It takes the reader through comminution, crushing, grinding, separation, flotation, magnetic, electrostatic, hydrometallurgy. It goes through the whole field.

07-00:44:10

Burnett: Was there a limited supply of that kind of coverage?

07-00:44:14

Bhappu: Yeah, I published it through Society of Mining Engineers.

07-00:44:19

Burnett: So, it's got that *imprimatur* of the SME?

07-00:44:22

Bhappu: Oh, it sold like hotcakes, and I got lots of comments. But not another one [new edition]. I thought that maybe if I retire or something, that would be a nice little project, to update it.

07-00:44:37

Burnett: Update it and expand it, yeah.

07-00:44:40

Bhappu: Then, I also wrote another book, along with one of my graduate students from Socorro, Raul Deju. He was a Cuban. Wonderful, very brilliant mind, the environmental problems of the mining industry, there was a book published. So, both those books are in great demand. Do we have a few more minutes?

07-00:45:14

Burnett: Sure, yeah.

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<sup>3</sup> Roshan Boman Bhappu and Andrew L. Mular, *Mineral Processing Plant Design*. (New York, NY: Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, 1980).

07-00:45:16

Bhappu:

Another thing that I did that helped the mining industry—and I'm talking about research innovation, entrepreneurship, and then distributing the ideas and the knowledge through technical publications—when I was at Socorro, I wrote about 100 papers. That was at New Mexico Tech, and then when I came into practice, many of my technical papers were generalized because whatever I learned on our research, I had a technical, and that was given to the client.

07-00:45:57

Burnett:

Right, it's proprietary.

07-00:45:58

Bhappu:

He didn't want to publish it after seventeen years. So, that was when I have maybe 1,000 publications, if all of the final reports counted as a publication. One of the things I found out, working with the United Nations, that was when I was working for Mountain States, is I felt that many of the mines were in water-short areas, deserts. They were using up freshwater, limited freshwater, for mining. So, I suggested to United Nations that we form a seminar, a two-week seminar, and invite all the professors who are available. It was in the summer, so they could take time to come. Researchers in places like Saudi Arabia, Egypt, Morocco, South America, all in the desert areas, to contribute what they had learned. Many of them were research-oriented, from universities. Some were practical people. Some came from Germany, from Japan, China. We had an international crowd, and that was a big seller. I have a publication called *Mineral Processing in Water-Short Areas*, that came out. It's a thick book with lots of ideas from all over the world. Some of them were generated by ourselves. Many of Gaudin's articles, Arbiter was in that, Arbiter was a wonderful process engineer in Columbia University. Australians, they were in a lot of water-short areas. So, the theme was two-fold: one is how can dry processing help us? Instead of water as a medium, can we use air as a medium? It seems we do. Shaking table, jig, all can be done with air being pulsated, would make up a medium, settling medium, and the heavier particles will come down.

07-00:48:27

Burnett:

Compressed air?

07-00:48:32

Bhappu:

Cyclones is a legend—everybody can make a cyclone separation. Cold beneficiation, that was easy, and you don't need water for that. I had ingenious flow sheets come out of that because these were contributed by engineers from all over the world, through the United Nations. It became an archival volume, and I'll see if I can get one of those for you.

07-00:49:11

Burnett:

We can have a list of your official publications, not your proprietary ones, and we can put that in the index.

07-00:49:18

Bhappu:

That's what I thought, coming into Mountain States, I had more time, and I wasn't teaching, I wasn't in research, so I was available to the public for a consultation fee. United Nations took advantage of me, and said, "You should work with us." I said, "Look, I'm with a private company, you just pay like anybody else. You are my client, and I'll do that for you." Research innovations, and many of the ideas that came up in water-short areas were beautiful, and followed similar patterns as water. So, instead of water, you use air as a medium. Many, many places in the world have no water, and we set up some plants in New Mexico that are operating very well. Wherever there is density difference or you want to separate fine particles from coarse particles, fluid flow, and air can be your nice fluid. Doesn't have to be water.

07-00:50:34

Burnett:

So, this must have been inspiring for you. You're being exposed to a kind of experimental play that can lead you to inspire you to do new kinds of designs.

07-00:50:45

Bhappu:

That's right. That's when I went to see, in Brazil, at that gold mine, Serra Palada, I saw all kinds of contraptions I could never have thought of. They were based on simple gravity, pulsation engine, and pumps.

07-00:51:03

Burnett:

These were the poor miners who had contraptions and jigs?

07-00:51:09

Bhappu:

They were recycling, and some of them were large companies, but using whatever was available as a medium to separate. So, now, I tried to cover what are the research needs.

07-00:51:29

Burnett:

Off-camera, you told me about one consultation that you had was kind of fun, which was the dagger. Can you tell me about that?

07-00:51:45

Bhappu:

Old historians used to come out and say that they had found an artifact, and was it foreign or was it locally made? Like swords, and they said, "Oh, well, it came from the Vikings, must have brought it when they came from Europe to United States, they brought it with them." Somebody would say, "No, we had an iron-ore industry in Michigan, we had good"—

07-00:52:21

Burnett:

Blacksmiths?

07-00:52:22

Bhappu:

Making implements, the blacksmith. So, we can make the same. They said, "No, this is from Morocco, they are best." "No, no, no, this was made in United States." Morocco would fight with a neighboring country, "No, we were the ones who came out." So, I said, "Look, in order to settle that,



Mountain States will offer you an option. We'll ask you to give us a dagger or an implement of war or any artifact and we would be free to select small particles from that." We will subject that to a simple x-ray analysis and ICP analysis, induced coupled plasma. That gives me a whole spectrum of sixty elements. I would run that on what they claimed to be local, and what they claimed to be foreign, because if it's foreign, somebody else must have brought it. So, we will compare the two, or take them from two different countries, and put that in.

I went to the United Nations and said, "Look, they're going to have a fight over this all the time. Let us help you." So, we got into a project, so we would do local iron-ore analysis, and look at the iron-ore analysis from Michigan or England, Birmingham, or anywhere else, or Central Europe, and say, "What are the patterns and especially the trace elements?" You'll always find iron, okay? You'll always find nickel. You'll always find cobalt. Those are standard elements in the ground. But rarer elements, a little bit of niobium, little bit of titanium, little bit of a trace element—

07-00:54:31

Burnett:

That's the signature.

07-00:54:33

Bhappu:

That would set apart an artifact. It's not necessarily daggers, but sometimes people say, "Oh, this was in old Germany or Romania," and try to sell antiques. We would be able to tell you where the antique came from, as long as we had local ore to compare. So, it is a detective story, it's a sleuth. It's like any kind of an x-ray analysis or more detailed analysis, chemical analysis. It sets apart one geographical area from another because geography is created by nature, and whatever goes into one deposit, if you are in the neighborhood, and the same principle of mineral deposition is followed, or geochemistry. It has to be that. So, that is a byproduct of research, and now, everybody uses that to identify. Especially detectives and police, they say, "Where did this come from?" Or, "Where did this particular missile come from?" Whatever it was, a weapon, where did it originate?

07-00:55:59

Burnett:

That's the technique they use.

07-00:56:00

Bhappu:

They compare the patterns. This, I thought, was a byproduct of our research and now universities do that all the time. Metal detection is also very good for trace elements because what is the challenge, we'll go into next session, is would be the small amounts of rare earth or gold or plutonium or whatever comes? Okay, where are we going to find it? If you follow that principle, if the total stock of rare earth is in a cone and it extends with age, we are somewhere in the first 20 percent of the world's resource. There is 80 percent is still present in the ore. Now, is it going to take us 100 years, 1,000 years to

extract those metals? In between, you are going to have synthetics, so you have to look for what those do. Metal will not be replaced, that's for sure.

07-00:57:11

Burnett:

It's a question of what is recoverable at any one time.

07-00:57:16

Bhappu:

So, two things, abundance and recovery—and economics—will govern. This is why education, research in universities, and Bureau of Mines are very, very critical. And exchange of information, because somebody in Ghana may come up with a solution with everybody's knowledgeable. An idea can come out from anywhere, from a developing country or developed country. If you look at publications today, there's always a Chinese name, a Japanese name, a Hungarian. Lots of old publications in Germany—Germany, Heidelberg University and others, were like Cambridge of those days. The Japanese are very good at it, and so is China. I have seen their operations. They are beginning to realize and appreciate, and China and Japan both are very much interested in seabed depositions. There is a store of metals that has been washed down by ages, by rain and by wind and erosion, whatever you want to call it, and have deposited in the ocean. Well, why are we calling it the Red Sea? The deposit down there is reddish, and that has manganese in it. They form manganese nodules in there. So, everybody claims that "this is my sea, you cannot mine in that." And that's where United Nations has to come in and say, "Who is the owner here and what can you consider? – the continental shelf, is that a boundary to you?" But in Japan or China, who's going to mine?

07-00:59:30

Burnett:

They overlap, right.

07-00:59:33

Bhappu:

Who's going to be mining in the forest? People go and challenge. You go to Arizona, you can fly over and say, "Oh, I can see a little copper mine, I see a little red area, and you say "that's a good target." But when you fly over a jungle, it's all green! Where do you drill?

07-01:00:02

Burnett:

Well, the question will be new methods for determining...

07-01:00:05

Bhappu:

That's right. This was a big challenge to Mountain States when Klöckner, a German company, with bases in Brazil, asked us to help. So, we set up a laboratory, Mountain States Extension in Brazil, in São Paulo, along with their geological department. It's not a very big one, but sufficient to identify [minerals].

07-01:00:36

Burnett:

In the rainforest?

07-01:00:40  
Bhappu:

They would take me on a single-engine plane. Only the pilot had a seat—the rest of us were hanging on to each other in a single-engine plane, going over. The pilot, “You see that little white line in the mangroves?” “Yeah.” “Well, that’s our landing.” [laughter] I said, “My goodness, that’s not big enough.” Of course, this is all in Portuguese, but we had translators. So he was going down, and aiming for it. But then, there was this forest of vegetation. I said, “You haven’t put your landing gear yet.” He says, “Don’t be a fool. If I put it down, the landing gear will hit the trees!”

#### Audio File 8

08-00:00:00  
Burnett:

This is Paul Burnett interviewing Dr. Roshan Bhappu, session four, tape eight, March 6, 2014. So, you were in the middle of a story about flying into the Brazilian jungle.

08-00:00:31  
Bhappu:

It’s said that for an engineer, the opportunities are of travel, finding new jobs, as a consultant. If you are in the academic life, you research, publish your papers, and you’re sent out on a world convention or a congress to deliver your papers. So, that’s one way of travel and knowing other people in the world. Other people who are interested in the same thing as you are, you make friendships. Working for a mining company, you travel to find new papers and new technology. As an engineering and R&D group, you travel to practically all the seminars and conferences, all over the world, because that’s part of the operating cost. That’s where you meet the client.

If you are a United Nations consultant, you have the same opportunity to travel. Most of the seminars are the key to making friendships. One of the things that is important is being associated with a mining society. When you grow up with, like, American Mining Congress, or American Mining and Metallurgical Society, when you work your way up in management and become ultimately a president or a program chairman, you get invitations from other people to come and present. So, this is how you meet challenges, your friendship with your co-authors or future partners in progress. When I joined New Mexico Tech, when I worked with the United Nations, I had a lot of assignments. But I had more assignments when we started this Mountain States research group because you don’t believe something till you see it. Normally, the people who are inviting you at their cost want you to see what the problem is, and what you are going to do about it, rather than send you a little sample. They do send a sample, but they want you to see it, and *you* want to know what’s happening, what is associated, because you can determine whether it is coming from the same source or it’s an intrusion? Is it going to be limited, or is it a wide horizon? You draw your project plan based on that kind of information.

One of the benefits was, as a United Nations expert, I used to put on seminars every two to three years: Brazil, India, Australia. But as an entrepreneur trying to make some money out of it and make a successful company, I used to do a lot of traveling and present papers and so on. In one of my papers, and on one of my sessions, I contacted the Brazilian Institute of Mining. Brazil was coming with the gold production, and they said, “Please come to Rio and give us a presentation of about two weeks, and maybe bring a colleague. Two of you can cover the new methods of gold and silver, platinum processing, and recovery methods extraction. What are the problems, what kind of deposits should we be looking at?” So, I would normally take a geologist friend with me because, with geology, he can talk about the deposit, and most of them are geologists. They’re not too many metallurgists because that’s why they are inviting a metallurgist to look at the problem.

So, in one of the seminars at Rio, I met Klöckner, which is a German company. They had made up a program of spending millions of dollars in Brazil because Brazil was an unknown mining country with lots of opportunities. They said, after one of our seminars, “Why don’t you work with us?” So, we started corresponding. Soon enough, within a year, we had a laboratory in their office in São Paulo, and they would bring us samples. Not only that, but São Paulo had the University of Brazil, so that they had a mining department and a metallurgical department, so I made friends with them so I can use their facilities. It developed into a wonderful fellowship, you might say, and Klöckner decided that anything that is open air and visible will be explored. But something that is hidden, nobody’s going to look at it. So, they made up their mind that we are going to explore in the tropics, in the Amazon Valley.

08-00:06:21

Burnett:

The whole basin?

08-00:06:22

Bhappu:

Yes. So, it was a wonderful opportunity to travel, to see things, driving these little Amazon tributaries. It’s totally covered with all kinds of birds, and it’s just beautiful. As I say, we would go into a remote landing place. The pilot would not put his wheels down because he was afraid the wheels would—

08-00:06:49

Burnett:

Would catch on something?

08-00:06:50

Bhappu:

Catch with on of the vegetation. So, he would go very close to them and then land, and the landing field was on a slope. So, that would slow down the plane. Not the runway.

08-00:07:04

Burnett:

A ramp, it was a ramp?

08-00:07:05  
Bhappu:

Yeah, almost like a ramp. Before we went up, the plane was stopped. It wasn't a big deal. A few hundred yards is all he needed, and that was the only thing it cleared. Then, the neighboring tribes, Indians and indigenous people, would come to the plane. We would tell them, "This is what we are looking for. *Ouro*, gold, this is the kind." They told me, "Yeah, I've seen something," so that becomes the target. This particular place that we landed, somebody had discovered 140 pounds, seventy kilos of gold. Not a bar, but a gold crust. That's a big, big find, and Klöckner wanted to find out how extensive that was. So, we landed, we met the chief of the village, and his son, who spoke English and also Portuguese. My guide, all my associates from Klöckner were German and Portuguese. They explained everything to me, and we talked to the chief. The chief said, "My son will take you to where we found this big slab." So, he went there, we looked at the thing, and it appeared that there was much more gold in the area.

So, they now had a target; they established that. I was just going for the ride because they wanted to see what mineralization I'll have to work with. So, it was pretty easy. It was gold-heavy, gravity separation would just wash out everything. But the chief started, he says, "Why are you here? You want to pick up my wealth? You are going to be bad with my ladies, here? I don't think I want to sell you my –" He attacks an interpreter, who's a government, he says, "I don't want you to go for the government or any private parties. Especially people who I don't know, personally. I know I have a resource, my people are hungry, but I cannot make a deal with you guys." So, we said, "Sorry we came, but we'll try to give you some funding, and so on, to improve your schools." After we were moving, the chief asks the interpreter, he says, "I want to see this man, Bhappu."

08-00:10:02  
Burnett:

He pointed to you?

08-00:10:03  
Bhappu:

Yeah. So, he took me to his hut again, in a separate area, and he says, "You know, I don't see you are a European or an English or a German. Who are you? Where are you from?" So, I said, "I am an Indian like you. I'm originally from India." "Oh!" he says, "You are my brother." After we talked and I said, "We can do this," he says, "I will trust you, but I don't trust those guys." This has opened up an opportunity for us because I had some influence.

08-00:10:44  
Burnett:

No pressure, right here.

08-00:10:45  
Bhappu:

No pressure, and I was buying nothing, I'm just helping them. He says, "Look, I will get in touch with my principal provincial government and suggest that they work with you, and help us to extract our metals and make

our lives rich. So, these are the kind of experiences that you don't get, and the opportunities. Then, I went to Ouro Preto, where I found this library of valuable documents that were being eaten away by worms. So, we saved a lot of good data, and those guys said that any time you want to come and examine our volumes of what the *padres* had left, you are welcome to that, and help us. So, I approached Colorado School of Mines, I said, "Look," I told them, "why don't we have a cooperative arrangement for Colorado School of Mines and Brazilian Institute of Mining at Ouro Preto, to have a collaborative educational program?"

08-00:12:16

Burnett:

Can we return to that story in the Brazilian forest, were you then asked because he said, "I don't trust the other people," he said, "I'll trust you, Bhappu?"

08-00:12:28

Bhappu:

Yeah, but he said, "I will make arrangements to contact you through our government."

08-00:12:33

Burnett:

And did he?

08-00:12:34

Bhappu:

Oh, yes, they did. Then, that opened up a lot of new areas for us.

08-00:12:39

Burnett:

You facilitated that because he trusted you?

