THE LEGEND OF P9

Models, plants, students and the PDP8/I 1961 to 1982

1 : Planning the project

The planning of an industry funded research project on mineral processing at The University of Queensland (UQ) started with a letter on July 12 1961 from Frank White, Professor and Head of the Department of Mining and Metallurgical Engineering at UQ, to Beryl Jacka, Secretary of the Australian Mineral Industries Research Association (AMIRA). There was an accompanying proposal for research on automatic control.

The background to the proposal was that the methods of operating mineral processing plants before 1960 were rule-of-thumb and qualitative because there were no on-line methods of measurement of operating variables and process understanding was poor. That satisfactory results were obtained with complex ore bodies was often due at least partly to the skills of operators who had years of experience in their plants. By contrast other industries, in particular the chemical industries, were using automatic control techniques which had developed rapidly during World War II to improve the quality and quantity of materials produced for the war effort. Metallurgists from remote mining towns who were in the armed services during the 1940s took the opportunity to discuss their processes with engineers from other industries and when they returned to their own plants they knew the advantages of automatic control.

By the mid-1950s process control was being discussed in mineral plants. The main problems in implementing it related to the continuous measurement of pulp characteristics and to understanding the processes enough to design effective control loops.

The project proposed by White was concerned with the automatic control of grinding and flotation processes concentrating first on process understanding and then on automatic control. The link between the Department and Mount Isa Mines Limited ensured that the project would be industry-oriented and it is worth noting that this type of link has been crucial to the continuing success of P9. Excerpts from White's letter are given.

I am addressing this letter to you at the suggestion of Mr J W Foots, General Manager, Mount Isa Mines Limited. It concerns a proposed mineral processing project which, we consider, should be of undoubted interest and value to all sections of the mineral industry and could well prove to be the most important and, probably, the most rewarding line of investigation in the whole field of metallurgical and mineral dressing research....In fact the project is of such a nature that Mr Foots considers that it should be discussed by the Council of your Association.....As you will see the project concerns the eventual automatic control of mineral processing operations, with particular reference to grinding and flotation circuits.

AMIRA had adopted a new approach to research. It was formed in 1959 to represent the interests of the mineral industry on a statutory authority set up to take control of the R and D branch of the South Australian Department of Mines. The South Australian and Commonwealth Governments were the other members. During 1960 the AMIRA Council decided to become involved in R and D funding and it was this decision that persuaded Frank White to prepare his research proposal. The 14 AMIRA Councillors were invited to assess the proposal individually and the responses were reviewed by Dr John Nixon, Chief Research Metallurgist of Consolidated Zinc, who was Honorary Executive Officer of AMIRA. On October

26 1961 Nixon wrote to Maurice Mawby, President of AMIRA and Chair of Consolidated Zinc (later Sir Maurice), reporting that several Councillors supported a project concerned with grinding research while others were not interested. Nixon wrote that:

It may be of interest to note that A.J.Lynch (who no doubt prepared the submission) was on the Metallurgical Research staff at The Zinc Corporation Ltd. For several years, during which time he obtained an external Masters degree for his work on the Broadbent-Callcott theory of grinding. (T.Callcott is incidentally on Dr Worner's staff at Shortland). Following Lynch's work the throughput of the rod mill at New Broken Hill Consolidated was increased by over 15%. The Queensland project was discussed with C W Thomas, Chief Metallurgist of The Zinc Corporation Ltd, who thought that the grinding investigation should be sponsored by industry. When Prof White was in Melbourne on 23rd October 1961 I sounded him out on the minimum requirements for the grinding portion of the project. These would be £2,400 ($62,500) pa for Lynch and about £1,500 ($37,500) for equipment and other expenses.

(Monetary values in this note are written in currency of the day and 2011 currency because of inflation from 1961 to 2011 and the change from pounds to dollars in 1966. The consumer price index was used for calculation.)

On November 29, 1961, Beryl Jacka informed Frank White by letter that AMIRA would guarantee a sum of £3,000 ($75,000) per annum for a three year period commencing January 1st, 1962, for the project on the Simulation & Automatic Control of Mineral Treatment Processes.

