AMERICAN INSTITUTE OF MINING,
METALLURGICAL, AND PETROLEUM ENGINEERS

ORAL HISTORY PROGRAM

Fiona Doyle: Following Dreams and Curiosity

2022

PREFACE

The following oral history is the result of recorded interviews with Fiona Doyle conducted by Michael Free on March 20, 2023. This interview is part of the AIME Oral History Program.

ABSTRACT

Fiona Doyle discovered her love for science at an early age after conducting an alum crystal-growing experiment in her middle school physics class. Growing up in Newcastle, England, seeing coal mine refuse heaps and acid drainage, she became interested in the environmental side of science, wondering how the environmental impact of producing raw materials could be improved. As a young woman, Doyle went to Cambridge to study physics but ended up specializing in the areas of metallurgy and materials science instead, eventually becoming an engineer. At the time, there were very few female engineers, and opportunities for women were scarce. From the time of her first summer job in heavy industry at Clarke Chapman to her working at Berkeley straight out of her PhD, Dr. Doyle has been finding her own way to overcome barriers and help herself and others in her position succeed. Throughout her career at Berkeley, Dr. Doyle advocated for family-friendly policies while continuing her own research in leaching and hydrometallurgy with the goal of producing value-added products. She also participated in a study of the environmental impact of abandoned mines and acid mine drainage in California and served as the vice chair and chair of Berkeley's Academic Senate. Dr. Doyle was a recipient of the University of British Columbia extractive metallurgy lecture, the SME Milton E. Wadsworth Award, the TMS extraction and processing lecturer award, of which she was the first female recipient, and is a TMS Fellow. Dr. Doyle is an elected member of the National Academy of Engineering, where she currently serves as the chair of the Earth Resources Engineering section, where she advocates for improved environmental policies and international cooperation. Dr. Doyle's inspirational life story and hopes for the future of industry can be heard in her oral history.

Readers are asked to remember that they are reading a transcript of the spoken word rather than written prose. The narrator has reviewed, edited, and approved the following transcript.

TABLE OF CONTENTS

00:00:13 Introduction

Free:

Hi, I'm Mike Free, and I'm a member of TMS [the Minerals, Metals & Materials Society], a faculty member at the University of Utah, and also the chair of the Department of Materials Science and Engineering. I'm here today at the TMS annual meeting in lovely San Diego. I have with me Dr. Fiona Doyle, who's been a long-time professor at the University of California at Berkeley, and we're here to do an oral history for AIME and TMS. And so we welcome you, and I appreciate the opportunity to be here. So, we'll go ahead and get started with a question for Professor Doyle. Can you tell us a little bit about where you grew up?

Doyle:

So, I'm not from California. I was born in the north of England in an industrial town called Newcastle. It's the Newcastle that you don't take coals to because there used to be a big coal mining field there and that then spawned a lot of heavy industry. I am the third of five children, and neither of my parents went to university. My father left school at 14, did an apprenticeship, and was an electrical draftsman. My mother left school at 16. The war had just broken out, and she worked in the Land Army. After the war, she did 14 months of training, which qualified her to be a teacher in grade school. So, I grew up in this rambunctious, large family. We were very happy.

Free:

That's very interesting; it's a little bit of an unusual background for what we typically might see with the students and faculty that I'm aware of. But I think it's also interesting to take that a step further and talk about what influenced you to become an engineer.

00:02:18 Discovering My Love of Science in My Middle School Physics Class

Doyle:

Well, going long before then, I had an unconventional schooling for becoming an engineer; I went to a convent school for 14 years. We don't have many TMS members who attended a convent school for that long. As long as I can remember, though, I just loved science. The British educational system was very different from the American one, so when I started middle school, I started physics and really liked it. The year after, we started chemistry. I look back, and I think, golly, I was a really nerdy child because I remember in physics, we did this experiment (and there was lots of hands-on stuff—which I think is a great way to educate children, just get them excited) and we grew an alum crystal. I just thought this was so fascinating that you could organize how crystals grew that I then went out and, for months, spent my allowance buying more alum and grew this huge crystal. This was my introduction to hydrometallurgy at the age of 12, growing this enormous alum crystal at home. In the process, I actually learned; I figured out for myself—I didn't know what they were called—but I was observing nucleation and growth and was trying to control it. So, this was fun to me. Then in the British system, once you get to 16, you do general exams, and then you choose what you're going to do, just three subjects for your advanced level. There was just no question that I was going to do science because that was what was fun, and it was easy.

00:04:19 Following What Seemed Fun – Studying at Cambridge and Imperial College

Doyle:

And, you know, you didn't have to memorize; you just had to understand things, and you were fine. So, I did mathematics, physics, and chemistry. When it came time to apply to university, there really weren't many people who were engineers who had gone into engineering from my school. Most people, most of the girls who did science, went into medicine, and I didn't want to do that because my older sister did that, and it didn't look like fun. I thought about doing engineering, but I mean, I didn't really know any professional engineers, and I decided, no, I wanted to be a scientist. So, I went off to Cambridge to do physics. At Cambridge, you do natural sciences, and in my first year, I did a class called Crystalline Materials, which was offered jointly by the materials department and the crystallography department. I thought that was great fun. It was a lot like growing alum crystals, kind of on steroids, and learning a lot more about it. So, I continued doing that and ended up specializing in metallurgy and material science, but that was not within the engineering department. In the process of doing that, I mean, my life has really just been sort of following what seemed fun, I remember very clearly in lectures starting to hear about hydrometallurgy. I remember just being transfixed at the prospect of heap leaching when we were told about how you could pour acid or cyanide over a whole heap of ore and actually produce metals on a large scale.