08-00:12:41

Bhappu:

That's right, that's right. They didn't have any laboratory except the university. So, I developed a very close relationship with the University of Brazil in São Paulo, and he came to United States. I showed him all the mines, and he had a good idea of what to do. Just about three years ago, two years ago, I got an invitation because they must have read Ross Bhappu's name, and he says, "Oh, we knew a Bhappu." They say, "Are you connected with the Molycorp? Our deposit, our geologist has shown that we have monazite, similar mineralization as Mountain Pass." So, I showed them that, look, I'm not associated with Mountain Pass, but I'm an independent.

He came all the way from Brazil, set up a meeting, and we had a couple of hundred thousand dollars' spending to sample. He would send us the sample, we would look at it, and give him ideas to develop his mine. He says, "I have local engineers, I have local geologists, metallurgists, but they don't know anything. I have to work with University of Brazil, that's fine. So, we'll set up a laboratory—you become my consultant." They paid good money for it, and we made several trips. Usually, they were very much interested in rare earths, but then the rare earth market dropped because of the Chinese, and they showed me, they said, "Look, their economics doesn't permit them to

continue, but please, if you know of some investors, I'd be happy to cooperate with them."

08-00:14:43

Burnett:

I know we might be encroaching on the next session, which is going to be about rare earths and the politics thereof, but here's a way to maybe talk about it: as an outsider, there's a couple of pieces of information about the seventies and eighties. One is this kind of concern about the declining resources, that in 1972, the Club of Rome produces this report, and it's got all these charts with, like, declining production of copper and all of these basic elements that we need for modern civilization. Then, the other is your speeches in the 1980s and maybe 1990, about mining kind of reaching a nadir in the 1980s, that the production is the lowest it had been since World War II. So, on the one hand, there's an earlier period where they're like, "We're running out of these resources, we've got to conserve," on the other hand, the industry is trying to cope with really low demand. So, can you talk a little bit about the chaos of the market?

08-00:15:56

Bhappu:

The mining industry is, after all, an economic project or an enterprise. The supply and demand plays a very important role. If you have a copper deposit, Chile is the biggest, United States, and then Peru, Mexico, and all the rest of them. So, if you find another copper deposit, nobody is going to be unhappy. Fine, there's already competition, you know what the cost is, and you're in a competitive position. One of the things we found that, in the seventies and eighties, we were at a disadvantage because of two reasons. One is we didn't have enough metallurgists and miners, and secondly, our prices, our labor unions, were controlling our price structure. They were not necessarily helping us economically. Also, the production fell, so who are the winners? Chile, because they have the biggest production. Their mining rates, in those days, was at 10 percent of what we paid. Two, three dollars an hour, and I know that I was paying my engineers \$35 average. So, in the field and all, you are talking, \$35, \$40, \$50 an hour. We just couldn't afford it, even in the labor force could make \$15 an hour.

Of course, the Cold War and all the problems, the metal prices, the war industry, was at its lowest. People started stopping making tanks, and Navy started stopping big vessels. It was an industrial depression, and the price of metals went down from what they were. Gold, at one time, was \$35, it was established, thirties.

08-00:18:18

Burnett:

Right, it was fixed, there.

08-00:18:22

Bhappu:

We were putting up a plant in Nevada called Round Mountain, for Homestake Mining Company. It was completely a new concept. It was not agitation, it

was not heap leaching, but it was a permanent bed where we put little heaps like that, leached it for one week, moved it out, leached it, and moved it out. So, it all went into the same bed, and all the solutions were collected. Nothing else kept. That was our plant, and I've got a picture of that. I was presenting that paper in 1963, '64, something like that. I had a full audience, 500 people. My first remark was that gold that was up-valued to \$90, just yesterday, because now it was getting open. From \$35 into \$60, now to \$90—\$90, today, it's \$1,500. When it got into \$90, I said, "We are fools, sitting here, talking to each other. We should be out there, picking up the gold because the gold has gone up to \$90." People were anxious to hear [about this technique].

This is called a re-usable pad concept. Rather than put the mine deposit heaps all over the countryside, just the regular 200 feet by 600 feet rectangular, it was a seven-inch concrete, two sides, and then it was layered with four inches of tar or asphalt, so the trucks could go over it. You would mine 40,000 tons per week, 8,000 tons per five days. Put it into a heap, 40,000 tons, start another heap. We leached this, and we had five, six going continuously. So, every one of them became used, and we'd put a new one on that, and it'll come into production. So, it just kept on and on, and using the same bed, washing the same cyanide solution into the pit, into the solution tank, taking it through activated carbon, charcoal, absorbed everything. We'll wash it out with strong cyanide solution, and we could make gold bars. Very easy, it's simple technology, but the new concept was environmentally foolproof. There was no spill at all.

08-00:21:28

Burnett:

That was the time of Lang Swent, right? Lang Swent was the president of Homestake at that time?

08-00:21:33

Bhappu:

Yeah, that's right. When I explained to them they said, "Why didn't we think of this before? Why didn't the Homestake think of this?" So, this is the kind of opportunity that helped us, and it was environmentally friendly things. Also, I was saying that travel, as a consultant or as a teacher or as a professor, presenting a paper or being an official of a mining association, we would travel and we would be invited, and they say, "Why don't you have our annual conference in Tokyo?" Went to the board of directors, I was a president of SME. Next year, we had an invitation to Sydney, and I said, "Look, we have just been to China or Japan, but give until the fourth year, and we'll organize on there, in São Paulo. It just kept on, but I tried to bring all the mining societies of worldwide together, exchange ideas. Mexico was a very good one because they always had a conference, annual conference, in Acapulco. So, they invited me, so I would pass the word around. Our international committee was very powerful. We began to draw international engineers into our society, all the students were encouraged, foreign students, to become



members so that when they go back, they will become full members. So, international cooperation was part of my objective.

08-00:23:35

Burnett:

Your mandate?

08-00:23:37

Bhappu:

To internationalize the mining. We are talking to somebody else. We are using this Japanese, I told you, they had pollution in the water. This is why we are floating copper, it's copper pollution, why don't we put copper reagent? That will make a polymer, and we'll foam it off. Foam flotation. We never knew about it, but they did. This became a water treatment process for many of us. Ion exchange, and I'm only talking about processing—what about innovations in smelting and refining, from old blast furnace to fluid energy, fluid blast furnace, fluidized bed furnace that Outokumpu came out with? It made a revolution in the copper industry because it was not an open hearth with all the dirt and everything going. It was all in one chamber, and dust was collected. Metal became copper metal, it was taken out and then electro-refined. So, that was a smelting operation.

08-00:24:54

Burnett:

You said that was Outokumpu?

08-00:24:57

Bhappu:

Outokumpu, O-U-T-O-K-U-M-P-O, [sic] which is this Finnish, Finland, one of the big manufacturers of equipment, mostly furnaces. Talking to them, they say, "Hey, we have a problem in the North Pole, Northern Finland, can you come and help me?" They had slags and all that. I said, "Look, you don't have any facilities, but you can sprinkle water during the rainy season. Everything will freeze, so you won't be able to do much. So, it was very interesting. Anyway, what I feel is that internationalization of our mining community is an important and was an important step. My predecessors took it, and I made a big thing out of it. Our first meeting was in Japan, in a very good incident. We went to the amphitheater. All the machinery of Japan, Mitsubishi and all, trucks and drilling equipment. At the registration desk, there was a little booth. It said, "Jack of all Troubles." If you had a problem with your airplane ticket, registration, hotel accommodation, jack of all troubles, like jack of all trades, they say, "jack of all troubles." He was there to help you.

08-00:26:33

Burnett:

So, do you see yourself as a jack of all troubles? [laughter]

08-00:26:36

Bhappu:

Yeah, I always sign, "jack of all troubles." Just one more sentence. When I was invited by the Australian president of the Australian Mining Institute, that was the president in 1992, I was brought into Sydney. He came to Sydney, the president of the company, brought his own jet, took me to Mount Isa, and then all mines of Australia.

08-00:27:12

Burnett: In his jet?

08-00:27:15

Bhappu: Yes. Took one week to visit ten different mining operations and mining fields all over Australia. So, another wonderful experience was in Papua New Guinea, we were first to put up a copper plant. They had a big deposit. The guy who was running the show was from Tucson, he knew us, we did all the work. We went to Papua, actually, the pilot plant. We couldn't move all the forty, fifty tons for piloting. We ran the pilot plant there, working with the locals. We had lobster for lunch, or lobster for breakfast, because that was all they could offer.

08-00:28:05

Burnett: Well, that's good enough.

08-00:28:12

Bhappu: I remember I thought this same thing happened to us in Pakistan.

08-00:28:17

Burnett: In the late eighties, you went to Pakistan.

08-00:28:24

Bhappu: No, this was middle nineties, they had the problem before 9/11. We had a very good relationship, Afghanistan and Pakistan, and they had all these emerald deposits. So, we organized a seminar, '94, '98, and then, of course, we were at 9/11, so it stopped. Three trips, and working with the local people. This is when Afghan says, "Don't tell us about explosives, we know everything. Tell us about emeralds." We went to Azad Kashmir, which is a separate country, now. It was a part of India, but Pakistan wanted to claim it, so it became Free Kashmir. It was a fun place to go for to skiing and winter games. Their biggest resource is rubies. The manager took us around, showed us the resources, and picked up in the basket, rubies, a handful of rubies. There must be about 100 of them, and says, "I'll sell you that for \$12,000." In real money, it's closer to \$500,000 to \$1 million, once they are polished. But they were that hungry for knowledge. He says, "I pick up maybe fifty per day with about 5,000 people in the field. Tell us how to." So, I explained to them scientifically that this is the way to do it, he says, "We want you to come again," but with 9/11, that was my last trip there—2000.

Ruby is 4.7 gravity, very heavy. I give you a list of gravities. Calcite, the main rock, is about gravity of 2.7. Big difference. So, we would use the gravity to collect good rubies and bad rubies and mixtures. The good rubies would be selected, and we handpicked at this stage because they were ready to be picked. But with the one that was with the calcite, I said, "Do you have a little hydrochloric acid?" He says, "No, but I've got a laboratory, let's see." So, I took a little bit of hydrochloric acid, put it in water, and I poured it over it. And the limestone just evaporated, CO<sub>2</sub> came out, it collapsed, became lime

calcium oxide, and rubies were left behind.” He says, “My goodness! I never thought of those things.” This is the kind of opportunity we have. Not for enterprise, but for a challenge to pass on the information. Azad Kashmir is a small country, small resources. Gemstones are its only export product, so why shouldn’t we help them? Rather than a German group come and pick it up from them, take it to Germany, or Irish, or Brazilians who are very good people for gems and minerals.

08-00:32:07

Burnett:

Can I ask a question about that, that ties into what you were saying before about the internationalization of the AIME and the SME? You were doing all of this work to get these national mining communities—because they’re national, right, the Australians and the Japanese—together to share ideas, to share information, right?

08-00:32:32

Bhappu:

Knowledge. Also, to have a geological session, say, “We have this deposit, we don’t know the potential, we invite you to come and look at that.” So, it’s an invitation for the mining people for investments.

08-00:32:47

Burnett:

So, is there a tension because you’re doing research, you are scientists, and there is this notion of an idea that scientists are universalists, they share information, they’re part of a community of one, and you’re also in business. You’re also working for individual mines. There’s stories about J. David Lowell would get ideas, who would go through Newmont, let’s say, and they have their own private library with their own private scrolls and documents, and reports. It’s proprietary and it’s secret. Can you talk a little bit about whether or not, or how you manage a tension between the identity of engineers as scientists, with this desire to share, and businessmen who need to keep?

08-00:33:49

Bhappu:

What happens is that our mining societies, or international societies, have two types of audiences. One is the practical operation—geologists who want to know the deposit—and then there are the metallurgists and flotation experts, like Fuerstenau or Gaudin, he used to go to every one of them. We encourage both the groups. The academic is there to share academic knowledge at equal level.

08-00:34:26

Burnett:

Basic knowledge, basic research.

08-00:34:31

Bhappu:

Much of the basic research also deals with mineralization—what are the crystals, and what habits are there, what are the properties and potential methods of processing? So, that is a challenge to the metallurgist. A guy like me, if I go to the meeting and it’s in, say, an author from Morocco and he has

a problem, I said, “I think that I’ve got a solution for that.” He says, “We’ll be very happy to help you.” So, that’s how we communicate. In the mining community, on the practical side, there are two guys. One’s looking for deposits, and the other guys are trying to learn something new by exchanging ideas. The mining guy who’s there to sell his property or buy a property, he will be interested in what are the new mines’ locations? Usually, one of the presentations is the geological survey of that country, which says, in the last decade, or the last five years, or last year, these were the new discoveries. Then, that gives the guy the idea of the potential that is there.

The guy who is making deals is in the pub, having a drink, and saying, “I’m interested in buying your property. I will go through this and that.” Now, as far as sharing the information, the mining companies, like Newmont, my son used to—his job, was one of the metallurgists for Newmont. They would never give out information unless they have a deal. This is where sometimes, the mining community membership or the management or the US Bureau of Mines, we always have some people from the State Department at these sessions. They are looking for collaborative projects, especially for critical metals. They want to know where the rare earth coming from, where is it located? So, they are more like spies. They want to know what is happening throughout the world. So, it’s a mixed audience, and you are never going to get their books or their—

08-00:37:08

Burnett:

Reports or documents?

08-00:37:10

Bhappu:

Yeah, on that particular property. However, the technology is such today that Newmont is interested in gold, and there is not too much new in gold. The old processes are still there, unless you are going to come out with a breakthrough process that will pick up only gold and nothing else. There is nothing new that they can share except the location. Maybe their geologist has found a deposit that is in a remote location. They now are trying to make a deal with you, with the government. “Well, we want a concession on it.” There are local people who’ll say, “The United States doesn’t have the facilities or the organization,” so Newmont, what are they going to do? They’ll make a subsidiary in Brazil, or subsidiary. They have all kinds of powers to deal and share information. After all, the head, Newmont, benefits. So, they are willing to share in a particular case, but they need a deal. They are not going to give away free advice.

However, you know that mining people are talkative. They want to share information over a drink or so. You are alert, you might get a lead. Then, there are people like us, who are looking for challenges. “Oh, your mineralization is refractory gold, you can’t leach it with cyanide.” So, I would go and contact him and say, “You have this kind of a prospect.” Even Newmont sometimes, I

say, “Look, there is a way to do this, and we can help you. Let’s have a project with you,” so they subsidize us. Once they have the concept, they go into their own lab, and confirm it. Then, they go ahead and invest in it. So, it is, it’s a give and take. There is a good criticism that maybe we are giving too much away, or we are not getting enough in return. By educating them, what do we get? Well, we get friends, okay, but friendship doesn’t last when one guy comes with extra money and says, “I will bid you so much more.” There goes the project. International governments, there is a coup, and now there is a completely new management, new Bureau of Mines or minister of mines. You have to start making a deal all over again. But there are the basics—I was originally from my forefathers, when I go to conferences during the 1960s, ’70, ’80, ’90, many of them, I stood and said I got them, at Colorado or New Mexico. They are very, very afraid when we say, “We want to help you.”

They invited me, and this is a very interesting issue, I was in Tehran. It was my last day. I had visited a copper project called Sarcheshmeh, which Mountain States helped construct and build. I was having a drink. He looked like a European, and he was sitting next to me, and we started talking. He says, “I’m a petroleum engineer. Who are you?” “I’m a metallurgist, and I represent Mountain States, and we are helping the local industry.” This was before the shah was deposed. A few months before.

08-00:41:13

Burnett:

Seventy-nine.

08-00:41:15

Bhappu:

When we came to the end of friendship talk and mining and all, he says, “May I give you just one advice? You don’t know me, you have never talked to me, you are a stranger to me. But I feel that you mean well, that you are an old Zoroastrian. I know about the Zoroastrians, and I want to give you a friendly advice of one engineer to another. He says, “Do not get involved.” The government of Iran wanted to offer me the directorship of their Bureau of Mines. They had a Bureau of Mines, but it was a low-level thing. They had heard about my achievements, and one of the ministers of mines or industry was a Zoroastrian. He convinced the king and his associates that a strong Bureau of Mines would be good. He says, “We have a potential Zoroastrian who would be willing to come back and help us.” So, this is the message I got, and I didn’t know that.

Part of my reason for coming was also to do a fact-finding. How true was this? I did meet the minister, a very short time, we hugged each other and he wished me well. He says, “We are interested in you.” This guy in the night tells me, “Do not get involved in the mining industry or any industry in Iran, Persia, because the king is not going to be there.”

08-00:43:12

Burnett: The shah, you mean?

08-00:43:14

Bhappu: “Shah is not going to be there next year.” So, there was a conspiracy going on, and disposing of shah. At least, people knew about it. I didn’t know about it. I said, “I will certainly take your advice.” The next thing I knew, that chief minister, the advisor, the Zoroastrian, has joined University of Boston as a chancellor. [laughter] So, it’s a small world, and I’m glad I didn’t take that job because I would be in a heap of problems, moving the family. Nobody knew who was the chief, and the mullahs were running the country.