By July 10 1962 13 companies had agreed to participate, they were Broken Hill Proprietary Co. Ltd., Broken Hill South Ltd., Cement and Concrete Association of Australia, Consolidated Zinc Pty. Ltd., Electrolytic Zinc Co. of Australasia Ltd., Mary Kathleen Uranium, Mount Isa Mines Ltd., Nairne Pyrites, North Broken Hill Ltd., Peko Mines, Territory Enterprises Pty. Ltd., United Uranium N.L., Western Mining Corporation. Later King Island Scheelite, Aberfoyle and Mount Lyell joined the project.

The UQ Mineral Processing project was the fourth project in which AMIRA participated but the first which it supported from a proposal. The other projects were:

- the Baas Becking project at CSIRO on the formation of ore bodies by bacteria with support of £6,400 ($160,000) per annum for 5 years and similar contributions from CSIRO and the Bureau of Mineral Resources. This project had started at BMR in the late 1950s and AMIRA took responsibility in 1960. The project continued until the mid-1980s.
- a grant of £4,225 ($106,000) to Dr Keith Norrish of the CSIRO Division of Soils for an XRF machine to work on the analysis of mineral products. This project was still operating in 1990.
- the wire rope project at the University of New South Wales which was concerned with the non-contact testing of Koepe hoisting ropes at high speed. This project closed in 1975.

Why was the mineral processing project recorded as P9? Jim May gave the answer:

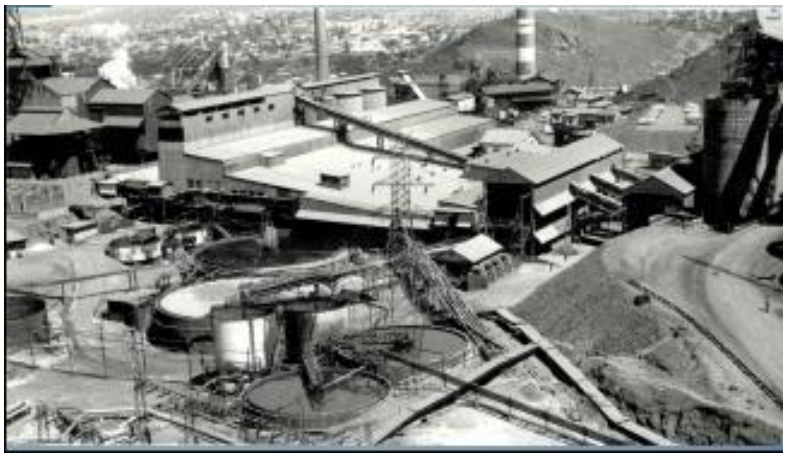
When I arrived at AMIRA in July 1968, I found that there were some dozen or so projects underway and several more about to start. There was no numbering system for projects and the filing system was not very sophisticated. It became clear we needed to set up a project numbering system. From memory I don't think this was properly instituted until sometime in 1970. I have no real recollection of exactly how the numbers were allocated to the existing projects but it wasn't exactly in the order the projects had commenced and I have no recollection of why.

So the Wire Rope Project (which had commenced in August 1962) got number 1, the Amdel project on Fluid Beds got 2, the Mine Ventilation project at CSIRO, which didn't start until late 1969 or early 1970, got 3. The Mineral Processing project which commenced in 1961 should have had number 1 but ended up as number 9. It had the title of Simulation & Automatic Control of Mineral Treatment Processes. The shortened project title of Mineral Processing was not used until the first extension commencing in August 1964. So P9 was the file number given to it (in a somewhat arbitrary fashion by the look of it) and that has continued ever since.

Not even Frank White, who was the quintessential optimist about his Department, could have imagined that his proposal for research would result in a project which is still working 50 years later. The research group was based at the UQ Experimental Mine in the Brisbane suburb of Indooroopilly, where small open pit and underground operations produced 227,343 oz of silver and 1,796 tons of lead during 1919-1928. The mine is on a 3.5 hectare site, 5 km from the UQ's St Lucia campus in Brisbane and in the early 1950s White arranged for it to be transferred to UQ at negligible cost. The importance of the site to P9 was that the 5 km distance between Indooroopilly and St Lucia combined with the degraded mine site and the industry involvement in the project, which was then undesirable, did not encourage UQ authorities to be interested. So P9 went its own way, always within UQ rules, and always with enthusiasm as the driving factor.