I thought this is really fun; I want to do more of this. So, I did my final project doing that, and then I went to Imperial College and did a master's in extractive metallurgy and specialized in hydrometallurgy for my project. John Monhemius, who was supervising my project, said, “You really should think about doing a PhD, Fiona.” I had really always wanted to work in industry, but I could not get a good job that used hydrometallurgy. At that point, really all of the hydrometallurgy jobs were in South Africa, and politically, at that time, I didn't want to work in South Africa. Also pragmatically, when I did an interview with Anglo, they said, “Well, if you're going to get ahead, you have to go underground, but we don't allow women underground.” It seemed like a dead end. So, staying to do a PhD seemed like a good thing to do. In fact, when I finished my master's, I noticed on the paperwork that it was a master's in engineering. I thought, “Oh, isn't that interesting? I decided I wasn't going to be an engineer, and I've become an engineer.” So that's how I actually got into engineering. It was following my interests, and somehow, fate worked out so that even though I'd deliberately decided that I wasn't going to be an engineer, I ended up being an engineer.

00:07:55 Finding Help Along the Way Through Mentors and Advisors

Free:

Wow. Well, that's really interesting. Your background, and especially a lot of this, seems to be self-driven in terms of your interests and just following your passions. It sounds like you've had a couple of maybe mentors along the way that have kind of helped to guide some of these decisions. And you've mentioned one already. Are there others that played a role in mentoring and helping you steer this direction?

Doyle:

So, at Cambridge, there was a faculty member, Jim Charles, who was a pyrometallurgist, but he took an interest in advising me. I attended a women's college at Cambridge, and there weren't any faculty

fellows there who were in materials. So, Jim Charles was sort of my *de facto* advisor as an undergraduate, and he was the one who told me about the master's program [in Extractive Metallurgy] at Imperial College, and he said, “You know, I'll talk to my friend Jim Jeffs, who's getting this going; I think that you'd be a good candidate for that.” So, he helped me along the way. Then, at Imperial College, I did my research with John Monhemius, but Richard Burkin was the professor of the hydrometallurgy group, and John was a more junior faculty member. I actually deliberately decided to work with John rather than Richard Burkin because Burkin had lots of students; John didn't have many; being more junior, I figured that John had more of a vested interest in my success than Burkin had, and it was a very good decision. Richard Burkin also, in a way, took me under his wing. One of the things was that he occasionally hosted very, very nice dinners for the whole hydrometallurgy group at his home. His wife was a wonderful cook, and they had a lovely house and a garden. I must have said the right things because I made comments about how wonderful the food was because it was—it was really good—and I also was interested in the camellias and the azaleas and things like this. So, I think he decided that I was okay because I had broad interests, and so he'd sometimes talk to me about food.

I remember once he decided that I was looking particularly hungry, and he took me to lunch at the Cafe Royale, which was a wonderful experience. He gave me professional advice along the way as well. Then, when I got to Berkeley, I was lucky enough to have a few mentors. Jim Evans was the chair of the search committee [that hired me], and he and his wife were very, very helpful in terms of helping me get settled in this foreign country. They've been lifelong friends. You know, we're still good friends. Doug Fuerstenau, now, who was one of the early people featured in this oral history program; he was also a mentor. Doug, most people know, used to be rather gruff when he was younger. I either worked out [how to interact with him], or he wasn't going to be too gruff with me. Early on, my colleagues would send me to talk to Doug about difficult issues in the department. So, it's like, “Fiona, go talk to Doug about this.” And Doug was sort of a mentor, although he was not so much a kind, gentle mentor as somebody who would come in and say, “You really need to be writing more papers, Fiona. You'll never get tenure at this rate,” and so on. And then another colleague, the late Neville Cook, who was a mining engineer and worked in rock mechanics. He also took an interest in me as well and invited me to his group meetings and helped me understand how this whole American academia thing worked because it was very different from the British system.

00:12:29 Overcoming Discrimination in Industry – My First Work Experience

Free:

Good. Good. That's very interesting. Maybe you can tell me just a little bit about your first job in industry. Then, it could tie into internships or whatever.

Doyle:

So, my very first job in industry was actually when I was in high school. My family, I think, the best to describe it was that we had modest means. My parents always said, if you wanted things, “Well, we can't afford to do this for five of you, so you can wait until you’re old enough to get a job, and then you can do these things.” So, as soon as I was old enough legally to work in Britain, the first time I worked was in retail, and it was very, very poorly paid. The next year, I thought, well, I have skills, and I actually got myself a job as a lab technician doing analytical chemistry supporting a drug development group at a local pharmaceutical company. And it was fun. I was doing all of these titrations. I also learned a lot of instrumentation, and I learned a lot of techniques that I continued to use throughout my career. The

work convinced me that I didn't want to do chemistry, which is ironic since I ended up doing applied chemistry, but there we are. I certainly didn't want to spend my time doing quantitative or organic analysis, but that worked well, and I worked there for a couple of years in the summer. Then, between my second and third years at Cambridge (and this was a three-year undergraduate program, so before my final exams), I decided that I should get a job doing metallurgy. My father worked for a big company that did heavy engineering.