08-00:44:00

Burnett: Sure. Well, there’s a theme running through these questions and answers, and that is, what motivates people to do what they do in the mining industry? There are several motives, one of which is, of course, money, but there are these other factors. We talked off-camera about the fact that the value of mining in the mining industry is not limited to its dollar value, that it’s more, much more important. It’s a foundational industry. In addition to money, there’s these personal relationships.

08-00:44:36

Bhappu: Those are very, very important, and especially when I see young people from Iran at a graduate level, getting their doctorate at University of Utah or California, coming to me and saying, “What should I do? I don’t want to go back.” I’m an Iranian, I want to help them, but you look at what’s happening there, what am I going to do? Well, you feel guilty. I would say, “Well, don’t forget it, we’ll give you a job and I will arrange with the immigration that you should be classified as assigned shelter.”

08-00:45:18

Burnett: H1-B.

08-00:45:22

Bhappu: That’s what my son, who is a lawyer, he’s a historian, he’s a geologist, and an environmentalist, he’s the one who is helping me. His name is Homeē. We never talked about my wife, but my present wife and I were kids together. We grew up together, since we were five years and up. She graduated, went to Europe, became the manager of Swiss Air, and was stationed in the Karachi airport. I knew her, and I met this lady in Colorado School of Mines, and we got married in 1953, and then we went to Pakistan to find the job. Didn’t find it, and then we immigrated. So, we have four children with my first wife, and she passed away about twenty-five years ago. She had cancer, liver cancer. My present wife’s brother was my schoolmate. Her first husband was with Pakistan Airlines, he was originally with Tata Group. He’s a Parsi. So, he had to come to Pakistan to take over the mechanical department, maintenance

# Periodic Table of the Elements

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 About Chemistry

1A	1 <b>H</b> Hydrogen 1.00794	2A	4 <b>Be</b> Beryllium 9.012182	3B	21 <b>Sc</b> Scandium 44.955912	4B	22 <b>Ti</b> Titanium 47.887	5B	23 <b>V</b> Vanadium 50.9415	6B	24 <b>Cr</b> Chromium 51.9961	7B	25 <b>Mn</b> Manganese 54.938045	8B	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	1B	29 <b>Cu</b> Copper 63.546	2B	30 <b>Zn</b> Zinc 65.38	3A	5 <b>B</b> Boron 10.811	4A	6 <b>C</b> Carbon 12.0107	5A	7 <b>N</b> Nitrogen 14.0067	6A	8 <b>O</b> Oxygen 15.9994	7A	9 <b>F</b> Fluorine 18.9984032	8A	2 <b>He</b> Helium 4.002602		
	3 <b>Li</b> Lithium 6.941		12 <b>Mg</b> Magnesium 24.3050		39 <b>Y</b> Yttrium 88.90585		40 <b>Zr</b> Zirconium 91.224		41 <b>Nb</b> Niobium 92.90638		42 <b>Mo</b> Molybdenum 95.96		43 <b>Tc</b> Technetium [98]		44 <b>Ru</b> Ruthenium 101.07		45 <b>Rh</b> Rhodium 102.90650		46 <b>Pd</b> Palladium 106.42		47 <b>Ag</b> Silver 107.8682		48 <b>Cd</b> Cadmium 112.411		49 <b>In</b> Indium 114.818		50 <b>Sn</b> Tin 118.710		51 <b>Sb</b> Antimony 121.760		52 <b>Te</b> Tellurium 127.60		53 <b>I</b> Iodine 126.90447		54 <b>Xe</b> Xenon 131.293
	11 <b>Na</b> Sodium 22.989769		19 <b>K</b> Potassium 39.0983		37 <b>Rb</b> Rubidium 85.4678		38 <b>Sr</b> Strontium 87.62		41 <b>Nb</b> Niobium 92.90638		42 <b>Mo</b> Molybdenum 95.96		43 <b>Tc</b> Technetium [98]		44 <b>Ru</b> Ruthenium 101.07		45 <b>Rh</b> Rhodium 102.90650		46 <b>Pd</b> Palladium 106.42		47 <b>Ag</b> Silver 107.8682		48 <b>Cd</b> Cadmium 112.411		49 <b>In</b> Indium 114.818		50 <b>Sn</b> Tin 118.710		51 <b>Sb</b> Antimony 121.760		52 <b>Te</b> Tellurium 127.60		53 <b>I</b> Iodine 126.90447		54 <b>Xe</b> Xenon 131.293
	19 <b>K</b> Potassium 39.0983		20 <b>Ca</b> Calcium 40.078		21 <b>Sc</b> Scandium 44.955912		22 <b>Ti</b> Titanium 47.887		23 <b>V</b> Vanadium 50.9415		24 <b>Cr</b> Chromium 51.9961		25 <b>Mn</b> Manganese 54.938045		26 <b>Fe</b> Iron 55.845		27 <b>Co</b> Cobalt 58.933195		28 <b>Ni</b> Nickel 58.6934		29 <b>Cu</b> Copper 63.546		30 <b>Zn</b> Zinc 65.38		31 <b>Ga</b> Gallium 69.723		32 <b>Ge</b> Germanium 72.64		33 <b>As</b> Arsenic 74.92160		34 <b>Se</b> Selenium 78.96		35 <b>Br</b> Bromine 79.904		36 <b>Kr</b> Krypton 83.798
	37 <b>Rb</b> Rubidium 85.4678		38 <b>Sr</b> Strontium 87.62		39 <b>Y</b> Yttrium 88.90585		40 <b>Zr</b> Zirconium 91.224		41 <b>Nb</b> Niobium 92.90638		42 <b>Mo</b> Molybdenum 95.96		43 <b>Tc</b> Technetium [98]		44 <b>Ru</b> Ruthenium 101.07		45 <b>Rh</b> Rhodium 102.90650		46 <b>Pd</b> Palladium 106.42		47 <b>Ag</b> Silver 107.8682		48 <b>Cd</b> Cadmium 112.411		49 <b>In</b> Indium 114.818		50 <b>Sn</b> Tin 118.710		51 <b>Sb</b> Antimony 121.760		52 <b>Te</b> Tellurium 127.60		53 <b>I</b> Iodine 126.90447		54 <b>Xe</b> Xenon 131.293
	55 <b>Cs</b> Caesium 132.9054519		56 <b>Ba</b> Barium 137.327		57-71 Lanthanides		72 <b>Hf</b> Hafnium 178.49		73 <b>Ta</b> Tantalum 180.94788		74 <b>W</b> Tungsten 183.84		75 <b>Re</b> Rhenium 186.207		76 <b>Os</b> Osmium 190.23		77 <b>Ir</b> Iridium 192.217		78 <b>Pt</b> Platinum 195.084		79 <b>Au</b> Gold 196.966569		80 <b>Hg</b> Mercury 200.59		81 <b>Tl</b> Thallium 204.3833		82 <b>Pb</b> Lead 207.2		83 <b>Bi</b> Bismuth 208.98040		84 <b>Po</b> Polonium [209]		85 <b>At</b> Astatine [210]		86 <b>Rn</b> Radon [222]
	87 <b>Fr</b> Francium [223]		88 <b>Ra</b> Radium [226]		89-103 Actinides		104 <b>Rf</b> Rutherfordium [261]		105 <b>Db</b> Dubnium [262]		106 <b>Sg</b> Seaborgium [266]		107 <b>Bh</b> Bohrium [264]		108 <b>Hs</b> Hassium [277]		109 <b>Mt</b> Meitnerium [268]		110 <b>Ds</b> Darmstadtium [285]		111 <b>Rg</b> Roentgenium [288]		112 <b>Cn</b> Copernicium [285]		113 <b>Uut</b> Ununtrium [288]		114 <b>Uuq</b> Ununquadium [289]		115 <b>Uup</b> Ununpentium [289]		116 <b>Uuh</b> Ununhexium [293]		117 <b>Uus</b> Ununseptium [294]		118 <b>Uuo</b> Ununoctium [294]

Lanthanides

Actinides

57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90765	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium [145]	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.500	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668
89 <b>Ac</b> Actinium [227]	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03888	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium [237]	94 <b>Pu</b> Plutonium [244]	95 <b>Am</b> Americium [243]	96 <b>Cm</b> Curium [247]	97 <b>Bk</b> Berkelium [247]	98 <b>Cf</b> Californium [251]	99 <b>Es</b> Einsteinium [252]	100 <b>Fm</b> Fermium [257]	101 <b>Md</b> Mendelevium [289]	102 <b>No</b> Nobelium [259]	103 <b>Lr</b> Lawrencium [262]

Alkali Metals	Alkaline Earth	Basic Metal	Halogen	Noble Gas	Non Metal	Rare Earth	Semi Metal	Transition Metal
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department, so he was the vice-president of operations. She was with the Swiss Air.

So, we kept in touch, but he passed away twenty-five years ago. Her kids came here, to Dallas, went to university, and university in Boston, where our son got his environmental science degree. Then, later on, he went to Chicago and became a lawyer—immigration law. Now, he's working with me because things are a little tight. He wants to look after his mom and dad, quote, "dad." Both ladies were just outstanding. I can't say enough of either of them. They're just wonderful ladies, very comfortable, family-loving. I'm glad that I had my first wife in the growing years, and I'm glad that the last twenty-five years, where I became a professional, my other wife, second wife, was there, and her children. So, we had four children from the first family, and ten grandchildren from the first relation. I acquired my wife and two children from her marriage. They are now helping me, and so, we are a close-knit family. We used to contact each other when we were married outside, and we used to go to Karachi, and meet with them, and they would dine us and entertain us. We did the same. So, it was very congenial.

They said that after, for each successful person, there is a successful lady who guides him and guards him and nurses him, and that is the wife. They both took good care of me. So, I'm very grateful to both of them, and to my children. My Ross was a perfect example of following the Zoroastrian religion, being a leader in the industry. He will be, obviously, two years, he'll be the president of the Mining Society for sure, they tell me that. My one daughter is in San Antonio, and she and her husband are very close to the Mexican community. They are bringing in enterprising leadership in estates, especially for hospitals and health facilities. They are promoting that, and on the side, he is promoting wine, also. My other daughter is in Washington, DC. She's married to that politician, Reagan's child, you might say.

08-00:50:08

Burnett:

His biographer, yeah.

08-00:50:10

Bhappu:

He's doing everything Reagan-ish. He's got the same ideas today. My first son, as I said, is a self-made handyman, but working on new designs. He's a painter and a pottery maker.

08-00:50:25

Burnett:

Right, a craftsman, an artist.

08-00:50:28

Bhappu:

He worked with Maria, the potter in New Mexico. So, each one—

08-00:50:33

Burnett:

Has these talents and the spirit that goes in these different directions.



08-00:50:38

Bhappu:

I mentioned that my family, we are very family-oriented. Normally, parents and sons and daughters, they usually stay together, back in Karachi. They have a big mansion. One wing goes to the parents, other wing to the one marriage and to the other. They seldom separate too far from each other, but now it's divided. So, every week, every second, third day, we are in touch with each other.

08-00:51:13

Burnett:

They visit you, right?

08-00:51:14

Bhappu:

Not real visit, just telephone visit, you know? We keep in touch. The important thing is their support. You are away for sometimes with two weeks, but I had made up my mind that if I'm going to be away on a trip for two weeks, I'm going to take my wife with me. That was a good policy, and when they are young, the kids are home, they are the only ones who are looking that I'm away on a trip. When I leave Tucson, my little girl, before hello, she'll say, "Daddy, don't get me anything, don't get me anything." She's still a little one. As soon as I land, the first thing she says is, "What did you get me?" [laughter] So, family is important, and I think every successful person has a family to thank.

08-00:52:11

Burnett:

Has a strong family, yes.

08-00:52:14

Bhappu:

So, I'm grateful that God gave me wonderful support.

08-00:52:19

Burnett:

That's wonderful.

08-00:52:20

Bhappu:

So, I feel that challenges are going to be there. We talked about it some more. Some of the mining companies are going to be outstanding, like Newmont, they are always there. I'm sorry that they have to let people go, but they are trying to make profit and be profitable. Education was very important, and many of us became doctors and lawyers, but I elected to become an engineer, and especially a mining engineer, because of the influences that were given to me when I was growing up. I feel that the mining industry is here to stay. It'll be a different kind of industry ten years from now. You will still have big facilities, big opportunities, and tomorrow, I'm going to talk to you about what is new. How much time do we have?

08-53:28

Burnett:

We have a few minutes.

08-00:53:29  
Bhappu:

Okay, here, I'll tell you one of the innovations that could be of help to us. I told you that one of the government institutions, the Department of Energy, DOE, asked me a question when I started my engineering practice with Mountain States. They came around and he says, "We are asking, do you know how much energy you are putting into making one ton of copper from this natural mine that we saw?" He says, "Why don't you make a case history, select a scenario that's a 40,000-ton-a-day operation, 0.5 percent copper, and let's say that's going to be an open-pit mine. You're going to have crushing, comminution, flotation, and a smelting operation. You are an integrated mining company. Tell me how much of the power, *my power*," as he says, "you are going to use to make that one ton of copper? I would like you to take it." I said, "This'll be costly." He says, "It's no problem. Make sure that what you give us is something that we can rely on. You have a very good reputation, you are educated, you are a researcher, and I think this is something that will benefit the industry."

So, I said, "I'm going to use some consultants." Have you heard of Professor Wadsworth at the University of Utah? A wonderful person. He's a great friend of Doug [Fuerstenau], and of Maurice [Fuerstenau] and mine. He was the head of the department, University of Utah. He has many, many followers, and one of the mentors in our industry, especially in our branch. So, I asked his help, and I had one mining engineer professional who I hired because I didn't have that much of a mining background. We started putting cost of energy to every operation, from exploration to development to start-up to construction, and through refining and making the copper metal. The whole area of mining.

So, our geologists we had in-house, they made cost analyses, saying "it's going to take so many drill holes. The deposit is 40,000 tons a day. In order to make money out of it and make a good return on your investment, we'll at least have to have a thirty-year operation." So that's the reserve, they calculated. If that's the reserve, then the underground, 1,200 feet deep at the lower level, and this is going to be the cost. The mining method, the cost. This is going to be the cost of trucking from the bottom of the mine to the open-pit mine, and going through the crusher, through the grinding mills, through the flotation, through the smelting and refining, environmental control, water treatment, all inclusive. Energy, where are you going to buy the energy? But they said, "Don't buy it, don't put up your own plant. Use the current rate in Arizona as a standard." Kilowatt hours.

So, we jumped at it. It took us one and a half years to do this work, so you can see that it was expensive. All the participants made good money on that one, I'm not ashamed to say, but that was a big challenge. We came up with a magic number of 100 million BTUs to make one ton of cathode copper ready for market, from an open-pit mine in Arizona, taking Arizona labor rates,

water rates, electricity, everything. Two operations came out as outstanding energy users. One is the truck. Let's say that you have a one-mile open-pit, and say ten kilometers of truck operation. So, the truck has to go down, pick up the load, come up, then you drive one five to ten kilometers, to the mill plant. There will be a stockpile and a crusher. It'll go through the big primary crusher, a secondary crusher, a tertiary crusher, at one and a half inch crush. Go to the ball mill, re-grind, go to flotation, you'll have flotation, you'll have the tailings go out, and that flotation concentrate will go to a smelter near Miami, Arizona, which is about 120 miles of trucking. You will make so many tons of concentrates, which would be running around 30 percent copper, or it'll go the smelter and make 99.9 percent copper smelter.

So, if you look at trucking, it's the most important energy consumer in the mining operation. On the other hand, on the milling operation, metallurgical, it's the ball mill. Tremendous energy to crush from half an inch to 48 mesh or 100 mesh, 200 mesh. So, the crushing comminution is the second most significant energy consumer. Now, if you divide the scenario into mining, geology mining, milling operation, concentrate, smelting, and refining, it seems that 30 percent of the total energy can be calculated, or 30 million, approximately, BTUs goes in the mining operation. About 50 million BTUs goes into crushing and grinding and all that energy, and about the last 20 percent goes into smelting, refining, all the auxiliary. Out of the 30 percent of the mining, 66 percent, or two-thirds, goes into this trucking, at \$0.90, diesel. Sixty-six percent of 30 percent, so nearly 20 percent of the energy of the total mining is in one little operation—trucks! Going up and down.

08-01:00:55

Burnett:

Not including the transportation from the different stations?

08-01:00:57

Bhappu:

No, just taking up to the station, that's it. In the milling, it's the ball mill, those crushers, the ball mills, the grinding. Very horrendous. It's about fifteen to twenty kilowatt hours per ton energy that goes into grinding. That, in the milling of, what did we say, 50 percent, 66 percent goes in comminution. So, two operations in the whole mining area, from exploration to smelter, two operations: trucking, transportation, and milling, grinding, consumes 50 percent, 50 million BTUs.

So, what is the answer to that? The answer is, why does the truck have to go around and around and around and up to the top? Can't we crush the ore at the site of mining, down below? Put a moveable crusher, so you can move it from one level to another. Not every day, but every two years, three years, move that. That crushed product, then, you put a primary crusher down there, crushes down to eight inch rock. You put that into a conveyer. So, from there, you go to this way, to this way, and this up. So, everything is conveyed. Conveyer is cheaper than trucking, it's less expensive, it's limited, so you

have a machine shop and all, you can keep track of it and repair it. There, you save about, I would say, at least 25 percent, 30 percent of the energy. Go ahead.