2 : The 1960s

2.1 1962-4 The group which worked on the Mineral Processing project from 1962-64 was Alban Lynch (research officer funded by AMIRA), David Moore and TC Rao (funded by scholarships), and two technicians funded by UQ. Lynch modelled rod mills, ball mills and plant circuits, Rao modelled cyclones, and Moore studied breakage functions. Mount Isa Mines Ltd supported the work by allowing the circuits in its concentrator to be the experimental test sites and by meeting accommodation and transport costs. This was the start of the P9 tradition of plant based research, and of graduate students spending months at plants on thesis projects which had the objectives of improving circuits by modelling and providing data to support the AMIRA project.



No. 1 concentrator at Mount Isa in 1962

Arrangements for visits to Mount Isa were made via Bill Wickham, the MIM Company Secretary in Brisbane, who would be asked by Lynch to phone metallurgical staff at Mount Isa to ask permission for a visit and to buy airline tickets. Long distance calls were taboo at UQ because of cost.

The cyclone model was the first success. MIM had replaced their spiral classifiers with cyclones but results were poor and a rig was built for extensive cyclone testing. This was the rig on which Rao and Chris Madsen, a Norwegian sailor and MIM employee, worked for 18 months. From their test work in Mount Isa, and the analysis of data by Rao in Brisbane, came the cyclone model which is still used today, albeit with improvements.

The grinding models developed by Lynch used data collected from sampling surveys. There were three main circuits in the concentrator, two for copper ore and one for lead ore, and each contained one rod mill, three ball mills and six cyclones, so there was plenty of data. All experimental work was done by Lynch and Rao and two years were required to complete the models.

The breakage function was an important component of the mill model and the validity of using a step matrix to represent it was investigated by David Moore using irradiated size fractions. His conclusions were that a step matrix was valid and that the Broadbent-Callcott matrix technique was suitable for models, but that any breakage function was suitable provided that it was used with its companion selection function. David Moore was a UQ BSc (Hons I) graduate in Science and a University Medallist whose research schedule had to fit with his interests in Rugby Union and politics. He was Queensland Rhodes Scholar in 1964. It was fortunate that a 15 hr half-life radioisotope was chosen for his work so particles had to be broken as soon as possible after irradiation otherwise the experiment would have disappeared. Longer half-lives may not have been given such urgent attention and he may never have completed the research!

In late 1964 funding was renewed by AMIRA at the increased rate of £7,750 ($192,000) per annum for three years and MIM agreed to pay Lynch's salary and make a grant for equipment.

2.2 1965-7 The 8 month strike at Mount Isa during 1964-5 impeded experimental work because the mine did not operate but modelling continued in Brisbane and by 1966 models were available for hydrocyclones, rod mills and ball mills. When Bill Whiten was recruited in 1966 he brought much needed computing skills which were put to work writing a programme for the GE225 computer at UQ to simulate a circuit containing one rod mill, three ball mills and six hydrocyclones. The simulation indicated that rearrangement would result in an increase in capacity and this increase occurred immediately the new circuit was operated. The phone call from Mount Isa telling of the increase was ample recompense for 5 years of work. The additional income which the increase in throughput generated for MIM was welcome because mining operations were being expanded and this would have been a factor in the establishment of the JKMRC by MIM three years later.

The first residential school was held in August 1966 to explain the new modelling and simulation technique to plant metallurgists. The school was two weeks duration and a Fortran course was part of it. The course was attended by Al Schlechten, Head of Metallurgy at the Colorado School of Mines, and at his invitation the course was given at CSM in 1967. This started the P9 international activities.