I asked him, and he said yes, that they did have a metallurgical department. So, I wrote asking for a summer job. I'd written to various companies asking for summer jobs, and I'd always got letters back saying no thank you. My male friends who were doing the same major were all getting jobs, and I thought, “I wonder whether they just don't want women.” So, I wrote to Clarke Chapman, and I mentioned that my father worked there and that I was going into my final year doing metallurgy and materials at Cambridge, and I decided to just sign it F.M. Doyle. The personnel department phoned up my father and said, “Oh, we understand that your laddie wants a job here.” I had not told my father that I was applying, by the way, which was probably a faux pas, but he had enough children he rolled with the punches on these things. They said, “Oh, it looks very interesting. So, he's at Cambridge and wants to do metallurgy. This sounds wonderful,” and, you know, continued for a little bit, and my father finally got a word in and said, “Well, yes, but it's not a laddie; it's my daughter.” He said that he could tell that they took a deep breath and thought, “Oh, we can't say no now,” because it was illegal to discriminate against women. So, they proceeded, and they gave me an interview, and so I started. When I started, I was conscious of the fact that everybody was feeling very, very restrained and on their best behaviour.

A few days into it, I was preparing some samples, and I stamped one with the wrong stamp, and I let out an expletive. I apologized, of course. The guy who was in the same lab as me left, and what I learned afterward was that they were told that they could not swear in my presence. As soon as I swore, he walked out and said, “It's okay; she swears.” Then everybody was a lot more relaxed; they could actually just treat me like a coworker. So, I spent the summer doing a project on liquid metal embrittlement. It was shortly after there had been a big disaster, which I seem to recall had some fatalities, in a power plant that had Clarke Chapman equipment in it. They had tracked down the failure to being liquid metal embrittlement of the steel by some galvanized wire that was in the structure. They wanted a better understanding of liquid metal embrittlement so that they could ensure that they weren't going to have any problems going forward. So, I was working on that, and I spent most of the summer preparing metallographic specimens and then looking at them down the microscope and doing microscale indentation and all of those other things. At the end of that, I decided that physical metallurgy wasn't for me. So then, I definitely had to do chemical metallurgy.

00:18:24 Figuring Out What’s Next and Finding Work in the United States

Free:

Let's talk just a little bit about this transition in going from your academic studies and transitioning to your professional life. What can you tell me about some of the challenges you faced and maybe what you did to overcome those challenges?

Doyle:

Well, even before we talk about the transition to what I'm doing, I talked about the fact that I didn't want to be an engineer. I also emphatically did not want to be an academic. In fact, I used to say that I

had to get out of university before they discovered that I wasn't very smart and I really wanted to work in industry. Unfortunately, the year that I finished my PhD, the economy was pretty depressed. The previous year there were a few people from the Hydromet group who had got fantastic jobs because oil companies had been buying up mining companies. British Petroleum had a big Hydromet lab in the south of England, and quite a few people had gone there, and these seemed like fantastic jobs. I really wanted to do that, but they stopped hiring before I was on the job market, and I applied for various other jobs. There was one job available in extractive metallurgy in the UK, and it was at the Avonmouth lead smelter, and I was informed that they would not employ women of childbearing age. I said to my adviser, John Monhemius, “Well, isn't that illegal?” And he said, “Fiona, if it's not safe for women of childbearing age, I think the people who should be concerned about legalities are the men who are working there because the ambient lead probably isn't too great for them as well.” So, I ended up thinking, “Well, what am I going to do?” And I was looking at a couple of job offers that were fine, but they weren't for a PhD level.

They were actually bachelor's level jobs. I noticed in those days, jobs—there was no internet, it's really hard to remember what it was like—but jobs used to be advertised in periodicals and in the Journal of Metals. I saw these advertisements for academic jobs in the United States, and all they seemed to want was a PhD. In the United Kingdom, you had to have several years as a postdoc to even be considered for a lecturer job, and I did not want to do a postdoc. So, I thought, “Well, I'll apply to some of those jobs in the United States.” And I did. Much to my surprise, I landed a job at Berkeley. At that point, I had no idea of the academic reputation of Berkeley. I was totally clueless about the American system. It was like the Groucho Marx line about not wanting to belong to a club that would have you as a member. I figured, well if Berkeley is taking me straight out of my PhD, they can't be very good academically. It was only when I got there that I actually realized that “Oh, this actually is a very good place.” Interestingly, I had always wanted to live in the San Francisco Bay Area. Well, not always. From when I was 14 and was doing geography - I'm a real map nerd - and I used to stare at the atlas and we were doing North America.

I’d look at the map of California and think, “This looks really cool. I want to live there.” And then it was, “I'm going to live there.” I had no idea how I was going to do it, but getting a job at Berkeley was a way to live in the San Francisco Bay area. So that was another of the advantages. I got to Berkeley, and I was clueless about the American system. I had to start teaching graduate classes, and because of the British system, I had taken some master's level classes, but there was no coursework as part of a PhD in the British system. The attitude is, well, all of the information is in the library, and you know how to read, so just go to the library, and you'll find out what you need, which is one approach, but it doesn't prepare you well for teaching graduate-level classes. So that was a learning process. My colleagues were very, very supportive.

00:23:38 Challenges at Berkeley – Being the Only Woman in My Department for 19 Years

Doyle:

I suppose I look back on it, and one of the big challenges, quite apart from the fact that I didn't understand the American system, was that I was the first woman in my department and I was the only woman in my department for 19 years. I was department chair before we hired another woman, and I was only the third female faculty member in the College of Engineering. So, I was this peculiarity. Fortunately, people were very, very gracious.