08-01:02:56

Burnett:

Perhaps we should stop the tape and finish this story next session?

08-01:03:01

Bhappu:

Okay.

Interview #3 March 7, 2014

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09-00:00:00

**Burnett:** This is Paul Burnett, interviewing Dr. Roshan Bhappu, in Tucson, Arizona, March 7, 2014. This is session five, and tape nine. So, we were last talking about energetics and this environmental accounting of mining that you undertook at the request of a client. You were talking about suggesting replacing trucks with conveyors, and the use of portable crushers, which would reduce the energy use. Can you talk a little bit more about that?

09-00:00:59

**Bhappu:** As you know, mining is an energy-intensive industry because of the heavy machinery that is used, starting with the trucks, the shovels, and especially the trucks. In an underground mine, the material comes right to the surface, so you don't have to worry about it. But in the open pit mines, sometimes you may have several kilometers of driving from deep into a mine to come to the surface in a circular, cyclic manner. Depending upon the price of diesel, this could come into a pretty hefty amount of energy that is used. The Department of Energy asked us, selected us, to come up with an estimate as to what is a general consumption. Now, let me remind you that this was nearly twenty years ago, so it can change.

Of all the mining energy, and energy is one of the first criteria that a mine location looks at—do we have energy, do we have water, those are the two critical factors—energy-wise, they want to make sure they are not very far from the main line. However, in later years, now, people in Nevada, especially, find that energy is getting a little bit out of hand. They feel that putting up a small plant to generate their own electricity, would be profitable. Especially if you are looking at a twenty-year or forty-year mine life. Also, locality, because many of the mines try to be discovered in some locality. So, maybe you put up a central facility by miners themselves. This becomes a very big item of energy cost.

09-00:03:26

**Burnett:** When they set up their own plant, what is the source of electricity? They're mining, say, coal for example, and processing it?

09-00:03:32

**Bhappu:** In coal mining, they are thinking about setting up their own energy because you find coal, for instance, in Northern Arizona, Colorado, New Mexico, is a big generator of coal. Now, they'll be thinking about maybe other coal, or maybe oil, or gas. The biggest thing is hydroelectric. Those mines that are situated in the hydroelectric areas, especially in the North or Northwest, they are very fortunate because they can get some pretty good rates.

So, trucking in the mining sector, which amounts to about 20 percent of the total energy, amounting to about 100 million BTUs, 30 percent, 30 million BTUs are used up in the mining sector. Of that, two-thirds, 66 percent, is in trucking. On the other side, when the ore comes to the surface and goes through liberation from crusher to crusher, primary, secondary, tertiary, and even sometimes a quaternary crusher, and then goes into the ball mill. Then, it got ground very fine, and then the flotation. So, that unit operation of comminution is a big guzzler of electricity. We are talking about 50 percent—so, 50 percent milling, 30 percent mining, and 20 percent is crushed, smelting, refining, the other operations, warehouse and machine shops, things like that. But between mining and metallurgy, two unit operations, trucking and comminution, take up about 50 percent of the energy.

So, anything we can do to save on those two issues – do we really need to use the trucks? The trucks are getting bigger and bigger and bigger, which is good, but at the same time, you are paying for it and you still have quite a few accidents. It's not as safe—all the mines are running very safe in that respect. So, the first idea comes, why not crush it in pit, down to the one level, and then go up in a conveyor? They do only one stage of crushing, which is primary, which takes the big boulders and all that and brings it down to about minus-eight inch, which can be on a seventy-two-inch belt, can be transported. So, that has become a trend. If Mountain States started early in the game and now everybody's following it and considering it as an alternative. However, people who already have trucks and investment, they are not going to change. But in the new mine, we think that's maybe a major innovation.

Then, there is an extension of that, that if you crush, you might say, at the bottom of the pit, bring it up. If you use the primary crusher to do that, you already have a minus-eight inch material. Now, that material is not ready to go into a ball mill, it's too big for it. On the other hand, there is a development of what we call SAG mill. S-A-G. It does the job by crushing the ore by the ore itself, rather than using steel balls, although there is a trend that you might use maybe 5 percent, 10 percent balls.

09-00:07:59

Burnett: Steel.

09-00:8:01

Bhappu: Usually, it is autogenous crushing, that's what it is, semi-autogenous crushing. Minus-eight inch is a perfect size for this big SAG mill.

09-00:08:13

Burnett: How big is minus-eight inch with SAG? Oh, eight inches and smaller.

09-00:08:21

Bhappu: Eight inches, yeah. That's easy to convey, and you can just feed it directly into the ball miller or SAG miller, which has a big diameter. So, they could be

up thirty feet, thirty-six feet, forty-eight feet in diameter. Big, big, giant things. Takes lots of power. People say, “You are using too much energy,” but we made an energy calculation. If you consider that the broken ore goes through the secondary crusher, the tertiary crusher, it has to have smaller additional conveyors to go from one stage to another, it needs dust collector. So, when you add up all the energies, SAG mill appears to be favorable. Also, less equipment, you might say, to maintain. So, SAG milling has become very important. Even though you may not have an in-pit crusher and conveyor, our trend today is to just go to the primary crusher, and then go to SAG mill. So, there are some advantages.

I feel that the energy is a consideration. There will be more and more innovations coming up, and the energy question is not going to disappear. Should you put in a solar energy? Maybe that’s the new thing. Especially in Southwest, we have plenty of solar heat, and many of the countries around the world, in the desert area, dry area, have plenty of sunshine. So, that’s going to be the trend in the future. This, you can put it into a small mode. You don’t have to have a full-scale power plant. You take a few acres to put in the windmills. So, solar and the wind power are the two new items to add to energy conservation. Taking advantage of nature and not using fuel to do that.

That brings us to another, is these new ideas that are coming up, new innovations. They require very heavy machinery and very robust—robust and light. So, that opens up a whole new area of what I call physical metallurgy, or alloys and materials of construction, the big blades, and things like that. So, this is something, and we’ll talk a little bit about the railroads. That’s where the importance of the railroads will be, in new alloys, which will facilitate making lighter and more robust equipment and accessories.

So, we have talked about energy, and now I don’t want to just say the energy. Water is very important, so we talked about water conservation and recycling. The reason today many of the miners are looking for old operations all throughout the world, is because they have a source. In the old days, they were not that efficient in their mining practice, crushing practice, and especially in gravity and flotation and so on. So, that opens up new areas of research. So, I just mention that these are auxiliary equipment and cost, but it has to be there. Now, we can go to what would you like to?

09-00:12:35

Burnett:

I would say that there’s a kind of approach that you take in general. You challenge assumptions, right? So, there’s an assumption that the way we do things is the best way, and you look for and you ask the question, “Is that really true?” Sometimes, it’s an outside client like the Department of Energy that’s asking that question, and you’re just there, but there’s a reason they’re asking you, right? So, it’s not just metals and things like that, but you also think about organization. You also think about the kind of accounting the

mining companies do. So, you wrote an article, or you've talked about accounting, I suppose. You've talked about organization as well. Is that something that your consulting group has dealt with, how to organize a mine so that it's more efficient?

09-00:13:39  
Bhappu:

After we have done a research project and we all come up with a flow sheet, the first question that the client, even after we haven't done any details, but even at the preliminary stage, he said, "Now, what is it going to cost me?" So, we provide what is called cost estimate, and that's based on two sources. One is your private source, what you learn, what you have experienced in your previous mining operations, and then there are companies who provide up-to-date cost analysis. There are several of them, in England and Washington, state of Washington. There, they give you every year an update on the labor rates, energy, water, and also equipment. Usually, a good engineering company keeps a good record. If you have built a plant, say, two years ago or five years ago, you can update that to today's prices by using factors, 1.5 times, or something that is reasonable. Of course, the labor rates are very critical because it has to account for all the supplies, all the utilities.

So, preliminary cost estimates, we are going through a scenario right now where we have developed a very nice process. The question is, is it cost-effective? You may find that the processing may be cost-effective, but if it's an underground mine, that adds a big burden, especially on rarer metals—gold and silver. Deep deposit, one mile deep in South Africa, the biggest cost is mining, in that case. It isn't processing. Processing is only maybe 20, 30 percent. It's the biggest cost of underground mining, and that has brought up a lot of questions and challenges. When you mine the material underground by block cave, you can have big boulders, so why not do the same thing as we do with in-pit crushing? Why not put in-mine crushing and just haul it out, or haul it up. Or go on a conveyor. So, there are people are thinking about that, and so, cost is very critical from the beginning because you have raised a certain amount of funding and you say, "Well, I've got \$500 million," but then you say, "But by the time you finish, you may have \$1 billion." So, the project then has to generate and go out and raise additional funding. Today's prices, you can go up to \$1 billion very easily. In the old days, it was millions, now it is a billion, and more.

So, costing, accounting are very important, and it starts right in the laboratory. When you write a report, you make all the observations, all the parameters, make sure that they are the right units. You want to make an accounting of what goes in and what goes out because that gives you the efficiency or the recovery factor. Are you recovering if you are putting ten pounds ore of copper from the open-pit mine? What is your last cost? If you take copper today, say at a \$3.20, maybe copper will go down in the future. So, you don't



take the current price, you usually take maybe an average of the last few years.

09-00:18:08

Burnett:

Right, a rolling price for the last five years or ten years.

09-00:18:11

Bhappu:

Exact. So, normally, the feasibility studies come after doing the metallurgical testing, coming up the flow sheet, the first thing that you do is do a preliminary cost estimate. You come out with a factor which is plus or minus 20 percent, 25 percent. Then, if you feel you are robust, you can go right into the project, or if you are not totally decided, that maybe I don't have all the data, you run a pilot plant, which is usually a bigger size operation. Instead of 100-pound samples, now you are talking about 100-ton samples, and so on. So, in progression, pilot plant, especially if you go to World Bank and others, they want demonstration. Sometimes, it's not the pilot plant. We call it demonstration plant. To prove, is the in-situ mining going to work? That pilot test that you do, costs you maybe \$20 million, \$30 million, maybe more, because you have to do these, you are not doing it in a small column or a small flotation cell. You are doing it on a mass, sufficiently large scale.

So, the pilot plant, and then you go to final feasibility. Now, that's when you come down to the nitty-gritty, and you bring in roads, buildings, warehouse, machine shop, welding shops, and water treatment plant. Everything comes in, and especially if you are using heavy machinery. The machine shops are a pretty big, hefty expense. You find that the incidental costs, ancillary facilities, may cost you as much as the plant. So, it is important that you add all these costs. If you are in Mexico, you may have maybe cheap labor, but maybe you might need more people, depending upon how sophisticated the mining is. In many areas, if you have a new mine, you may have to build a whole colony for your staff. If you are especially away from large centers. You find that towns like Miami, Stanford, Globe, they all grew up in the mining, but they are 5,000, 10,000 people. So, many of the population are workers.

Many of the companies, to bring in good talent, entice the people to come to the mine, will provide good facilities, and that would include housing. Another most important is hospital because families won't move until you have a good hospital. The next more important is education, so schools, and if you go to South America, the whole village is totally a self-contained community because they expect that of you. Here, you can fly in and fly out, or drive. They don't have that kind of facility. So, the cost of foreign investment in mining could be quite high, not from the plant view, but from auxiliary facilities—healthcare, safety, ambulance facility, all that comes into play. When you add up, you need a bean-counter to say, "Hey, you started at a \$500 million project, now you are looking at \$700, or even by the time it goes

into operation five years from now, maybe \$1 billion.” So, you should be prepared, and this is where a good mine administration comes in for big companies.

Now, many of the larger companies, like Molycorp and others, they have a tradition, and they have a backup and background of cost estimating. It’s very difficult for a new company to come out, and they depend upon engineering companies to provide that information. That feasibility goes to the banker, to the investor. He will measure, well, what kind of return do I have? If I invest \$100 million, am I going to get my money out? The site of the country, developing country, how safe is it if I make my investment? Well I get anything bank from them? If I build a plant in Ghana, is the government going to give me concessions? Is that giving me a tax-exempt for maybe ten years? Because taxes and all that also adds to the cost. So, when you keep a ledger for a mining project, oh, you’ve got so many items on the exploration side, the mining side, the metallurgical side, smelting, and finally, transportation becomes very important, so that has to be added.

A good administration always has bankers and people, their board of directors are selected for their experience. So, you may have eight or ten people on the board; only two or three of them are maybe mining people. The rest of them are all economists.

09-00:24:19

Burnett: Finance, right.

09-00:24:22

Bhappu: Lawyers—always the law [laughter].

09-00:24:27

Burnett: So, there are all kinds of expertise that go into the mining, and that’s very important.

09-00:24:35

Bhappu: The board of directors play a very important role, and they are the ones who will fire and hire and it requires experience. You can’t just pick up your friend and make him a board director, or your father. You have to have experience, yeah.

09-00:24:56

Burnett: So, I want to switch tack a little bit and talk about my predecessor, Lee Swent. She grew up in a mining community and spent her whole life in mining communities. She talked about in a number of her other oral histories, the extent to which mining is a kind of a family business, in a couple of senses. It is literally often a family business that a son or a daughter will continue, in perhaps a different field, but they’ll go into mining. Friends and family can intermarry through the generations. Mining is also a family business in a

figurative sense, in that it's a very tight-knit community. Can you talk about the extent to which your family members have been involved in supporting the mining community, or actively involved in mining work?

09-00:25:56  
Bhappu:

Well, this is especially true in research-type organizations because sons or daughter may be very much interested. Not necessarily in the mining, but they say, "Look, Dad, I'd like to help you," and they go and get a degree in economics. Not necessarily mining, but anything to do with a supporting capacity—maybe a lawyer. Some of the parents insist, and as a teacher, professor, I've found that maybe 30-50 percent of the people who become freshmen [in mining fields] are being pressured to go into the mining. They drop out readily. That's a ratio of about 50 percent will drop out. Now, people make up their mind and all, and they don't insist.

But sometimes, the family gets very dominant and wants you to go into mining. This is always a tradition. "Oh, well, I went to Colorado School of Mines, son has to go to Colorado, and I'll give a donation or something." I think people are now making up their own minds, and this is why the mines are growing, and we need more and more students. It is important that we cultivate that because your son or daughter may not necessarily be interested. After all, she has her own life to lead, and you can guide her, but not necessarily make her a miner. Tradition is always there because people who grow up in a mining environment, they like to follow that.

09-00:27:49  
Burnett:

I'm astonished by the strength of the professional identity of members of the mining community. I don't know what you can compare it to, like sort of the brotherhood of police, perhaps. "No one else understands what it is we do," and there's a sense of not circling the wagons, but there's a sense that the work we do is special, the work we do is fundamental, and there's a closeness amongst the professionals in the mining community.

09-00:28:29  
Bhappu:

This is true because if you see a family growing up in the Miami Globe area, you would think that you would like to do what his father is doing, but many of their people are laborers. They don't want to go into mining. Only those people who are in managerial positions and all, they say, "Look, I grew up in the mine, it's a noble profession, and I'm going to continue with it." He'll take the necessary classes and so on. Other people join the thing because it's a father-to-son legacy. He says, "Well, if I don't continue, I won't have the necessary funding for retirement," and all that.

But things have changed now, so most of our mining activity is now going overseas. The question is when you have an overseas mine and you are an American citizen, you seldom go to that mine. The children don't go to the

mine unless in their initial years, growing years, they are at the mine site. Soon after that, high school or so, they're going to college and they'll find their own profession. So, yes, it is family trend, and you always find that if you have four or five children, you'll at least have one or two that is interested. [laughter] Not necessarily in mining, but in associated professions, right.

09-00:30:12

Burnett: Some kind of associated work, yeah.

09-00:30:15

Bhappu: Many people look at the nursing profession and they find that, look, the poor guy got hurt, and we don't have facilities. So, they will go get their—especially in foreign assignments—degree in medicine or nursing, and come back to help with the locals. Of course, people who grow up in Catholic communities and others, South America, they are very, very sympathetic and they tend to follow that.

09-00:30:52

Burnett: So, you talked about father to son, following in the footsteps, kind of, professional tracks, but could you talk about women in mining communities?

09-00:31:08

Bhappu: Most of the big mining companies were centered in New York and larger cities. Many of the ladies, wives of the officials and president and others, lived in large city. They want to help their husband or father to help in the mining profession. So, they may not become actively involved in mining, but they will say, "Look, I'm interested in education and I'm interested in my son, my daughter, or my neighbor's son, or my relative to go into mining." But that takes money, so they made up their minds from the beginning that the work of the ladies' organizations, the Women's Auxiliary of the American Institute of Mining, that we would become a funding source for students because that is the biggest need. A president of a company has enough money to send the kids, but he says, "Look, the metallurgist, he is a very good worker and he has a bright son. What opportunity does he have, if his father doesn't help him?"