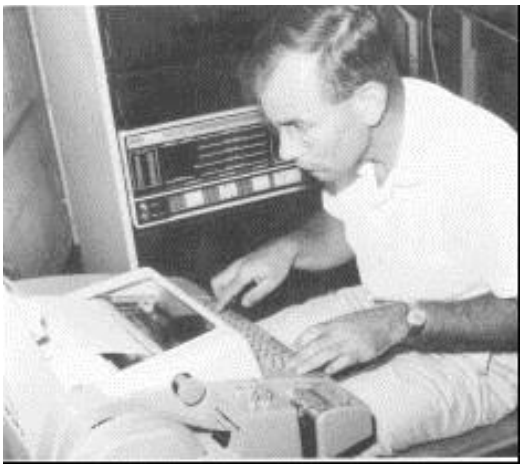
In 1967 research was extended to other plants and to automatic control. At Broken Hill the grinding circuit at NBHC contained a rod mill, 2 ball mills, and 2 rake classifiers and simulation indicated that rearrangement would improve the production rate and flotation efficiency. When tested these both occurred. The first project review meeting was held at ZC-NBHC while the work was in progress. Metallurgists attended from ZC-NBHC, the North and South mines, and Cobar. The meeting was arranged at short notice and no papers or reports were presented but lively discussion continued for some hours.

At MIM in 1967 a control system for a copper grinding circuit was designed by the instrument engineer Ken Dredge using an equation derived from the cyclone model to predict the cyclone overflow size (it would now be called a soft sensor). The variable speed drive on the pump was controlled by the pulp level in the sump, and ore and water rates were controlled by the soft sensor which was built into an analogue computer. Again the milling rate increased.

2.3 1968-70 Late in 1967 a proposal was written for the second renewal of the project and this time automatic control and flotation were the main topics. The result was a grant of $28,000 ($319,000) per annum for three years which included the cost of a PDP 8 digital computer and input/output devices. This was the first digital computer used in an Australian mineral processing plant. UQ must have assisted the research group with an advance of some of its cost since companies were asked to pay one third of the cost of $19,472 ($218,000) in 1968, 1969 and 1970.

UQ admin staff may have been reluctant to visit the UQ mine but they assisted when asked and never questioned the style of research. Early proposals were not discussed with sponsors, they were written by Lynch and the method of communication was mail via the PMG Department (Australia Post). Grants went to UQ which was the banker and the final authority.

The 1968-70 grant was large by UQ standards and because of P9 the Mining Department was for some years the largest recipient of research grants at UQ. The main purchase in 1968 was the PDP8/I computer and for several years it was used for control trials in plants in Mount Isa and Broken Hill. These trials involved recording and stabilising circuit performance and controlling inputs to increase feed rates. Their success was an important factor in the widespread acceptance of computer control in Australian operations. This computer was also used for the control of a small scale grinding circuit in the JKMRC pilot plant and this provided a valuable training base for both postgraduate students and industry personnel.



PDP8/I computer with teletype, paper tape reader and punch

In 1968 the research group was still housed in the 18m by 15m corrugated iron shed and the student room was crowded with new students arriving, which was invigorating but uncomfortable. One student was Cliff Braes, an experienced metallurgist who was seconded from Zinc Corporation to study flotation kinetics. He brought his own plant data and this was the start of modelling plant flotation circuits. He concluded that more must be known about composite particles and this soon became a major project within P9.

A surprising feature of P9 was the growth of the student group from 1968. Some students may have been interested by the lectures Lynch gave to final year students at no cost to UQ which were concerned with computers in mineral processing. Other students wished to stay in Brisbane to compete in top class sporting teams. Whatever the reason the students were welcome, including the Honours students of whom 6 were working for their theses on aspects of P9 in 1968.