I never experienced any harassment or any sort of what I would describe as discriminatory behaviour in our department. At the same time, I look back and realize, oh, yes, I had colleagues who were networking, playing golf, and things, and they never invited me. They would go off to the faculty club bar, and I was never invited to these things. So, I definitely missed out on some of the networking. I think that one of the reasons why both my colleagues Neville Cooke and Doug Fuerstenau took me under their wing is that both of them had daughters about my age, and I think that they could see that it was different for me and they wanted to stretch out a fatherly hand to help me and give me some pointers on how to navigate an academic career. I'm very, very grateful to them for having done that. So, yes, by the time we did hire another woman, as I said, I was department chair. We had email at that point; we had moved into the modern age, and I used to enjoy sending memos to my colleagues, particularly when I was department chair. I would just always address it to 'gentlemen.' When we hired another female professor, I had to stop and start saying, 'colleagues' rather than 'gentlemen'. It was just how it was. It was very, very male-dominated.

00:26:21 Good Friends and Great Advice

Free:

Let's talk a little bit more about that. I mean, you said that you were the first woman in your department for a long time, and you had some help with the mentoring and stuff. Were there other things that the university did or others on campus that helped to make it easier to connect and to feel more a part of the community as a woman in engineering?

Doyle:

Yes. So, early on, Berkeley had two provosts. There was one for most of the campus, and there was one for the professional schools and colleges. When I got to Berkeley, the provost for the professional schools and colleges was a woman. So, it was either once a year or once a semester; she would invite the female faculty members in engineering to lunch, and we'd sit around a small table in the faculty club. That way, I did get to meet the other women, and there were a few more added within a year or so of my arriving. I had one colleague in particular; her name was Pam Eibeck. She was an assistant professor in mechanical engineering, and she got tenure and then left and ended up as the president at the University of the Pacific. She decided that she was much more interested in teaching rather than research. So, she pursued a career track that would be more focused on teaching and education. But in the early days, Pam and I used to get together very frequently and vent about how outrageous our colleagues were. She always had much more outrageous stories about the colleagues in mechanical engineering than I had about the ones in material science and mineral engineering. I mean, we really did help each other and help each other keep sane. One of the sanest pieces of advice I ever got was from Pam.

I remember her saying, as we were sort of both looking at tenure, "I'm working as hard as I want to work, and if that's not enough to get tenure, then I don't want tenure." And I thought, "Well, that's a really good way of looking at it." I obviously still remember her words because I think that they really capture the importance of maintaining a work-life balance. I think that that's very important to have a productive academic career. It's not just ensuring that you're a happy person, but I think that that balance is very important. Balance is something that I've always tried to ensure that my students followed as well because, particularly for graduate students, their research is the focus of their existence at the moment. If you've got nothing else going on in your life - as you know, research has its ups and

downs - and when your research project hits a down, if that's all there is, it's a very miserable place to be. Subsequently, when I was the Vice Provost for Graduate Studies at Berkeley, I really saw the statistics on the incidence of mental illness among graduate students. I didn't know those in the earlier days, but I could see that it was very important for students to maintain that balance.

So, friends, early on, helped me keep that balance. Also, there was a network of female professors at Berkeley because there weren't that many female professors in the early 1980s either. That also helped me maintain perspective. Early on, I got involved in our academic senate, which I enjoyed because it was engaged in thoughtful matters outside of my immediate department, and I enjoyed the balance of that. I did eventually become the vice chair and the chair of our academic senate, which was an interesting chapter of my career. What I would say there is that the biggest shock that I had becoming chair of our academic senate was realizing - and this is such a no-brainer it should have occurred to me earlier - that most faculty don't think like engineers. Having that sort of brought home to me then, I think, set me up for being an administrator at the campus level and I realized that engineers do tend to think in a logical way. We don't always agree, but we will typically use a certain process to get through differences of opinion and get down to solving the problems.

00:32:04 Raising My First Child and Finding a Work-Life Balance

Doyle:

There are some people who just love analyzing situations and don't even want to admit that there's a problem. But before I leave the topic of what helped me and what did not help me, one thing that was a real difficulty in being one of the first female faculty members in engineering was that when I was expecting my daughter, who's my older child, so this was 1991, I inquired with my department administrator, the manager, and said, “Do we have maternity leave?”

And she said, “Oh, no, I'm pretty sure we don't have maternity leave.” So, I thought, okay, all right, well, I have lots of sabbatical credits. So, I arranged to take a sabbatical leave for the semester after my daughter was born, which I did. I didn't get very much research done, as you can imagine. When she was nine months old, the university published a booklet—this was pre-Internet days—there was a booklet of support for university employees. I was reading through this, and I saw that there was indeed maternity leave. It was just that our manager had no idea that there was maternity leave because nobody at the College of Engineering had ever needed maternity leave before. By the time my son was born, I was able to avail myself of our maternity leave policies, which weren't as generous as they are now, but at least there was something. I'm so glad that things are a lot better now for parents.

Free:

Yeah. Yeah. Well, that's very interesting. So how did you—let's come back to this situation you were talking about with having a family, and you're talking about work-life balance—how did you juggle the other demands in life as you went and worked along in your profession? What are some things that were very helpful for you in terms of managing that balance?

Doyle:

Friends. I'm from the UK, and my parents and all my family were in the UK, so there was nobody from my side of the family available to help me. My husband is from Michigan, and his parents were there

and were older, and they really couldn't do very much traveling either. So, they weren't available to step in when children were sick or whatever. Fortunately, when I was expecting my daughter, the house next door to ours was sold, and the couple who bought it - I still remember meeting Pat on our front lawn, and she had a bump as big as my bump - were also expecting their first. Their son was born a month after my daughter Katherine was born, and we decided that we would share a nanny, and that worked quite well. So, Pat and her husband were also a long way from home. Her husband is from Australia, and Pat's father was a quadriplegic in Georgia, so her parents couldn't travel at all. So, we became each other's backup. When the children got chickenpox at that point, they were in the same daycare, and they got chickenpox at the same time. We would take it in turns to look after these hordes of children, the four children that couldn't go to daycare.