The women's society [WAAIME – Women's Auxiliary of the American Institute of Mining, Metallurgical, and Petroleum Engineers] worked in two areas. One is to raise funding, and women's auxiliary started with the big mining push in the early nineteen's, and they found out that over the years, 100 years, they raised millions and millions of dollars for this very worthy cause. State financing can be there, you can get scholarships, but that's not available to everyone. For instance, in a college, mining college, you have a school of mines, you might find a senior who has come from the industry to learn, but he needs tuition. He has a family to sustain. The scholarships and many of the awards, you must have a—

09-00:33:45

Burnett:

A 4.0 grade point average?

09-00:33:47

Bhappu:

Yeah. But what happens to a guy who is a good student? An average student doesn't have an average grade of 4.0; he is only, say, 3.0. Should he be discarded because he's not up on that? So, they feel that these are the kind of people we should be helping because the good student is going to get a scholarship. It's the guy who is medium, he's working part-time and his wife is working and he has kids, and if his wife can't work because they are living in not a big metropolis but in a small village where there are not that many opportunities? So, they have raised that amount of funding for such purposes.

In the last twenty years, things have changed, since people like myself and those who have come from foreign countries or who graduated University of Bombay or university in Chile or Brazil, they want to come to United States. They have made women's auxiliaries in these foreign centers, but it's administered from the United States because that's the umbrella organization, and all of those are affiliated. So, they raise money, and many of the hundreds and thousands of dollars go to Mexico, Peru, Chile. Then comes the people like Saudi Arabia, they send a lot of students, but they can sustain it. They said that in order for their students to get acquainted with the American life, they donate money to the women's auxiliary to say, "Cultivate my student. Not just academically, but culturally." So, women play a very important role. Not only that, but when I went to Colorado School of Mines, we had maybe 1-2 percent, 5 percent ladies in the total mining enrollment. Today, we may have as much as 20-30 percent, which is very good to see because recently, a majority of the winners, award-winners are ladies. Many of our presidents are ladies, now, because in the last ten years, we had three lady presidents. Which is very good because it tells the ladies, "Yes, we are interested in what you can contribute."

So, there are two ways to contribute: one is in technology-wise and experience-wise, the other is in donation and raising funding, especially for scholarships and students. So, I admire them, and they have been very helpful. My wife, as well, worked previously with Swissair as a manager of the east, and she's very capable of handling. She may not know anything about technology, but she's a good manager, personnel manager, and other expertise that you need to run a small company.

09-00:37:26

Burnett:

Right, administrative.

09-00:37:26

Bhappu:

Now, if you are a big company, you can hire secretaries and all that, but in smaller towns and especially in smaller companies, you find that the wives and daughters, this is where the family comes in. Sometimes the son feels,

“Look, dad, my dad’s getting older. Well, I’m a good accountant, I’ll join the company, guide them in finance.” Or, “I’m a lawyer in all kinds of law and litigations come in. Well, I’m going to help him in the legal matters.” So, this is a trend. That’s why family life is important.

09-00:38:10

Burnett:

Yes, absolutely—to get that support, for sure. So, we’re now at a stage where we’re going to talk about recent transformations in the mining industry. You have some special expertise that dovetails well with these new concerns, new rising concerns. Last year, in March 2013, there was a bill before the House of Representatives called the Critical Minerals Policy Act of 2013. It passed the house with virtually unanimous bipartisan support. It’s before the Senate now, and it seems to be going well. The gist of the Policy Act is to review, on every level, the permitting policy for mines that would be concerned with the mining of rare earth minerals, and if possible, to streamline them, because there are a lot of environmental regulations surrounding mining in general, and especially with rare earths because some of them—and many of them—are quite toxic. The reason for this is because there’s a large geopolitical concern about the cornering of the market by Chinese rare earth producers. Could you tell us about your role in rare-earth mineral extraction, and what you think about this change?

09-00:40:06

Bhappu:

I think the rare earths is a very good example, but this is also true for other metals. Not like copper, we’ve got plenty of that. Iron, we have plenty of that. But, when you go to rarer metals, these are being used in the industry more and more as additional, small amount in the iron, aluminum, or manganese to make metal more strong, more useable, and repairable—and also, light. You don’t want to have very heavy machinery. It’s like the airline industry, they have got better and better metals to work with. So, alloying is a big thing, and tracers like titanium, zirconium, niobium, and all those were in short supply. We depended very heavily, or we still depend very heavily, on foreign sources. This is of concern for our defense, our future, because these critical metals are the implements, mostly, for war armaments, armor plates, ship’s hulls. Molybdenum is essential.

09-00:41:48

Burnett:

Guidance systems, electronics.

09-00:41:51

Bhappu:

Electronics and all kinds of new things come in, and that’s where these new elements are being used. If you totally depend upon a foreign country, there are two things you can do: you can say in the time of peace, you can stockpile, fill up your warehouse with that, hoping that the conflict will end in two years or five years. So, the politicians know this thing. They know that in time of conflict, Russia may not supply you a thing that is more important to them and they are oversupplied. They say they can put it on the market, but they can

withdraw that, too. That's what has happened to the rare-earth business. First of all, rare earth is not rare.

09-00:42:52

Burnett:

Right, we should say that.

09-00:42:53

Bhappu:

Rare earth is called rare earth because it's difficult; it's a series of sixteen elements that are very closely associated. First type and the second, the heavies and the lights. Isolating one element from the rest, which behave similarly, was very difficult. We didn't have expertise in ion exchange, solvent extraction, high-pressure technology. So, they became rare. I'll just mention one thing here that will be important. This little book is –

09-00:43:52

Burnett:

- *Extractive Metallurgy of Rare Earths*.

09-00:43:54

Bhappu:

Yeah. Written by two Indian chaps from India because in India, in the Travancore district, they had beach sands in the south of India. They had, of course, the titanium and zirconium were very important to steel, but then they found out that the same beach sands had thorium and uranium. So, they began to see that there is a big concern about radiation, that's one thing, and the supply and demand for uranium and other elements which are important to the power industry. So, one of the Zoroastrian scientists, Dr. Bhabha – I think he was an MIT graduate – he said, "I'm going to take this challenge and start the Bhabha Research Institute for Radioactive Materials." These kids were working, and then they came to the United States, got their education, and then they wrote this book for more like a public knowledge. It has geology, it has resources, which countries have the mines, what are the critical elements, how can you process this ore, the physical separations, the chemical separations, how they make rare metals, one isolated from another?

China jumped on it, in those days. They don't have as many mines, but they're big mines and big producers. The grade is very high grade, so even if they make 20, 30, 40 percent recovery, they are happy about it because the resource is there. So, the competition has come up, and if you look at the rare earth – to come back to this point, it's not rare. But, as the technology grew in chemistry and surface chemistry and especially in liquid separations, solvent extraction, ion exchange, and so on, it became very important. People used to make a bulk REO, rare earth oxide. Usually, rare-earth oxide is 1 percent or more. I'll come back to that again, but anything about more than 1 percent, 2 percent, up to 10 percent, was being mined and processed, and they made 50 percent recovery or something. The last product was nearly 90 percent rare-earth oxide. Then, it went into making one or two or three elements.

So, the demand for rare earth, initially, was very limited because they hadn't isolated the pure elements, and they were not totally able to capitalize on the good qualities of those elements. So, the rare earth industry was limited. China took the dominant factor because they had the deposit, they had the labor, they were not, in those days, very concerned about environmental laws, and so on.

09-00:47:36

Burnett: Environmental damage.

09-00:47:40

Bhappu: So, they became a leader. Even today, 96-97 percent of the rare earths comes from China. China is a dominant factor: they can hold the supply, they can let it go. They won't do that intentionally because there will be other restrictions and other constraints.

09-00:48:00

Burnett: Right, trade retaliation.

09-00:48:05

Bhappu: Yes, retaliations. They're miners, too, everybody. So, they allow people to tolerate them, you might say, as long as they don't out-produce them. So, what was the United States' role? Up to 1950, these people, the authors call it the Dark Age of rare earths. People didn't know much about it, although some of these elements were isolated by scientists, especially in Europe and America. They had good properties, but it was the "Dark Ages." From 1950 to 1980s, '70s and '80s, it became an "Enlightenment Age." People began to appreciate that. People like Molycorp and others began producing because we had known the resource, but we didn't have the big resource, a big, high-grade ore so we could make an economical recovery. We picked up maybe two or three elements that were of most interest. Like, thorium, monazite has thorium and bastnäsite has the cerium group of metals, so we capitalize only on those higher-grade materials in the rare earths. It was a limited opportunity. Many of the IBM and all those began to come on in because they say, "Well, we need this element." We couldn't supply it, so they went to, of course, China. So, there was a lot of importation. But those metals were now isolated and separated in the United States.

Now, Molycorp came into existence because I told you that in 1946, that discovery was made. I came to the United States in '48, I was at the Colorado School of Mines Research Institute, and I was working there part-time and later on full time. The first samples we began to get from Molycorp were rare earth.

09-00:50:36

Burnett: At that time, at the very beginning?



09-00:50:39  
Bhappu:

Yes. We were very intrigued—what is this rare earth? So, we had to really start. We knew that in order to make industrial use of the rare earth, we had to make it into a very high-grade, clean, pure product. So, in those days, all we did is make as pure, as high grade of rare earth oxide as possible. The rare earth oxide was a 4-5 percent, whatever we were given, and we made gravity separation, magnetic separation. We looked to see what the physical and chemical properties were. We found out that these are fluorocarbonates, that bastnäsite is the mineral that we wanted to recover. Even today, of all the rare-earth operations, the mineral component used to be monazite, which was readily available as a beach sand and things, then came bastnäsite, and then came xenotime.

Those were the major minerals, and we found out that physical separation, although it could be applicable, there weren't enough differences in the physical property. All the monazite is magnetic, so magnetic separation became a big thing. Wherever there is monazite sand, they call it the black sand. There is always a little magnetite and a little titanium, columbium [niobium] and all that. That's where the rare metals came in. They didn't call it rare earth because you could isolate them; they were rare because they didn't have too many deposits of that. Anyway, so the Molycorp bastnäsite had its own unique properties. We had to go talk to people like Gaudin and others to see how it's a fluorocarbonate. It's like calcite's a carbonate, but yeah, we can float the calcite, we can float zinc carbonate, we can make a flotation product out of it, but bastnäsite was a different beast. It wasn't a metallic component like copper, iron, zinc, lead. It was a disseminated material in the carbonate. But we knew we could float calcite, calcium carbonate. We knew we could float phosphate, as was done in the Florida phosphate industry. So, we tried what we call non-metallic flotation.

This is where we knew that the phosphates were floating. Bastnäsite is a fluoro material, but some of the others are phosphate-oriented. We have calcium fluoride, we can float that as a calcium fluoride—but in a small component of the fluoride in a carbonate matrix, it was difficult. So, we knew some of the ideas, we talked about it to the university, we exchanged ideas, and we finally came up with a flotation option. But it took six different steps to depress one mineral after another.

09-00:54:37  
Burnett:

Right. When you say it's disseminated, it's distributed through a complex mineral?

09-00:54:40  
Bhappu:

Distributed in a matrix, yeah. So, we have to grind it very fine, and we had to first take one part of the material, get it off, and it took a series of depressants, activators, and chemicals that influence the surface chemistry. So, we went

through, and we also found that heat was very critical. So, between reagent selection, good depressants were limestone and silica and aluminum. Those were the extraneous gangue material. So, finally, we were able to float bastnäsite, after going through treatment.

09-00:55:38

Burnett: At least six steps.

09-00:055:40

Bhappu: Making associated gangue material non-floatable, so we had to go through that series of steps, and we made a concentrate. People were happy.

09-00:55:54

Burnett: This was when?

09-00:55:58

Bhappu: Nineteen-fifty-two, '53.

09-00:56:01

Burnett: Okay, so this is three years, four years after they discovered it?

09-00:56:05

Bhappu: This was experimental. We knew that gravity didn't work. We knew that in order to make a separation, we had to go to flotation. We knew how to float the carbonates and the fluorides as pure minerals, but we had so many impurities, we had to make those impurity minerals non-floatable by coating them, by putting new surfaces on them. So, it was a series of cut and try, and finally, we came up with the flow sheet. Then, of course, we ran a pilot plant, a little pilot plant. This was around, let's see, I had already come to Miami, so it was during the early years, and then when I was at New Mexico Tech. I was a consultant to them, and so we continued that research afterwards. The plant didn't start operation till about the seventies because there were a couple of things that were bothering them. The first was it was a mine, there was no environmental loss, but it had a certain amount of radioactivity, and they were very concerned about that. Molycorp came much later. It was Chevron and other companies, who started the previous operation. But Molycorp came in later, so we call it a Mountain Pass ore because it was originally not Molycorp. Molycorp came much later, and so, the mine was operating. When they reached a mining level and new laws came in, in '70, they stopped the mining operation.

09-00:58:16

Burnett: In 1970?

09-00:58:17

Bhappu: Seventies, to say, "Are we doing the right thing?" They stopped for a while. Then, they again, Molycorp bought them.

09-00:58:31

Bhappu:

Molycorp, for last ten years, before last year, say from eighties, nineties, they were not operating. They were only working with the stockpiled material. No active mining was considered.

09-00:58:48

Burnett:

Oh, so, in the eighties and nineties, it was a processing operation, for existing ore that had been mined?

09-00:58:51

Bhappu:

A processing operation, to make one or two products. That was what they were interested in, and to supply to the world market, and especially the US market. So, the operation was limited, but the directors and the operators of Molycorp quickly realized that they were not going to be competitive. They can't be competitive, just making a rare earth oxide and then selling it to General Electric or somebody. They had to make individual products. It wasn't till late, about 2000, when we started making the separation of different elements that make up the rare earth oxide.

09-01:00:02

Burnett:

Should we perhaps change the tape, and then we can continue and pick this up?

09-01:00:05

Bhappu:

Why don't we do that, yes, so I can get the other things ready?

09-01:00:09

Burnett:

Perfect.

## Audio File 10

10-00:00:00

Burnett:

This is Paul Burnett, interviewing Dr. Roshan Bhappu, for the Mining Project. This is session five, tape ten, March 7, 2014. So, Dr. Bhappu, you were talking about the history of Molycorp, and the problems that they had. By the late nineties, they were no longer doing mining *per se*, they were just processing the ore that they had for one or two rare earth elements that were in demand.

10-00:00:40

Bhappu:

Stockpiled ore.

10-00:00:44

Burnett:

For the rest of it, it was not cost-effective.

## Roshan Boman Bhappu

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### ACADEMIC QUALIFICATIONS

#### College:

University of Bombay, Bombay, India; Up to B.S., 1943-47, Chemistry-Geology  
 Colorado School of Mines, Golden, Colorado;  
 Metallurgical Engineer (Met.E.), 1950,  
 Metallurgical Engineering; M.S., 1951,  
 Metallurgical Engineering; D.Sc., 1953, Metallurgy-Mining

#### Others:

Mass. Institute of Technology, Cambridge, Mass.; Special Graduate Student, 1950-51,  
 Mineral Engineering

International Correspondence School, Scranton, Pa., Diploma, 1957-58, Business  
 Administration

### PROGRESSION IN CAREER

1951-1953	Teaching Assistant, Colorado School of Mines, Golden, Colorado
1953-1955	Project Engineer, Colorado School of Mines; Research Foundation, Inc, Golden, Colorado
1955-1959	Resident Metallurgist, Miami Copper Company, Miami, Arizona
1959-1968	Senior Metallurgist, State Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology
1959-1972	Research Professor, New Mexico Institute of Mining and Technology
1968-1972	Vice President for Research, New Mexico Tech Reserve Foundation
1969-1970	UNESCO Expert - Updating of department of Mining Engineering, Middle East Technical University, Ankara, Turkey, on Sabbatical Leave
1970-1972	Chairman, Department of Metallurgical and Materials Engineering
1970-1972	Director In Situ Mining Research Center, New Mexico Institute of Mining and Technology
1972-1981	Vice President, Mountain States Research & Development
1972-1987	Director, Mountain States Mineral Enterprises, Inc.
1981-1983	Vice President, Mountain States Mineral Enterprises, Inc., Marketing and Sales Department, and Corporate Director of Research & Development
1983-1987	Sr. Vice President - Technology, Mountain States Mineral Enterprises, Inc.

1987- Founder and President, Mountain States R & D International, Inc. (MSRDI)

### **MANAGERIAL LEVEL OF RESPONSIBILITY**

1957-1959 Chief Metallurgist, Miami Copper Company, Miami, Arizona

1964-1972 Vice President for Research, New Mexico Tech Research Foundation

1969-1970 UNESCO Expert – Updating Department of Mining Engineering. Middle East Technical University, Ankara, Turkey on Sabbatical Leave

1970-1972 Chairman, Department of Metallurgical and Materials Engineering, New Mexico Institute of Mining and Technology

1972-1981 Founder and Vice President of Mountain State Research and Development

1972-1987 Corporate Director, Mountain States Mineral Enterprise, Inc.

1981-1983 Vice President, Mountain States Mineral Enterprise, Inc. Marketing and Sales Department

1983-1987 Senior Vice President – Technology, Mountain States Mineral Enterprise, Inc.