Companies were receptive to on-site research and mill managers would meet requests if mill results would not be jeopardised. A typical approach was for Lynch and the plant manager to discuss research in the mill office, decide what to do and invite students in the P9 group to get on with the job even if it meant long road trips to distant sites such as Kalgoorlie. Peter Isles was a graduate mining engineer whose P9 project was to model mixing in ore bins because ore flowed through them on the way from the mine to the mill and the mixing which occurred affected the flotation response to an ore change. The experimental work was done at Mount Lyell where a bin was half filled with 1% copper ore, then covered with a thick layer of 10% copper ore taken from a small high grade section, then filled with 1% ore. The bin discharge was sampled continuously and samples were assayed for copper. The assay data collected was used to validate a mathematical model of ore flow through a bin which had been developed prior to the Mt Lyell test. Similarly MIM filled a bin with very coarse ore to provide data on the effect of ore size on the rod mill model.

At MIM in 1968 modelling and controlling crushing circuits became an objective of P9 research. On-line data were difficult to collect because the chart recorders showed only thick black bands of ink as crusher feeds and power consumptions varied wildly. Bill Whiten undertook sampling of the MIM number 2 crushing plant and after developing models of crushers and screens he designed a control system which maintained maximum power consumption in the secondary crushers by controlling their feed rates using crusher power and level sensors in the bins. Crusher station throughput was increased considerably.

Jim May took up his appointment as CEO of AMIRA in July 1968 and he became a valuable advisor to P9 staff on the direction of the growing project.

1969 was very important for P9 for several reasons.

- Jim Foots, Managing Director of Mount Isa Mines Ltd (later Sir James), recommended to his Board that MIM should give UQ $125,000 ($1.25 million) to establish a research building at the University mine and a grant of $25,000 ($250,000) per annum for 5 years for operating expenses.
- The number of students was increasing which was good for P9 but it highlighted the problem with accommodation since their room was small and directly under the sloping iron roof.
- Joan Porter, a 22 year old secretary from Gunnedah, NSW, joined the group and her uninhibited style brought discipline into the non technical side of P9. When Joan returned to JKMRC after time out with growing children her style was unchanged and still effective despite the 20 year interval.

The JKMRC was built in 1970 and the luxury of individual rooms and snake-free toilets in that building was sublime. Joan's desk was in the foyer and had a telephone with extensions, and other facilities included a small conference room in which there were lively debates after seminars, an electronic laboratory and a remote terminal to the PDP10 computer at St Lucia. There were no formal meetings but seminars and daily discussions in the lunch room meant that there was no lack of communication.

3 : The 1970s

A new style of proposal was written for P9 support in late 1970. The MIM grant had been announced and it paid for the salaries of P9 staff so the proposal requested a scholarship and travel expenses for 7 students at a cost of $4,000 ($40,860) each. Projects would be relevant to automatic control, such as the dynamic behaviour of grinding circuits when a change in feed occurred and the kinetics of flotation in large cells, and would be carried out in plants by students working for their higher degrees. This type of research was suitable to companies and became the trademark of P9. AMIRA was asked for $34,000 ($347,272) per annum for three years and companies contributed $39,500 ($403,000) which was a pleasant surprise. When added to the $25,000 ($255,000) pa from MIM the P9 project which was the only JKMRC project at the time, was well placed financially. It was also well placed mathematically because Whiten had developed techniques to calculate the material balances and the model parameters. The tempo of plant research increased after 1970 with plant studies up to 6 months duration carried out at several locations including:

- Mount Isa where projects included the simulation of a three stage grinding circuit responding to changes in ore and water rates (Mal Lees); the kinetics of chalcopyrite flotation in large cells (Don McKee); and the simulation and automatic control of a chalcopyrite flotation circuit (Emmy Manlapig),
- Philex Corporation in the Philippines where the kinetics of flotation of a chalcopyrite ore with only a few composites was investigated (Bill Johnson). Two Philex metallurgists were seconded to the project,
- Cobar Mines at Cobar and Peko Mines at Tennant Creek where data were collected for a model of autogenous mills (Geoff Stanley). They were new in Australia and their pros and cons were being debated,
- Broken Hill where the flotation kinetics of galena and marmatite were investigated at NBHC (Grant Thorne),
- Kambalda and Savage River where there were further studies on the modelling, control and simulation of autogenous mills (Geoff Gault),
- Pinjarra in WA, St Helena in South Africa and Henderson in Colorado where different aspects of SAG milling were investigated by one student (Geoff Duckworth),
- Mount Newman in WA where the crushing model was applied to minimising fines in the iron ore product (Mark White).