There were also many other friends as well. One of the things that I realized very early on is you never pass up the opportunity to volunteer to help somebody when you can. Volunteer to give somebody's child a ride and so on because then you can ask people for help when you need it, or, more likely, they will just volunteer to help out. That was so enormously helpful; I don't think I could have made it without that. And, of course, my husband, fortunately, was very supportive of my career. I could not have done it without him. I say this kind of as an afterthought. Yeah, he was pretty important. He worked at Lawrence Livermore National Labs, which is about a 40-minute drive from our home in Oakland. So, he used to go to work early. I'd get the children ready and then to daycare or to school, and then he would do the pickup in the evenings so that I could work later. There was an awful lot of balancing there. We used to have to negotiate when we went to conferences and all of those other things so that we could get through.

Free:

Yeah, that was challenging, I'm sure.

Doyle:

And I mean, that aspect of life is as challenging now. We have better parental leave policies, but in this country, it's still really hard for dual-income families to raise children. In the Bay Area, it's very, very difficult to raise a family on a single income just because the cost of living is so high.

Free:

Yeah. Well, with just a little bit more, maybe we could go into this work-life balance. So were there other things that—you had a lot of support with friends and your spouse, and it's challenging even at that—but were there any other things that you had that helped you with the work-life balance aspect of maintaining that semblance of having that balance?

Doyle:

Well, as I mentioned earlier, I did have some work-life balance even before I had children. I was doing different things: fixing up my house was a big-time sink, and teaching myself how to do various things. Again, there were no YouTube videos showing you how to do sheetrock or things like that, but I discovered that finishing off sheetrock is actually awfully like frosting a cake. If you can frost a cake, you can do walls. It's really the same skills. I've always enjoyed the outdoors and hiking and things like that. So, when my children were particularly young and needed a lot more attention, other things in my life

didn't happen, but I was able to keep work going at a reasonable pace.

00:39:41 Realizing My Teenage Passions – Improving Environmental Impact of Metals Processing

Free:

Well, let's take a little bit of time to talk about some of your research, some of the things that you're passionate about. Some things that you've really enjoyed in terms of the research you've done over the years.

Doyle:

I think in order to understand kind of where I've been going in the various different things that I've done; I have to go back to being a teenager. I remember, even though I'd never intended doing this, there were a couple of books that I read that have really influenced the way that I have approached all the research in my career. I remember reading a book early on about environmental impacts of manufacturing and everything else. This would have been the time of Rachel Carson's *Silent Spring*. It wasn't that, and I can't even remember the name of the book, but I remember sort of becoming aware of the environment, and that actually wasn't very hard to do because the countryside around Newcastle still had refuse heaps from coal mining and you would drive by these. The mines might have been closed, but you would drive by these, and you'd see acid mine drainage coming off them. Some of them smelled to high heaven because there was a lot of pyrite in the coal, and this was oxidizing, and there'd be sulfuric acid, and from lower down hydrogen sulfide and stuff like this. So, these were an eyesore, and I was very much aware of them. There was a lot of air pollution in Newcastle when I was a child. I remember my mother talking about hanging washing out to dry - because we didn't have dryers in those days - and the clothes just being covered in soot before she could bring them in.

We heated our house with coal as well. So, I was aware of the environment. Then, I also read a book about the fact that society was going to run out of resources, and there were all these projections that we were going to run out of copper by 2000 and various other things. That made an impact on me. I thought, “Oh, right, you know, this could be a problem.” So, these are things that have been at the back of my mind really throughout my career. I would say that the one common theme of the research that I have done has been an interest in improving the environmental impact of producing raw materials, and very much aware of the fact that you need mining because we need raw materials. But at the same time, we want to produce our raw materials in a way that doesn't damage the environment. Lots of the disparate things that I've done have been along that theme.

Free:

Low impact.

Doyle:

So, in my PhD work, which was working on a process called hydrolytic stripping, and the concept was that if you removed iron from, say, a zinc-producing circuit by solvent extraction rather than precipitating jarosite or goethite, then you would eventually have an iron residue that wasn't as contaminated as jarosites and goethites were at that time, and that was appealing. Then, John

Monhemius and Gunner Thorsen had discovered a process whereby if you take a carboxylic acid that's loaded with iron and hit it with water at high temperature and pressure, you will precipitate out iron as a clean hematite or goethite. I did my master's project doing goethites and jarosites, and then I went to the higher-temperature process for my PhD. We were actually putting in cobalt and nickel and producing what we would now call nanocrystals of spinel ferrites. We didn't use the term nanocrystals in those days, but that's what they were. I actually became very interested in the concept of using hydrometallurgy as a way of producing value-added products. This reflected my education in materials. So, I was interested in rather than just producing raw materials that would then be processed again and again to produce final products, I was interested in the concept of, "Can we produce products at the mine site or at the processing site that are further down the line towards final products so that we can miss out some of the processing and the reprocessing?" So, I actually did quite a lot of work on precipitating different products from solvent extractants.