1987- Founder and President of Mountain States R & D International, Inc. (MSRDI)

### **FIELDS OF SPECIALIZATION IN MINERAL PROCESSING AND METALLURGY**

- Energy and Cost Saving Technologies.
- Preconcentration of Minerals (Savings in Energy / Cost) by Heavy-Media-Separation (HMS)
- In-situ Extraction of Metals (Solution/Chemical Mining)
- Bio-extraction of copper and gold.
- Bio-Remediation of Underground Waters (Environmentally Friendly Technology)
- Scientific Extraction of Gemstones (rather than hand picking) Diamonds, Rubies Emeralds, Etc.

### **MEMBERSHIP**

AIME, ASM, ACS, AAAS, Sigma Xi, CSMAA, NMMA, MRMSA, MMSA  
Foreign Affairs Committee

### **PROFESSIONAL ENGINEER**

Arizona Registration No. 4144 - Metallurgical Engineer

## PROFESSIONAL ACHIEVEMENTS

Elected: Fellow of the Society of Sigma Xi  
 Listed: American Men of Science  
 Leaders in American Science

### APPOINTMENTS:

- Special Consultant to the United Nations for Organizing Mining and Metallurgical Educational and Training Seminars:
  - UN Interregional Seminar on Ore Concentration in Water-short Areas, February 14-25, 1966
  - UN Working Committee: Exploitation of Low-grade Ore Deposit, April 3-7, 1972
  - UN Interregional Seminar on Hydrometallurgy, 1973
  - UN Seminar on Small Scale Mining, 1980
- Representative from New Mexico to the Federation of Rocky Mountain States, 1970-1972
- Director of Metallurgical Research for National Science Foundation Programs at NMIMT, 1960-1972
- Director, National Science Foundation USA/Mexico Workshop on Non-ferrous Metallurgy, 1983
- Editor of SME; Minerals and Metallurgical Processing, Quarterly Magazine 1980-2005

### AMERICAN INSTITUTE OF MINING METALLURGICAL & PETROLEUM ENGINEERS AND SOCIETY OF MINING ENGINEERS:

- Chairman, Central N.M. Section AIME, 1965
- Senior Delegate, Central N.M. Section AIME, 1966
- Senior Representative, CSD, Southwest Region, 1967
- Chairman, Chemical Processing Committee, MBD, 1967
- Chairman, Hydrometallurgical Committee, EMD, 1968
- Chairman, All-Institute Waste Disposal Committee, 1968
- Chairman, Council of Section Delegates, 1968
- Secretary/Treasurer, MBD, 1970-1972
- Chairman, Mineral Processing Division of AIME, 1978
- Director, SME/AIME, 1979-1981
- Member, Member Program Committee of the American Mining Congress, 1980-1982
- Member, Oil Institute Program Committee of AIME, 1982-1983
- Member, Public Affairs Council AAAS, 1982
- Member, Working Party #62, 1982
- Review of Technology Coverage of SME/AIME, 1982
- Chairman, Publications Committee SME/AIME, 1982
- Member, All-Institute Program Committee, 1983
- Chairman, SME Book Publication Committee, 1983
- Chairman, All-Institute Program Committee, 1984
- Chairman, Robert H. Richards Award Committee, 1984
- Member, International Advisory Committee, 1985-present

- Member, SME Gem Committee, 1986-present
- Editor, Minerals & Metallurgical Processing, SME, 1986-present
- President - SME: First Asian President (20,000 Members)
- President AIME First Asian President (200,000 Members)
- President – Mining Foundation of the Southwest, 2005

## RECOGNITION BY PEERS IN THE PROFESSION WORLDWIDE

Worldwide Consultant to United Nations and World Bank (1960 to Present)

Assignments to:

- **Turkey**--Middle East Technical University (1968-1970)
- **Ankara, Turkey**--Updating Mining and Metallurgy Departments
- **Albania**--Evaluation of Mineral Industry in Albania for World Bank
- **Pakistan/Afghanistan**--Workshops for Gemstone Mining – UNDP (1985-1990)
- **Pakistan**--Saindak Copper Project – Baluchistan, for UNDP, 1984
- **Pakistan** Dudar Lead – Zinc Project, Baluchistan, for UNDP, 1993
- **India**--Consultant to Hindustan Copper and Hindustan Zinc Co. (1978-1980)
- **India**--Kolar Gold Mines, for UNDP
- MSRDI Projects for Clients Worldwide (about 40 countries)
 

Australia	Brazil	Columbia
Papua New Guinea	Philippines	Cyprus
China	Cameroon	Turkey
Peru	Chile	Mexico
Bolivia	Namibia	Japan

## AWARDS:

- Van deist Gold Medal for Outstanding Achievement Colorado School of Mines 1968
- Distinguished Member of SME, AIME, 1980
- The Robert H. Richards Award of AIME, 1984
 

*“In recognition of his International Accomplishments in the field of Mineral Processing and for his tireless efforts in applying research and development to education and engineering for the benefit of the entire minerals industry.”*
- Honorary Member of the American Institute of Mining Metallurgical, and Petroleum Engineers, 2006.
 

*“For more than 50 years of dedication and outstanding service to the international mining industry, including academic research and operation.”*

**Note:** This honor reserved for no more than 100 living engineers worldwide.
- Medal of Merit, American Mining Hall of Fame, 2006
 

*“For Innovative Metallurgy”*
- Outstanding Zarathusti Professional of the Year, 2008
- The Gold Medal Award, Mining Metallurgical Society of America, 2010

**PUBLICATIONS AND PAPERS\****Thesis:*

1. M.S. "Treatment of Chromite Ore from Pakistan", Colorado School of Mines, 1950.

*Thesis:*

2. D.Sc. "Effect of Fine Particle Sizes on Sulfide Flotation", Colorado School of Mines, 1953.
3. "Effect of Fine Particle Size in Sulfide Flotation", Quarterly of the Colorado School of Mines, vol. 50, No. 2, April 1955.
4. "Ions and Electrons - Keys to Metal and Mineral Processing", New Mexico Institute of Mining and Technology, December 1959.
5. "Use of Microorganisms in Recovery of Metals", New Mexico Academy of Science Meeting, Socorro, New Mexico, April 8, 1960.
6. "Application of Flotation to Nonmetallurgical Fields", American Association for the Advancement of Science Meeting, Alpine, Texas, May 4, 1960.
7. "Metals in Antiquity", New Mexico Archaeological Society Meeting, Socorro, New Mexico, June 28, 1960.
8. "Have Flotation - Will Separate!", Mines Magazine, February 1961.
9. "Economic Recovery of Selenium from Sandstone Ores of New Mexico", Circular No. 58, New Mexico Bureau of Mines and Mineral Resources, March 1961.
10. "Froth Flotation of Ion-Exchange Resins and Its Application", Technical Sessions, Commemoration of the 50th Anniversary of Froth Flotation in the U.S.A., Denver, Colorado, September 18, 1961.
11. "Economic Recovery of Selenium from Sandstone Ores", Annual Meeting of the AIME, New York, February 1962.
12. "Studies on Hypochlorite Leaching of Molybdenite", Circular No. 66, New Mexico Bureau of Mines and Mineral Resources, February 1963.
13. "Sulfonate Flotation of Beryl", (coauthor M. C. Fuerstenau), Am. Inst. Min. Eng., Soc. Min. Eng. Trans., Vol. 226, p. 164-174.
14. "The Role of Hydrolysis in Sulfonate Flotation of Quartz", (coauthor M. C. Fuerstenau), Am. Inst. Min. Eng., Soc. Min. Eng. Trans., Vol. 226, p. 449-454.
15. "Recovery of Valuable Minerals from Pegmatitic Ores", (coauthor M. C. Fuerstenau), Circular No. 70, New Mexico Bureau of Mines and Mineral Resources, February 1984.
16. "Hydrometallurgical Recovery of Molybdenum from the Questa Mines",



(coauthors D. H. Reynolds, R. J. Roman, and D. A. Schwab), Circular 81, New Mexico Bureau of Mines and Mineral Resources, 1965.

17. "Design of an Apparatus for Determining Isoelectric Point of Charge", (coauthor R. A. Deju), Circular 79, New Mexico Bureau of Mines and Mineral Resources, 1965.
18. "Surface Properties of Silicate Minerals", (coauthor R. A. Deju), Circular 82, New Mexico Bureau of Mines and Mineral Resources, 1965.
19. "Studies on the Hydrometallurgical Recovery of Molybdenum from the Questa Mine", Research in Chemical and Extraction Metallurgy Symposium, University of New South Wales, Sydney, Australia, February 1965.
20. "Molybdenum Recovery from Sulfide and Oxide Ores", (coauthors D. H. Reynolds and R. J. Roman), Journal of Metals, November 1965.
21. "Manganese Dioxide - Sulfuric Acid Oxidation of Molybdenite", (coauthors Ronald J. Roman and Dexter H. Reynolds), Trans., Met. Soc., AIME, Vol. 233, December 1965.
22. "Winning Metallic Values from Leach Solutions by Sorption Process", (coauthors Dexter H. Reynolds and W. V. Long), Trans. Soc. Min. Eng. AIME, Vol. 235, December 1966.
23. "Differential Disintegration", lecture presented at the United Nations, Inter-regional Seminar on Ore Concentration in Water-short Areas, New York, February 1966.
24. "Concentration Methods Using Limited Water and Saline Water", lecture presented at the United Nations Inter-regional Seminar on Ore Concentration in Water-short Areas, New York, February 1966.
25. "A Chemical Interpretation of Surface Phenomenon in Silicate Minerals", (coauthor R. A. Deju), Circular 89, New Mexico Bureau of Mines and Mineral Resources, 1966.
26. "Selective Separation of Molybdenum, Tungsten, and Rhenium by Sorption Processes", (coauthor D. H. Reynolds and J. Y. Lee), presented at the Second Annual Operating Conference of Met. Soc., AIME, Philadelphia, Pa., December 1966.
27. "A Correlation Between Surface Phenomenon and Flotation in Silicates", (coauthor R. A. Deju), Circular 90, New Mexico Bureau of Mines and Mineral Resources, 1967. Paper presented at the Annual Meeting of AIME, Los Angeles, February 1967.
28. "Chemical Mining - Theoretical and Practical Aspects", (coauthor P. Johnson), paper presented at the Fall Meeting, SME-AIME, Las Vegas, Nevada, September

1967.

29. "The Challenge of the Century", paper presented at the Annual Meeting of the Colorado Plateau Section AIME, Grand Junction, Colorado, December 1967.
30. "Theoretical and Practical Studies on Dump Leaching", (coauthors P. H. Johnson, J. A. Brierly, and D. H. Reynolds), paper presented at the Fall Meeting of AIME, September 1968, Minneapolis, Minnesota. Published in AIME Transactions, 1969.
31. "Chemical Mining - A Study of Leaching Agents", (coauthor P. H. Johnson), paper presented at the Annual Meeting of AIME, February 1969, Washington, D.C. and published at NMBM&MR Circular 99.
32. "A Kinetic Study of the Mechanism of Flow Through Porous Media", (coauthor R. A. Deju), paper presented at the 1969 Annual Meeting of AIME, Washington, D.C., February 1969.
33. "Contributions to the Study of the Calcite-Sodium Oleate System", (coauthor S. Escalera), paper submitted to the 10th Latin American Conference on Applied Chemistry, San Jose, Costa Rica, February 2-9, 1969.
34. "Microbiological Mining", a Research Colloquium presented at Sandia Laboratories, Albuquerque, New Mexico on May 21, 1969.
35. "Selective Flotation of Molybdenite from Chalcopyrite Concentrates by Potassium Permanganate", (coauthor S. Escalera), paper presented at the Annual Meeting of AIME, February 1970, Denver, Colorado and published at NMBM&MR Circular 106.
36. "Evaluation of Ground Mica Products from New Mexico Pegmatites", (coauthor W. E. Horst), NMBM&MR Circular 105, 1970.
37. "A Study of the Leaching Chemistry of an Impermeable Chino Dump", (coauthor P. H. Johnson), paper presented at the Annual Meeting of AIME, Denver, Colorado, February 1970.
38. "Relationship of Chemical Reactions Between Water and a Silicated Bed to the Flow Equation", (coauthor R. A. Deju), SME, AIME, Transactions, vol. 247, p. 115, June 1970.
39. "The Role of the Carbon Chain in the Surface Reactions in the Water-Sulfonate-Olivine System", (coauthor R. A. Deju), paper at the Annual Meeting of AIME, New York, N.Y., March 1971.
40. "Screening and Optimization of Hydrocarbon Oils for Molybdenite Flotation", (coauthor J. H. Smith), paper presented at the 1971 AIME Southwest Minerals Conference, Reno, Nevada, May 7, 1971.

41. "Computer Simulation of Fluid Flow in a Leach Dump", (coauthors R. Jacobson, C. McKee, and R. Roman), paper presented at the 1972 Annual Meeting of AIME, San Francisco, California, February 1972.
42. "Environmental Problems Associated with Mineral Processing" (coauthor Don H. Baker Jr.), paper presented at the 1972 Annual Meeting of AIME, San Francisco, California, February 1972.
43. "Optimization of Dump Leaching" (coauthors R. Jacobson, C. McKee, and R. Roman), paper presented at the Joint Meeting of AIME-MMIJ, Tokyo, Japan, May 24-28, 1972.
44. "Selective Flotation of Molybdenite from Copper Concentrates", (coauthor P. Valles), paper presented at the Joint Meeting of AIME-MMIJ, Tokyo, Japan, May 24-28, 1972.
45. "Studies on Selective Flotation of Molybdenum from Copper Concentrates", (coauthor P. Valles), paper presented at the Joint Meeting of AIME-MMIJ, Tokyo, Japan, May 24-28, 1972.
46. "Leaching of Low Grade Gold Ores - Economic Evaluation of Available Processes" (coauthors F. M. Lewis and J. A. McAllister), paper presented at the AIME Annual Meeting, Dallas, Texas, February 1974.
47. "Special Environmental Problems Associated with Mineral Processing" (coauthor Don H. Baker), paper presented at the AIME Annual Meeting, San Francisco, California, February 1974.
48. "Concentration of Magnesite Ore from Avsanli District - Western Turkey", (coauthor Z. Dogan), SME, AIME Transactions, Vol., 256, p. 174-178, June 1974.
49. "Gold Extraction from Low Grade Ores - Economic Evaluation of Processes" (coauthor F. M. Lewis), American Mining Congress, Las Vegas, Nevada, September 1974. Mining Congress Journal, p. 30-43, January 1975.
50. "Economic Evaluation of Available Processes for In Situ Extraction of Uranium", (coauthors F. M. Lewis and C. K. Chase), presented at the AIME Annual Meeting, Atlanta, Georgia, February 1975.
51. Technical Lecture Notes: "Economic Evaluation of In Place Leaching of Solution Mining Situations", Annual Conference of Understanding of Mining Industry, McKay School of Mines, Reno, Nevada, May 1975.
52. "Physiochemical Study of the Plagioclase-Solution Intrafaces Encountered in Flotation Systems", (coauthor S. Escalera), Technical Paper, New Mexico Bureau of Mines, Socorro, New Mexico, June 1975.
53. "Technical and Economic Evaluation of Copper Scrap Processing" (coauthor C. K.

Chase), Second International Conference on Environmental Problems of the Extractive Industries, Columbus, Ohio, June 1975.

54. "Evaluating Mining Ventures Via Feasibility Studies", (coauthor F. M. Lewis), Mining Engineering, October 1975.
55. "Analysis of Submerged Vat Leaching Versus Trickle Leaching", (coauthors J. Coburn, J. Keane, C. K. Chase), paper presented at the SME-AIME Fall Meeting, Salt Lake City, Utah, September, 1975.
56. "Economic Evaluation of In Situ Extraction for Copper, Gold & Uranium", (coauthors F. M. Lewis and C. K. Chase), SME-AIME Fall Meeting, Denver, Colorado, 1976.
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## PATENTS

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10-00:00:47

Bhappu:

Right. So, let me just make it clear that the Mountain Pass Mine is the mine. Of course, Molycorp owns that now, but it wasn't so. There were other operators before that. The last operation was conducted by Chevron Oil Company because part of the railroads were used in the oil piping and so on. So, Chevron was the last when the mine was partly closed for environment. Molycorp came very recently.

10-00:01:33

Burnett:

Well, there's a predecessor as in the Molybdenum Corporation, which ran it for decades, and then it fell into a bunch of hands.

10-00:01:43

Bhappu:

Yeah, Climax owns it.

10-00:01:46

Burnett:

They had shut it down because of leaks, in the 1990s.