Transfer of technology was always important in P9 and this was done via students working on site which was the most important technique, residential schools, reports and publications, meetings at mine sites and a symposium which was held in 1971. At this symposium there was a vigorous debate between Kelsall, who led a CSIRO unit working on modelling and control, and Lynch. It was more robust than the usual gentle debates at such meetings but the sound and fury achieved little.

Julius Kruttschnitt, Professor Alban Lynch, Joan Porter, 13 P9 students together with some JKMRC and UQ staff gathered at the JKMRC after a seminar by JK in 1971 on his life in the mining industry.

In July 1971 Lynch took 12 month sabbatical leave at the University of Minnesota and Whiten became Director of JKMRC for the year. He introduced Friday morning seminars in which every student spoke about his work, the word *his* is used because there were no women students in Australian mining departments then.

In the mid-1970s John Hall, a P9 student, and CSIRO scientists used an SEM at CSIRO to develop a technique to outline the surfaces of minerals in composite particles and from this work came QEM*SEM which was developed by CSIRO with backing from AMIRA. In the mid 1970s also a project was set up at JKMRC to model blasting because of its effect on downstream processes and this became an AMIRA project which continued for years and for a while rivalled P9 in size.

Proposals to AMIRA during the 1970s to support P9 covered the 1974-76, 77-79, and 80-82 periods and the annual amounts awarded were $42,000 ($319,000), $75,000 ($427,000) and $120,000 ($514,000). In the days of small research grants those amounts were large. Two portable computers, an HP2100 and a PDP 11, were installed by MIM and NBHC to handle their plant control systems and the results were available for P9 reports. Ten companies based outside Australia joined P9 during the late 1970s and a review meeting was held in Los Angeles in 1982.

In 1980 Narayanan, a JKMRC postgraduate student, and Whiten constructed an impact tester for measuring breakage functions, and developed the procedure for analysis of the breakage data. The test equipment has been updated and together with the analysis procedure is widely used today. By 1982 P9 had been operating for 21 years and 28 students working on the project had graduated from UQ with higher degrees. Funds given to UQ during 1962-82 by AMIRA to support P9 were about $8 million (2011 value) and the financial benefits to AMIRA companies far exceeded the costs because of higher throughputs and better controlled circuits.

Like any family P9 had its ups and downs, rejoicing with successes and the higher degrees which went with them and mourning the deaths of two fine engineers, John Bishop in 1977 and Grahame Walter in 1984. In 1981 Don McKee, JKMRC Alumni No. 7, returned to JKMRC after 9 years in industry and as P9 manager from 1982 brought new ideas into the direction and style of the project.

4 : Comments on the activities of P9 during 1962-82.

Why was P9 successful? Some reasons were:

- it was a project whose time had come because the mineral industry needed to improve its technology to meet the demands of the post war minerals boom. Grinding circuits in particular had to be improved because they limited productivity. It was probably their interest in grinding which persuaded the AMIRA companies to support P9,
- MIM had a particular interest in research and education and its support of on-site research was essential to the success of P9 in its early years,
- Frank White had the enterprise to initiate P9 and locate it at the Indooroopilly mine which he had acquired for UQ. This was several kilometres from the St Lucia campus and the isolation was valuable,
- postgraduate students were involved from the start and were enthusiastic about carrying out their research in the unscientific environment of mineral processing plants,
- the research theme of P9 which was the modelling and control of mineral processing circuits never varied and no projects outside the theme were accepted,
- the modus operandi of P9 was established in the early 1960s and was not changed for many years.

There were many visitors to P9 from other Universities during the 1970s. The common question was - how did P9 work? Nothing was secret and several left the JKMRC with the intention of starting a P9 look-alike in their own Universities. It never happened. P9 had developed during the 1960s as an unconventional University programme with no support from University Treasury funds and repeating it in another establishment would never be easy.

This history of the first 20 years of the AMIRA P9 Project was written by Emeritus Professor Alban Lynch dated 5/9/2011.