I worked on producing rare earths where you could actually control the morphology and size of crystals, which was important for phosphors and some of the applications of rare earths back when dinosaurs were roaming the earth and I was in the early stages of my career, as opposed to now when we're talking about renewable energy and hybrid vehicles and all these other things that we still need rare earths for; we need a lot more rare earths than we ever did before. I did—just sort of on the topic of rare earths—I did this wonderful consulting project for General Electric, and they were interested in using permanent magnets for MRI machines to sell in countries where the electrical supply was intermittent, so they couldn't run electromagnets all the time. At that point, the rare earth magnets were very expensive. So, they worked with an institute in Baotou in China, and I was the consultant on that project. We developed a process for producing a mixed neodymium praseodymium product that could then go directly into magnets as opposed to separating them out. So again, it was making the whole processing more efficient. I have a Chinese patent out of that work, so that was an interesting foray into rare earths.

Shortly after I arrived at Berkeley, I decided that I needed to do some leaching work because every self-respecting hydro metallurgist has to have some leaching work under their belt. So, I conceived this idea of translating my expertise on how iron precipitated to the direct leaching of zinc sulfide in autoclaves. The fall after I arrived at Berkeley, Ernie Peters was there doing a sabbatical leave, and he was interested in this. He had lots of experience in the area and gave me some pointers and that helped me get that project off the ground. He enjoyed having a hydro metallurgist there, and he would sometimes come into my office and regale me with stories of his past and gave me the history of pressure leaching in Canada, where, of course, it all started. That was very helpful. I also, with him, did a project that he conceived, and I then joined it on mathematical modeling of the leaching kinetics of zinc calcine. So, that actually gave me exposure to a type of mathematical modeling that I wasn't familiar with as well. That was very educational to me.

00:49:07 Just Absolutely Fascinating – Abandoned Mines and Acid Mine Drainage

Doyle:

In terms of other projects that I have enjoyed, well, I suppose going away from hydrometallurgy a bit, something that has almost become a lifelong hobby, is that in the mid-80s, one of my colleagues landed a project that was commissioned by the California legislature to do a study of the environmental impact of abandoned mines in California.

This was a guy called Mike Hood, who was a mining engineer, and he put together a team. I was on it. We had an environmental lawyer, some policy people, and we looked at lots of abandoned mines in California. There were, at that point, I think, two or three that were on the federal Superfund list, and then California had its own Superfund list. I got very, very interested in particularly acid mine drainage, which, as I mentioned, I'd observed as a child on the refuse heaps from the coal mining in Northumberland. I like the outdoors, I like hiking, and I discovered just how delightful it is to traipse around California looking at these environmental disasters as a result of mining in times when people weren't as enlightened as they are now. You know the history of California from the gold rush on is so coloured by mining and everything else. It was just absolutely fascinating to me. My husband is very, very patient with my desire to stop the car and go and take a look at [an abandoned mine]; “Oh, that looks like a mine over there. Let's go and smell the acid mine drainage and the sulfur and everything else.”

My family just says, “Oh, yeah, Mom's at it again.” Steve acts a bit as my guardian angel; he says, "I don't think this is a good place for you to go walking around, Fiona. There might be somebody with a shotgun. You need to think about that."

Free:

Safety first.

00:51:49 Working with Dave Dornfeld and My First Experiences with Ion Flotation

Doyle:

So, I have also done work on acid mine drainage, and this fits into the environmental theme of working out how you can actually mine sulphidic material and do it in a way that you then don't end up with acid mine drainage. You know, I don't like causing problems. Other work that I've done is also addressed at cleaning up the effluents from mining and mineral processing plants. Particularly, I've done work on using supported liquid membranes. I did some work on encapsulating the extractants within supported liquid membranes for removing metal ions as [a means to] clean up waste streams. I'd never done anything in flotation in graduate school, but I got interested in the concept of ion flotation, which is really misnomered because it's not like flotation at all other than that there are bubbles in there. So, I worked with Doug [Fuerstenau] on one ion flotation project and then spun off another one with an incredibly gifted student [Zhendong Liu].

He was responsible for all of the brain work. We—I say ‘we,’ I did have some influence—went back and looked at ion flotation kinetics in terms of the adsorption isotherms of metal ion surfactant complexes on the bubble. We were able to demonstrate that the rate-controlling step in ion flotation is the absorption of the ion surfactant complexes onto bubbles. Curiously, in the early days, a lot of ion flotation work was done in columns because people had flotation columns for minerals and thought big and long. What we discovered was that in ion flotation, everything happens in the first meter or so. So, to come up with an effective ion flotation reactor, you actually need something that's wide and fairly shallow; you don't need a big high column. Getting down into the fundamentals of that was very, very interesting. Going away from hydrometallurgy, I had about ten years in which I worked on chemical mechanical planarization [CMP], and I was working principally on copper CMP. This is the process for smoothing the metallic interlayers in the production of integrated circuits. When this was first developed, it was very much a head-scratcher in terms of people couldn't work out why it worked.

People thought that it was sacrilege to take integrated circuits that have been processed in these super clean environments and then expose them to this wet slurry with aggressive chemicals and particles, and you would end up with an atomically flat layer of copper if everything is working properly.

With several students over the course of ten years working in very, very close partnership with a colleague, Dave Dornfeld, in mechanical engineering, we got to the point of, at the nano level, describing the kinetics of it, and it truly is coupling of electrochemistry and the mechanical phenomena at the nano level. It was very, very interesting. That's a project that is, well, it's bittersweet to me because before we'd actually published the final papers on that, Dave died very suddenly of a heart attack. So, I actually published his work, now a joint work, and it was posthumously done. He was just a lovely guy. I really enjoyed working with him. Sometimes, the student would be in mechanical engineering, and sometimes they'd be in materials, but regardless of the home department of the student, they'd be in both group meetings and enriching the culture of both research groups. It was very nice, and I've done quite a lot of collaborative work, and I really enjoyed that.