10-00:01:51

Bhappu:

That's what it said, yeah. There was a leak in the tailings line, and so it was an environmental concern that closed down for the predecessors. Molycorp quickly was interested in molybdenum. They had a mine, a first mine, in New Mexico, near Questa. I got involved with them because they wanted to mine it. I went underground—it was an underground operation—near the Taos area, Red River. It was a very high-grade mine, and so they were able to have the 100-ton-a-day operation. But the mined ore was 3 percent, 5 percent, 10 percent, so it was no problem recovering molybdenum. So, Molycorp became very rich in exploiting molybdenum mines. Then, later on, they found out that they had much more lower-grade ore, and they had to go into open-pit mining. That's when I joined New Mexico School of Mines. My first project was Molycorp. Not because of molybdenum, but because they already had a mine, and now they were making it into a larger mine. So, the ore became less and less, and from 10 percent to 1 percent to 0.2 percent, it's amazing that it became a 10,000 ton a day operation.

So, I didn't get involved in the mining operation, but we set up a pilot plant in testing program at the New Mexico Bureau of Mines. This is where New Mexico Bureau of Mines' contribution came in. We had student help, so they could get acquainted. We ran the pilot plant, and actually put up a small plant at the mine site. So, I got to Molycorp; it wasn't Molycorp that I worked with when I was at Socorro, it was the Mountain Pass ore, and their previous owners. So, it wasn't till I came to Socorro and New Mexico Tech that I started being a consultant and working with the Molycorp. This is their molybdenum operation.

10-00:04:29

Burnett:

Right, in New Mexico?



10-00:04:30

Bhappu: In New Mexico, right. I just want to be clear.

10-00:04:32

Burnett: Sure. That's the sixties and seventies.

10-00:04:33

Bhappu: When I got involved with that, it is, of course, my first—not with Molycorp, but with Mountain Pass ore. Rare earth, just to show you, attached is a periodic table. The rare earths are elements in this area. See, they are so close together, and from element 57 to 71, is one series. The second is from 89 to 103. Total of eight in the heavies and eight in the light rare earths. This is the column enlarged, with each individual. That was the problem: they knew some of these values of each of the elements, but they didn't have enough information. As you can see, they occur as a class. It doesn't occur here like a silica and molybdenum, or fluoride. So, it was very difficult to understand the chemistry.

10-00:05:55

Burnett: Because of their similar character?

10-00:05:57

Bhappu: Similar characteristics. The Bechtel Institute was a very prominent research organization. A lot of work was done at MIT and others because it became, you might say, a challenge to the industry to make separate elements. Now, I didn't get involved in the isolation of different elements. I was most concerned with taking the mine ore and making it into a concentrate, and throwing away 90 percent of the waste, and making about a 50-60 percent grade product, which had all the elements together. All the heavies, the light, then they were roasted and they were leached, and each of the elements was extracted. It took years and years and years.

So, when Molycorp took over the project several years ago—not too long ago—they made the decision that we are not going to sell a concentrate, that our profitability depends on isolating each of the elements, and then selling that at a very high price. That is why they closed the mine, they didn't want to operate, because Chevron had closed it because of the environmental damage. They had a leak in the plant, so they had to stop, but they had a lot of stockpiled ore. So, Molycorp, when they took over, they knew that there was sufficient ore for maybe five years, seven years, so they could start the milling operation and try to make one or two products out of high, rich REO. In the meantime, they started looking at how to isolate elements. They accumulated a lot of knowledge and they had very high quality engineers. Many of their ideas were taken from universities, from the Bhabha Institute in India, which was a leader in the processing of monazite, and so on. So, it was an effort, an international effort, and finally the flow sheet was conceived. Then, they had to raise about \$1 billion.

10-00:08:31

Burnett:

The money. Just to be clear, it's kind of obvious but let's be explicit, this is an enormously expensive type of processing. It's ten times as expensive as other ore, copper, or other kinds of separation.

10-00:08:51

Bhappu:

There's too much chemistry involved. Flotation, if it's just mine and float, it's not a problem. That's why people made good money on those days because they would sell the concentrate, but knowing that they had competition from China, Australia, who also had the rare earth resources, and *they* started isolating. So, suddenly, they faced a point that it's not use making a bulk or rare earth concentrate, but make it into about eight different products.

10-00:09:30

Burnett:

Right, a finished product.

10-00:09:34

Bhappu:

Finished product. They are still doing it, and they are finding out new and new usefulness for that. So, this is where Molycorp is making its name. As I said, I got very close to it because of my son, Ross. Ross went to University of Arizona, got his master's in engineering, then he went to Colorado School of Mines. He decided than rather just becoming a metallurgist, he wanted to become an economic metallurgist, or take a course in economics, called mineral economics degree. So, he took a Ph.D. Colorado School doesn't give Ph.D.; it gives DSc.

10-00:10:27

Burnett:

Doctor of science.

10-00:10:28

Bhappu:

Doctor of Science. So, he followed, got his doctor of science. He worked for Newmont, and then he started his own business, working near Casa Grande in Arizona, with an Australian company. This is very interesting—that mine was ready to go, and it didn't get a permit because the environmentalists said, "We have an owl, a hooting owl, that is very rare." It's an owl—bird—and "We are going to make a survey." They are going to start mining and all, and they said, "If we see more than fifty pygmy owls, we'll stop the project." So, they had a whole team looking for owls. After months of research, they come out with a forty-nine count. They let one more hooting owl or pygmy owl, which are supposed to be rare. They said, "Well, now you're going to start getting a permit." But then, one of the ladies working for EPA came running and said, "Oh, I have the fiftieth hoot owl, pygmy owl." He said, "Where did you see it? Did you take a photograph?" "No, I just heard the hoot." That stopped the project. This is a real life story; it's not made up.

10-00:12:22

Burnett:

These stories circulate in the mining community?

10-00:12:29

Bhappu:

That's right. Rosemont is trying to do everything it can to get a permit, but then a scientist or biologist from the university will come, "Oh, I saw this lizard, and it's a dying species, we can't afford to"—

10-00:12:47

Burnett:

Disturb the habitat.

10-00:12:51

Bhappu:

The Indian communities around Tucson came in, "Oh, it's going to affect our water." Anyway, coming back to Molycorp, Molycorp started their operation, and they found out that in order to be competitive, they will have to make individual elements. Now, where are these individual elements going? I made a little list, here. This is the Molycorp brochure, and they list consumer electronics as one of the big users. National defense is the other big thing. Clean water, because now they are making a certain element, they are making into a mesh, which acts as the ion exchanger. It cleans up the water. Hybrid and electrical vehicles, the batteries, and clean energy. That's where I said lighter, but stronger. One of the big things they are making right now is magnets. As you know, the magnets get bigger and bigger. However, with the addition of niobium and other elements, you can make a small magnet that's able to lift or attract a large metal or iron.

10-00:14:20

Burnett:

Metal objects, right.

10-00:14:22

Bhappu:

So, the magnets became more powerful.

10-00:14:26

Burnett:

Those are being used in things like wind turbines?

10-00:14:28

Bhappu:

Those are being used currently. My research shows that glass industry polishing is 34 percent. Petroleum refining – that's why petroleum companies are interested – sixteen percent. Automotive catalysts: 15 percent. Alloys: 14 percent. TV, radio, and lights, et cetera, 9 percent. Permanent magnets, 8 percent. Other uses, 4 percent.

10-00:15:04

Burnett:

So, those are the percentages of the consumers of the Molycorp products?

10-00:15:06

Bhappu:

Of usefulness, of Molycorp, yeah. Or any products, any producer, right. Defense is, of course, a big thing, and so it comes under a critical element. This is why being a defense alloy and all that, and electronics, it was quite obvious that the Committee on Critical Elements and Metals take a personal interest to make sure that there is enough stockpiling of rare earth, considering that majority of the rare earth resource is going to come from China.

10-00:15:55

Burnett:

In March 2013, as well, the Department of Defense was authorized to purchase \$130 million of rare earths to create a rare-earth stockpile—which is a drop in the bucket, but still, it's significant.

10-00:16:13

Bhappu:

Well, that is our addition to the critical materials. I know that mining companies have not a very good platform in the government. However, you used to have the Bureau of Mines, but that agency's not available, so it's the Mining Congress, the AIME, SME. Now, we cannot interfere as a professional society, but we can give our opinion in lectures. We go down and try to impress our senators and our government leaders that this is a necessity, and you have to put the rare earth into a class by itself because it is a very precious commodity, it's a very defense-oriented commodity. If you take away all the cell phones in the world, what's going to happen? It's an essential element.

10-00:17:20

Burnett:

It's an essential, foundational set of elements for modernity.

10-00:17:28

Bhappu:

We, as mining professionals, we can't lobby. But we can give talks on it and explain the effectiveness of, you might say, the good qualities, and why they should allow this mining operation to go on. I was coming to say that our son, Ross, joined a group called Capital Finance, and they thought that raising the necessary capital for Mountain Pass would be critical. It's an independent agency, and Molycorp was funded. They went to the stock market and raised quite a few hundred million dollars in the first offering.

10-00:18:24

Burnett:

When was that? Was that 2010?

10-00:18:26

Bhappu:

Yeah, three years ago.

10-00:18:28

Burnett:

Since then, this is all that people are talking about, in the mining community and elsewhere.

10-00:18:32

Bhappu:

That's right. Suddenly, the stock went up, and it was not because he wanted to raise the stock. He thought it was essential to make different elements from the total rare earth oxide, concentrate on a few high quality ones that can go to the market readily. All the economics was based on making individual rare earth elements. They were successful and they elected him chairman of the board. Not because he was a Moly man or anything; his job was to make sure that all that money went into, in the last three years, to start the operation. So,

he was supervising the mining, the milling, the refineries, and all that, to make sure that they met the target. Two months ago, he resigned.

10-00:19:36

Burnett: He's done.

10-00:19:37

Bhappu: Day to day operation is not, but the problem is, is that once he became a chairman, I started getting samples from not only the United States, but from all over the world. "I got a rare earth—look at it!"

10-00:19:54

Burnett: These are start-ups and they don't have experience with this stuff.

10-00:19:58

Bhappu: People from Chile and Mexico and Brazil, especially. If you look at the countries of the world that have rare earths—China, actually the United States has more resources than China. They have only four mines but prospects in the United States may have twenty or thirty potential sites. Sites in Wyoming, the Rare Elements Resources, Bear Lodge.

10-00:20:43

Burnett: Bear Lodge, Wyoming, and Bokan, Alaska?

10-00:20:47

Bhappu: What was the last one? There were three of them.

10-00:20:53

Burnett: Well, there's Bear Lodge, Bokan, Alaska, and there's one in Illinois, I think.

10-00:20:57

Bhappu: Yeah, but those are smaller. Now, Molycorp has a big facility. Not in Denver, where their base is, near Pittsburgh. They have a big facility where they used to make molybdenum metals, so that was expanded into a research lab. So, why is rare earth important? Because it has very good applications. It's an essential element, and it has good potential. If anybody comes up with a good resource, people will invest in it. But what happened is every Tom, Dick, and Harry started going into the market, raising \$5 million and \$10 million, and finding out 0.1 percent, we got samples that had only 100 parts per 1,000,000.

10-00:21:46

Burnett: There's nothing.

10-00:21:54

Bhappu: They say, "Well, look at your copper industry, you have only 0.1 or 0.3 copper." But there you are treating 100,000 tons. That's what you need to do. You should be able to isolate that in less than 1 percent or 2 percent weight, and then treat 50,000, 100,000 tons. One of the things that we started doing research on is how can we understand what method we should use? So, we

started getting photographs and mineralogical data on— I can't mention that, but a good mining prospect. We found out that under high magnification that the bastnäsite, or the values of REO, were like whiskers on top of the rock. If you scrub that, you'll get 80 percent of it. So, just putting it into a tumbler and separating the fines from the coarse, we are able to separate it. Of course, that raised the stock. They said, "Well, that's innovation." It's elementary, but mineralogy, the character of the mineral, character of the metal you are working with, character of bastnäsite or monazite is very critical. Monazite occurs in the beach sands, so it's already concentrated. It's a heavy mineral. But bastnäsite and all the other rare earths—there are about 100 of them.

10-00:23:35

Burnett:

A hundred mineral compounds that contain rare earths.

10-00:23:36

Bhappu:

Mineral compounds that have been identified. Of them, five or six are the critical ones. As I mentioned, xenotime is a great thing. Bastnäsite is another one, and monazite. So, the whole chemistry that we know of and that is described in the book considers these as the main ones. However, today, we have a lot of other research going on, and more and more, I'll just mention one of them. As I mentioned before, we were interested in gemstones. Gemstones includes emeralds, and emerald deposits are noted for carrying a little bit of rare earth. So, big producers of emeralds have contacted us to say, "Look at our tailings. We have been mining handpicked, throwing away the waste. We have hundreds and thousands of tons of waste. See if there is any rare earth." So, we have a little project on that. Today, rare earth is in big demand, but the stock is not as high as it used to be because there's too many uncertainties. Even if you read Molycorp's report, dumping the ore from China or price fluctuations—

10-00:25:20

Burnett:

Is China aware of what's happening, and they are acting on the market to forestall this kind of activity?

10-00:25:27

Bhappu:

Oh, definitely. The Chinese are judicious people. They know that they can't do that. Of course, if it's a last resort, they might do it. But in that economy, to thrive, and getting concessions in other areas, it's a give and take. So, the politicians know what to do. So, I said, "Even our copper ores around here have a little, if you do a scan of ICP scan, there is a little bit of lanthanum, little bit of cerium, and lanthanides. So, Professor Gaudin used to say there's gold everywhere because there's always a little trace of gold found anywhere. The question is, is it of economic—

10-00:26:30

Burnett:

Value.

10-00:26:31  
Bhappu:

—and can you recover it? So, rare earth occurs in many, many deposits, and we are going to find many more in the future. However, it will be a challenge, how to recover them. As long as it follows the trend of the mineralogy of what we are used to, it's no problem. But if another mineral comes in with a little different composition, we may have difficulty, and have to start a research program. That is why Fuerstenau, at the University of California, Berkeley, and his associates, have been very much interested, because Mountain Pass Mine is in California, and he and his student associates have done a tremendous amount of work, knowing the history and the mechanism of flotation for other elements. So, they are going to be very successful, and I'm in contact with them to see how they can help us. Even University of Arizona just started a big program on rare earths because people have said that yes, we have rare earths.

10-00:27:42  
Burnett:

We need to know how to do this.

10-00:27:45  
Bhappu:

Every part of the state will have that. So, the people who get started earlier will have the edge. So I think that the rare earth industry is a newcomer after 1990s and 2000 years, last twenty years, it has become a darling metal because three years ago, two years, the price was \$6,000 a kilo. Now, it's dropped down to \$60.

10-00:28:26  
Burnett:

Sixty dollars?

10-00:28:27  
Bhappu:

A kilo. That's still high, but—

10-00:28:31  
Burnett:

It went from \$6,000 to \$60?

10-00:28:34  
Bhappu:

Because of the stock, because the demand went up, and the Molycorp decided they are going to get into this, and they saw what was happening. So, the price went up and the stock went up, and the stock also came down. So, now it has to stabilize, and that's the history of mining: a new mine gets into operation, everybody starts investing. Today, if you get into the market, my associates and my son were telling me that Toronto has a big convention, once a year, in late February/early March, where 40,000 metal traders talk to each other. It's like a stock market, "Well, you come and invest in me." He says that the junior companies, the \$1 million, \$5 million, \$10 million, they can't raise any funding. The only people who are raising funding are the large companies going into a large mine in South America, or mostly people like Barrick Gold, Newmont, they are bringing in new gold mines. As you know, the gold last

year was around \$1,500 an ounce, \$1,300. It's still about \$1,300. When I worked in the gold project, we were looking at \$35 and \$60 an ounce.

So, things in fifty years have changed, and the metal market changes. The center of mining activities will change. So, mining has become a very good profession, and many of us in developing countries are asking for help from the United Nations and the World Bank and consultants. Today, if you look at it, Canada is one of the forefront, Australia, of course China is always there, Argentina and Brazil are becoming big players. Unless the local government is going to help, nobody's going to give you the money. Peru, two months ago, said, "We are going to invest \$15 billion in two years to encourage people to come." So, that's the mining history.

10-00:31:11

Burnett: So, things have changed.

10-00:31:12

Bhappu: Yes, very much so.

10-00:31:17

Burnett: You had an optimistic talk in '95, but you were addressing concerns about low prices and increased regulation. Something seems to be changing now, with the questions at least around rare earths, suggesting that environmental regulations – while you need to preserve the environment, they're not questioning that – they're saying that we question whether or not all of this environmental regulation and the extent of environmental regulation is completely necessary. That Minerals Policy Act is requesting a review of all of the permitting. Which, I think, is quite a change in the orientation of government towards the mining industry in the United States.

10-00:32:13

Bhappu: Well, government regulation is a must because you don't want polluters to get into that. This is a bad name for the mining, it's bad for the public. So, if it is a legitimate operation, it's a clean operation, it is a proven operation, economically. There are no waste products, and especially as far as research goes, I cannot do research on ores from Brazil because there is a limitation on how much radioactivity I can bring in the United States. Molycorp had a very good project and all, but they wanted me to test it. We were blocked because the sample was at Lakefield, in Canada, and they could not bring the ore here.

10-00:33:07

Burnett: There were laws against importing radioactive material?

10-00:33:09

Bhappu: Yeah, so you have to have a license to import. You have to prove to the government agency that you're a safe operator. Even when we had a neutron-activated neutron analysis, we had to go through so much permitting for one little instrument. So, sometimes we overdo it, and this is my concern. They



said, “Well, if the public accepts it, then we will accept it,” the Forest Service and others, or Fishery Department. What happens? It just keeps on going. They say, “All right, let’s put a deadline” [on the window for requesting environmental-impact assessments]. The deadline has passed. Why? Because a guy came up and said, “Oh, my plant died, you’ve got to investigate that.”

10-00:34:01  
Burnett:

Sorry, what was that?

10-00:34:02  
Bhappu:

“My flowers will die if the Rosemont operation comes in.”

10-00:34:07  
Burnett:

So, they leave it open for a number of years so that people can come forward?

10-00:34:10  
Bhappu:

And then close it, but then if somebody comes in with some little item that is on the regulation—and you can find anything, anywhere—if there’s a trace of arsenic or something, which is permitted, but he says, “I’m afraid that it’s going to pollute my community,” all right. The company has to prove that that’s not going to—

10-00:34:45  
Burnett:

Each time.

10-00:34:48  
Bhappu:

Each inquiry. This just keeps them. So, you should have enough competence in the environmental departments to classify which is a waste, which is a problem, and which is not a problem. Bringing in a chemistry professor who doesn’t understand mineralogy but knows that arsenic is poisonous, is going to question. So, my request, and I’ve talked about it to EPA and others, is have competent people examine, go to the universities, authenticate it, and then allow the thing to go. Anybody can come with one inquiry and because of the law, you have to look into it.

10-00:35:47  
Burnett:

Well, that’s back to an earlier thing that we talked about and others have talked about, which is in the early stages of the establishment of the EPA, there was this back and forth. That has continued, where there needs to be a conversation between the experts at the EPA and the experts at the mines. What level is tolerable? The ideal answer is no poison, no toxins. But what is practical in terms of, yes, if we have arsenic, fine, but if it’s insoluble, then it might not be an issue.

10-00:36:27  
Bhappu:

Well, but some of the rivers bring in a lot of toxicity from the metals.

10-00:36:35  
Burnett:

From the mountains in general, yeah.

10-00:36:39  
Bhappu:

Nobody will be able to use the river water. The ocean has a lot of impurities. That's one thing I didn't mention about the oceans: we used the water from groundwater rivers, but the ocean is a good source of reusable water. Why? Because the flotation that we can conduct in clean water or potable water has certain ionic impurities. They may interfere with the flotation because we know that it's the surface that is a factor. However, water from the ocean, sodium chloride concentration, although high, does not – sodium in chloride – does not really affect that surface. So, mining operators, mining plants on the coast always use seawater, or try to use seawater.

10-00:37:44  
Burnett:

It's much better.

10-00:37:45  
Bhappu:

This has become very big in Mexico, Australia, and others, or Chile, the saltwater is the only water available, so they use it, make sure that there are no contaminants, and let it go into the ocean. They won't put tailings in there because tailings, over the years—

10-00:38:07  
Burnett:

Will be degraded.

10-00:38:08  
Bhappu:

Talking about oceans, one resource that is of the future is going to be the seabed.

10-00:38:16  
Burnett:

You mentioned that, a little bit.

10-00:38:17  
Bhappu:

The deposits of especially manganese-type and some of the rare earths and all that are associated with iron and manganese. The seabeds contain hundreds and millions and millions of additional resources. Now, I showed you that.

10-00:38:44  
Burnett:

This is a bell curve that you're showing, if we can pan out. You have a bell curve.

10-00:38:48  
Bhappu:

We are right at the top of that, but as the bell comes lower and lower, the mass of the ore available will increase, but it will be very fine, disseminated, very low grade. But the seabed deposits are concentrated, to concentrate things like manganese oxide and they run around 10-12 percent.

10-00:39:13  
Burnett:

And untouched.

10-00:39:14  
Bhappu:

Untouched. So, the Japanese are now the first ones. They have claimed a lot of areas in the Pacific Belt, and the Continental Shelf, that belongs to us. Russia says, "No, this belongs to us." Australia, everybody's claiming. So, this is going to be the new frontier.

10-00:39:34  
Burnett:

Yes. A good time to go into maritime law.

10-00:39:41  
Bhappu:

One of the things that I like to emphasize is that we talked about the family business, but what about these mining societies? Are they really doing well? I think you should be a member, you should be a contributor. Over the last fifty years, I've held about forty different positions, committee members, and it's the committee president or chairman who gears this to the future. Every year, we have several committees, we're working together, and it's good for you to volunteer. Since I was a student member, I became the student chapter chairman and all, and I continued that. So, I've been a member nearly sixty years. When I went to Colorado School of Mines, I showed exceptional talents, and so, there is a medal called Van Diest Gold Medal for young, budding engineers, within ten years after school. There are lots of medals available, about seven or eight metals, but the one I cherish most is the gold medal from the Mining and Metallurgical Society of America.

Why is that, American Mining and Metallurgical Society? People forget that Herbert Hoover, our president, was the mining engineer working in Australia, if you look through the historical records. He came to the United States, he was only born here, and then when he came back, he, of course, went into politics. He was the first recipient of the Mining and Metallurgical Gold Medal, in 1912. In the last 100 years, they've awarded only thirty medals, and about three years ago, I was awarded one of the last ones. The other thing that I feel, is that as a Zoroastrian, our community, young people, are moving to the United States, to Canada, and specializing in scientists, metallurgists, doctors, medicine.

10-00:42:07  
Burnett:

The professions.

10-00:42:08  
Bhappu:

But nobody takes much consideration of the metals industry. So, I'm encouraging them to come in, and have given talks on how to start, as entrepreneurs, start companies. What kind of a relationship should you have with your clients? What kind of talent should we be looking at? How do you select projects? In the old days, a handshake was good enough, but not at all now because you have to have a contract to work with. Many of these practices that I learned, it's not helped me, because the government changed, the people changed, small companies are picked up by big companies, and

they have different policies. But the chamber of commerce, the Zoroastrian chamber of commerce in 2007, made me the Man of the Year award, Zoroastrian Man of the Year. So, I'm very proud of that.

10-00:43:15

Burnett:

Yes, you should be.

10-00:43:16

Bhappu:

I'm helping my community, I'm helping future students, it's a good feeling that I'm doing something for my community. It's important that you live in a community—whether it's a mining community, it's New York City—as a member of the community, you need to contribute. Contribute in collecting discarded goods, or Goodwill, or be a mentor to the young kids, because you have the advantage. The kids are great. I would go to the little grade school and I'd put a little chrysocolla or malachite azurite, I'll put a little acid, and it turns green. I said, "Hey, see, now I have got copper in solution." So, the rock has disappeared, it's in solution. Then, I take out a nail, and I put the nail in, which has iron, and iron precipitates the copper. So, the copper color disappears. At the bottom of the beaker, I have copper.

The kids say, "Oh, that's magic," you know? I said, "No, this is science, and there are wonderful things to think about in the future." Many of these are demonstrated with analogies —why do you wash your hands with soap? Then, I say, "Well, the soap is similar to what we would use in a flotation process, we are taking out the dirt or we are coating it." Why does the bacteria grow if you have a little wound? Because there is a certain amount of toxicity. Why do you put iodine? Well, it kills all the bacteria. Why do you wash your mouth? It kills the bacteria. So, this is the kind [of question] of little kids, and sometimes starting with the kindergarten, there's a lot of them, and they are very, very curious. They want to know why, why, why, how, what happened? So, this is a message for our mentors and people who have been educated, to pass on their education benefits to the upcoming generation. That's the best legacy you can leave them, is with ideas, and looking to the future. Planes were great, but now, planes are going to be obsolete when you are looking at rockets and going to the moon.

Professor Gaudin, who I used to work with at MIT, in the first few months, he says, "You may be taking a dissertation thesis with me if you are going to be here," and I didn't know I was going to be there too long. He said, "We are going to talk about the metallurgy on the moon. It's a complete vacuum. No oxygen. So, how would you extract metals?" We thought about it. He says, "We'll take a load of ore to the moon, process it there, because it's a vacuum, vacuum-less, and we can have vacuum metallurgy." For instance, heat is there from the sun, the vacuum is created for you, so processing will be in ambient conditions.

10-00:46:58

Burnett:

So, back then, they were thinking about that, and today, there are commercial operations that are trying to think about asteroid mining.

10-00:47:11

Bhappu:

This is whatever the big thing is because the asteroid is concentrated. When it burns, only the high-temperature-resistant elements remain with it. Silica, of course, because it'll stay there. So, you may find that there are accumulations of rare elements in the asteroids, on Mars, or certain areas. The question would be, if there's no water, our technology of processing in water-short areas will come in. How do you do that with blowing air or using sunrays? Do you have to carry fuel with you? It opens up a challenge, and of course, everybody wants to go to Mars and all that, future kids. They get excited about all that. Again, working with the mining associations, it's not that they recognize you—which is nice—but the important thing is that you contribute.

When I was president of SME/AIME, I was asked, "What are the major things that you think you would like to do this year?" I would say, my first stress is education, naturally. I see a dwindling – less and less people going into mining. Mining colleges are closing. Only a few in mining. They switched not to mining, they switch to metallurgy or materials science because it's materials, okay, but the mining is out. All the precious equipment and all that is left behind, all the research. So, education is my first goal. The second goal is that we are talking – The mining community, it is a small community, and it talks to its own people, rather than passing the message to our neighbors. So, we should be encouraged to approach our Rotary Club or companions, whoever it is, up at YMCA, church groups, go and talk to them and tell them about us. What is mining? Don't dwell on one subject, but give them the idea about mining, and tell them mining is not bad. I got this tie when I was the president.

10-00:49:46

Burnett:

Okay, we'll zoom in, here. I'm going to go right in, there we go. The insignia.

10-00:50:09

Bhappu:

When I was president of SME, I went to St. Louis, and as a mark of presenting my views to them, they honored me with this tie. As you can see, it's the arch. So, I was sitting on the plane, coming home, and a lady, older lady sitting next to me, looks at me, and says, "Oh, you work for McDonald's?" [laughter] You see the hammer and sickle, there? I'm a miner, not working for McDonald's. So, I told my audience in the board of directors, so they say, "Let's change the logo." So, SME is trying to change their logo, coming out with a little pick and shovel is good to us. It's still good, but maybe we need to update something.

10-00:51:13

Burnett:

To update a little bit? I don't know.

10-00:51:16  
Bhappu:

So, my message as the president of the institution, the third and most important, was collaboration with international organizations. We cannot live alone; we have to live with others. I never came in contact with the Russians until I went to Russia, as a consultant. The young people are very nice, they are very good, but they produce all these metallurgists or miners, and one mine will have 100 metallurgists in the mine, geologists, because they can't put them into practical operations. Eventually, all these guys will be helpful. People working with Canada, I thought was a great thing we should cultivate, with the Canadian Mining Institute. Australia is another area. It's far away, but at least once a year, we can get together. Japan is a leading engineering, mining, and—well, not mining, they don't have as much mining, but they have a lot of processing, a lot of alloys, a lot of metal industries. India is another one, where mining is a very critical sector. When I talk about mechanization, they always ask me, "Can we compete?" I said, "Well, when your wages are so low, you should use hand labor as long as you can till your salary goes up."

10-00:53:02  
Burnett:

Till your growth is enough to justify spending on capital.

10-00:53:07  
Bhappu:

"You can't afford to put in machinery." Then, he says, "Well, you are an old Indian and you are trying to keep us down." I said, "No, I'm not just looking at pure economics. If you displace those guys with machinery, where are you going to put them? Then, you will be like this big mine, you have 90,000 miners using handpick shovels. You don't want to do that, either. So, these were my goals: international concern, trying to make better friends, and share technology. Patents were a big problem. Reports were a big problem. If I wrote a report as a process engineer, and I went to Canada, they would say, "You are not qualified." I said, "Look at my résumé"—They would say "you have to pass a qualified process."

10-00:54:08  
Burnett:

In Canada?

10-00:54:09  
Bhappu:

No, no, in the United States, to have that title to work on a feasibility report. So, the qualified person, or QP, is now more important than an engineer. We need to cooperate, and we should have some reciprocity. We should have equal – if you belong to a mining association in the United States, you should have equal privileges. Share it. Of course, he was going to live in a hotel, he'll pay his own way, but you can waive whatever his fees are for non-members. Those are the kinds of cooperation that I think are important, and this is what you tried to pass on and tried to implement.

10-00:55:06

Burnett:

Well, I want to ask one more question about rare earths. As far as your expertise in solution mining and the efficient and environmentally responsible mining practices, what do you think of the modern rare earth extraction processes?

10-00:55:34

Bhappu:

We have not started on it, but a German group is interested in recovering rare earths. Some plants, as long as it's close to the surface, open mine pits are very well. If it's an ocean placer deposit on the rivers in Brazil or in India, that's not a problem. But if you are living on a Continental Shelf and you have a rare-earth deposit which was a seabed at one time, okay, those guys are saying, "Look, I can't mine. It's too deep to mine. My costs are going to be \$150 a ton just to bring the ore up to the surface, and I have only \$50 value." So, he says, "Can't you use something of your in-situ [process]?" I said yes. So, they said, "We are going to bring you our geological background and tell you how the geochemistry worked to put the rare earths in that environment, what kind of effect was that, in the old? Was it a seabed type or high chloride concentration?"

So, we are now actually looking at an in-situ project because these are practically, Europe is all populated. There are very few spots. If you put up a big mine, you can't get away with it, so you'll have to go underground. So, if you go underground, why not look at solution mining? So, we are. It is the environmental laws on the surface that let us go into solution mining, but then it creates its own problem of migration of solutions and contaminating that. So, well, you have to do your research to make sure that all the solution that goes out is going to come up. We purposefully pump 10 percent additional.

10-00:57:54

Burnett:

You were sucking the stuff out?

10-00:57:56

Bhappu:

If you put 100 gallons, we take out 110 gallons. Sure, we have to process and clean up on the surface.

10-00:58:04

Burnett:

So, it's a bit like negative pressure in a bio lab.

10-00:58:08

Bhappu:

That's a good point. There are horizons, new horizons for us, is in-situ leaching, seabed mining. We have mines at 13,000 feet in the United States—Climax, Colorado, molybdenum mine, 13,000 feet. The question is, there is a whole community living there. What are some of the adverse effects of working in Peru at 14,000 feet? So, we are now trying to bring in the medical crew to help us because we are going to put up a community in these locations. Are we going to affect their health, children's health? One of the things they told immediately is at least once a year, especially if you're not

indigenous, they can do whatever they want, they are used to it, but a foreigner coming in, give him one month off a year to go to the sea level.

10-00:59:18

Burnett:

Otherwise their bodies will adjust?

10-00:59:19

Bhappu:

Their body builds up. So, that's one thing. Vacuum metallurgy and high-pressure temperature metallurgy is coming into its own. It has been on its own, but we need to come out with some more. Hydrogen reduction is coming out. What do you do with the ash from the coal? That has a lot of value, so now we are processing ash. We are also making it as a pellet, for pelletizing. So, there is a lot of industrial minerals that I haven't talked about. From the metal mine, it's industrial minerals that produce sand and gravel and phosphate and limestone. Those are the big, big, big industries, bigger than, as far as production goes, for the metal mine. So, the industrial mineral group has been brought in. They are making a big splash, and opening up new challenges, because they are used to bulk mining and isolation has not been practiced. So, that's a new challenge to processes guys: does it have to be physical, or can we go to chemical? Lots of times, they have a lot of calcium in solution, and all we have to do is add a little bit of sulfuric acid, make gypsum.

So, clean up the water. If there is mercury or arsenic, add a little iron or a calcium, you'll form calcium iron arsenate, which is the most insoluble product in the world. Those are the kinds of things. So, the challenge is great, it's a great profession, I can't say enough about it. But I would also say that the luck has much to do with it, too. The environment that you are brought up in, your family influence, your teachers, your religious group, your mentors in the high school, college years, school of mines, universities, and practical people. You can't do without practice. So, we purposefully add a certain amount of sessions which are practically oriented because not everybody is a researcher. We have to cater to that audience also, so we have theory and practice, they go together, and then we bring in economics. [laughs] Then, comes the tail, it's the tail that wags the dog. So, all these interdisciplinary sciences and your progression through your life form your character, and your character builds your profession.

Then, when you reach—I'm eighty-seven now—I said, "What else can I do?" I can work on the metallurgical projects, challenging projects, but I think it's important for me to do some public service.

10-01:02:41

Burnett:

Yes, and you have.



10-01:02:43

Bhappu:

Teaching kids or getting them interested in mining. Not necessarily mining—resources. Look at everything here, is made from elements, from mine products.

10-01:02:57

Burnett:

Dr. Bhappu, I thank you very much for taking the time to speak on camera for the audiences of the future, who will be interested in your life and your work.

10-01:03:07

Bhappu:

Very good. Thank you very much. I consider it an honor to be invited, and I feel that I've done a good job to educate the people, and also our future engineers.

10-01:03:21

Burnett:

Thank you.

[End of Interview]

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