Free:

That's good. That's fun to have those interdisciplinary kinds of groups going on. I've had some of those, too. That's been fun. Maybe you can tell me a little bit about some of the technical challenges that you've seen in your career and maybe some of your thoughts about the future of what we need to do to overcome some challenges. So maybe some just personally on your group and technical challenges you've had, but also just more in terms of the industry and where they're going, what challenges they face, and maybe some ideas on that end.

00:57:53 Doing Work on a Shoestring – The Power of Optimism and Creativity in Science

Doyle:

Well, in terms of technical challenges in my group, I think not enough funding is definitely an ongoing challenge. Fortunately, I'm fairly resourceful, so I do recall in the early days of my own flotation work having some fairly wild and crazy ideas and basically rigging up reactors out of used milk cartons, plastic milk jugs, and things.

Free:

That's creative.

Doyle:

It was, yes. I remember Michelle Matheson doing some work on, it was column leaching of some mining waste that was pyrite rich, and we ended up using used Coca-Cola bottles, the two-litre ones, inverted as the columns, and they actually worked very well. So, we have been creative. I think doing work on a shoestring has been sort of one of the themes there. In terms of technical challenges and particularly looking to the future, this is where actually I get very worried when I look at where the world needs to go to address climate change. Mining and mineral processing, and metallurgy are enormously important. I think we will get there, but when you look at the change in the materials supply stream that's necessary, for example, to reach the goals of electrifying our vehicles and so on, we need to have step changes in our production of lithium, rare earths for the various different kinds of renewable

energy sources, and the list goes on. I really worry about the fact that we don't see that many students who are interested in the primary industries, and they truly are crucial for the future of humanity.

01:00:51 Addressing Climate Change on a Global Scale

Doyle:

I know that that sounds like an extremely grandiose statement, but I honestly believe— I don't use grandiose statements lightly. I'm currently the chair of the Earth Resources Engineering section in the National Academy of Engineering, and we have a lot of members who are very forward-thinking. We have frequent discussions about how can we help to actually move the needle on changing the global mineral industry to deal with needs. I use the word 'global' with a lot of deliberation here because we often talk about our need for more domestic supplies so that we're not dependent on given countries that are producing critical minerals, but in order to address climate change, the whole world has to adopt renewable energy and cleaner transportation. So, it's not a question of, well, this country is okay in their limiting their supplies. We need to be thinking about this as a problem on a global stage. Unfortunately, the international political state at the moment is hardly conducive to solving humanity's problems on a global level. That's where we need to be. But, without question, hydrometallurgy, the whole of materials production, is going to be very, very busy for a long time if we're going to save the planet and save the human race.

01:02:55 Winning Awards and Gaining National Recognition

Free:

Good. Well, let's go ahead, and we'll move on into another aspect of your career. I wanted to talk just a little bit about some of the awards and recognition that you've received, and maybe you can just comment a bit about—I mean, I don't think you needed to talk about very many things—but what have been some of the meaningful awards and recognitions that you've received, and maybe why it's been helpful or impactful for you?

Doyle:

Well, one of the early awards that I got, and it was relatively minor— It's not a national award or anything, but the University of British Columbia was having an annual, I think it was an extractive metallurgy lecture, and I was one of the recipients of that. That was incredibly meaningful to me because the UBC Hydrometallurgy Group is so distinguished and so on. To be recognized by them was really special. That certificate has Keith Brimacombe's name on it. He was the department chair at the time, I think. So, just because he was such a special person, that was very, very meaningful.

Free:

Were there any others that seemed to have some impact for you?

Doyle:

Certainly, I'd mention the TMS extraction and processing lecturer award; that was a very, very meaningful one to me. I was the first woman, I believe, to get that award. I remember reading the paper

from Ernie Peters's award [the lecture that he gave when he received this award]; I think it was in one of the TMS publications. It said, "This is an award made to the man who is most distinguished," or something like that, but it mentioned man. I thought, "Well, that's a bit harsh. Does that mean that I'm not eligible for this?" Fortunately, TMS was more enlightened by the time anybody was thinking that I might possibly be a recipient of that award. The Milt [Milton E.] Wadsworth Award at SME [the Society for Mining, Metallurgy, & Exploration] was also incredibly meaningful. I first met Milt when I was a grad student at a NATO conference in Cambridge [U.K.] that Romy [Renato] Bautista organized. I also met Osseo-Asare for the first time there, and we've been good friends since. But Milt, at that conference, he looked so quintessentially American. He had checkered pants; at that point, nobody in Britain wore checkered pants. He gave a couple of great talks as well, and it was then that I started to realize just what a giant in the field Milt was. To get that award, it was just very, very special. Becoming a TMS Fellow was also very, very special. TMS has been very, very, I'd say, good to me and good for me. In my early days, it was wonderful to come to meetings. At that point, a lot of my friends from grad school would be at the meeting, so I'd get to see old friends, and of course, I made new friends. So, TMS made me the chair of the Hydrometallurgy committee fairly early on, and that got me onto the EPD [Extraction & Processing Division] Council.

One of the awards that was definitely the most surprising was being elected to the National Academy of Engineering. I was elected in 2016, and at that point, I was a full-time administrator at Berkeley, and I'd made my peace with the fact that I probably wouldn't get many more professional awards. To be elected totally out of the blue was very special because NAE's mission is to serve the nation.

Free:

What is NAE?

Doyle:

National Academy of Engineering. So, it's a big honor, but also it affords you an opportunity to make a difference for the country. I'm currently the chair of the Earth Resources Engineering section, and I'm active in quite a few other committees of the National Academy of Engineering, and I'm finding that very, very rewarding.

01:08:27 My First Encounter with TMS – Could They Not Pick a Proper Name?

Free:

That's good. Well, maybe we can go in a little bit more to talk about these professional societies that you've been involved with. You mentioned in particular that TMS has been good for you with some of the opportunities that it's provided to you. Can you tell us a little bit more about some of those opportunities, how they've helped your career, and how you first heard about TMS?

Doyle:

Well, the first time I heard about TMS, I was actually incredibly exasperated. I was studying literature for my PhD, and I saw a reference to a paper that was for TMS in some conference proceedings. So, I went to the library and was trying to find it on the index cards and just couldn't get anywhere. I went back to the lab and said to somebody, "I'm trying to find these references for TMS." And they said, "Yeah, the T

is for ‘the’.” And I said, “Oh, could they not pick a proper name?” So, that was actually my first encounter with TMS. When I came to Berkeley when I was a grad student, I belonged to some professional societies in the United Kingdom. I'm still a member of IMM [the Institute of Mining and Metallurgy, now IOM3, the Institute of Materials, Minerals & Mining], but when I came here, Jim Evans suggested that I join TMS, and I think he sponsored my application. So, I started coming to TMS meetings very regularly, and I benefited enormously from the technical programming. I learned a lot, but I also met a lot of people who had similar interests, which was enormously helpful. Then, I got involved in the committees, and people put their trust in me, probably because nobody else was volunteering to do things. But, in looking back at my career, I can see that TMS actually gave me my first administrative experience, and as somebody whose career went heavily in an administrative direction, TMS was enormously helpful and useful for giving me confidence in my ability to organize people, to manage things, to juggle lots of balls that weren't necessarily technical. Putting together the technical program is a challenge, and being there and doing it gave me a lot of very useful experience. So, being elected as a fellow of the society was just a huge honour, very, very meaningful.

01:11:37 Extend Your Hand to Help, and Others Will Help You – Advice for Students

Free:

Yes, that's great. So, what would you give as advice for young professionals and students in terms of what they could get out of becoming a member of TMS or another organization? I mean, this whole thing is under the umbrella of AIME. But I mean, what kind of advice would you give to students and professionals that are just starting their careers?

Doyle:

Definitely make a point of going to the meetings, but get involved. The programs have information about when technical committees are meeting. These are not exclusive entities. I think all of the committees are really happy to have people show up, especially if they show up and volunteer to do stuff. All you have to do is raise your hand to do stuff, and folks will say thank you very much, and they'll help you. That way, you get to broaden your professional circle. It really goes back to what I said earlier about juggling work-life balance. Don't pass up the opportunity to help, and if you extend your hand to help people, then actually, other people help you. It works professionally just as much as it does in your personal life.

Free:

Yeah, no, I found the same thing to be true. I’ve really enjoyed my association with TMS, and it's been a good thing for me. So, do you have any thoughts about what can be done to attract young people to the industry in general?

Doyle:

I think it's a very hard problem, but material science is finally now a recognized discipline. For so many years, it really wasn't. People would say, “What? What is that?” and you'd have to explain, and now it's realized. There's a huge amount of coolness in some of the work that's being done. I was looking through the technical program for the meeting last night, and some of the talks just sounded absolutely fascinating. I think that knowledge of how intellectually exciting the field is, in conjunction with I think

we need to do a better job of talking about its importance for the future of society to allow us to deal with climate change, to stop it, and to ensure that globally, people have a good standard of living. There's so much good that can come from it, and I think that there are many students who want to have an impact in the world. I think that if we can do a better job of explaining how this is a very good track to make an impact, I think we'll be successful.

Free:

Yeah, I think it's very good. I like that thought, and I agree with you on that. So, looking at your career as we wrap this up, you've had a lot of different experiences. Are there things that you would maybe do differently or things that, because of your experience, you look back and say, maybe I wish I would have done this a little differently or taken a little different track on this or that?

Doyle:

Now, that's an interesting question. I actually believe in trying not to second-guess what you would have done differently. I probably would have been better at delegating more in general and particularly delegating writing papers more to my students. I would have more publications if I hadn't insisted on being very, very comfortable with them before they went to be reviewed.

Free:

Okay.

Doyle:

And my students will probably say, “Yeah, we should just let us do a bit more.”

Free:

Let it go?

Doyle:

Yes.

Free:

It doesn't have to be perfect to go out the door.

01:16:20 The Cure for Boredom – Final Thoughts on a Fulfilling Career

Free:

So, are there things that, if you look at your career and sum it up in a really brief statement of just a few words, how would you describe it?

Doyle:

It's been a wild ride, and part of it has been the fact that I get bored fairly easily, which is hard to admit because when I was a child, if we ever said that we were bored, my mother would say, “Well, if you’re bored, I'll find you some work to do.” So, we never dared say that we were bored. But I like the variety of starting new projects and doing something fun, and then moving on to something else. I've also found that administrative positions, after a few years in an administrative position, I kind of get bored with it and want to move on to something else, and I've done that. So, perhaps the pithy description of my career has been that it's a cure for boredom.

Free:

Well, that's good. It's good. Well, it's fun that you can follow your passion. It's been fun to interview you and learn about some of your experiences. Is there anything else that you would like to comment on?

Doyle:

I'd like to thank you so much, Mike, for taking the time to do this. It's been fun. Thank you so much.

Free:

It's been fun for me too.