The Wigner Group - 1949-53

At the beginning of the new year I went to seek out Tom Fry. I found him all alone in a temporary lab. in the middle of Hangar 8, close to the GLEEP pile. The lab. was very primitive; just four walls, a door and no roof. It was full of piles of equipment and very untidy. Tom explained that our new labs, which would be on the north west side of the Hangar, were not ready so we would have to live in this messy environment for the next two months. Two other members of the group, Ron Dugdale and Dr. Ken Donaldson had a lab. in Hangar 10, and would join us when we moved into the new accommodation. Other members of the group were due to arrive in the next few months.

The group was named after Eugene P. Wigner a famous USA physicist. He had, many years before, warned about the changes that may be experienced in the materials used in the construction of a Nuclear Reactor.

The first experiment

Tom explained that we were going to put a semiconductor diode into the GLEEP pile and see how it would be changed by the radiation. The diode was a Germanium point contact device which was used as a detector in electronic equipment. It had a low forward resistance and a high reverse resistance. It was similar to, but a much more advanced form of the 'Cats whisker and Crystal', used in early Radio receivers. As he did not expect any quick changes, we would need to record the forward and reverse current through the diode over a long period of time.

Tom found a drum recorder which could be set to rotate once per day. This was essentially an Ammeter with a needle that just skimmed the surface of the rotating drum. A mechanical arm was lowered once per minute and pressed the needle onto the drum. A 'typewriter' ribbon in between made a mark on the chart which was attached to the drum. A two volt lead-acid battery and a variable resistance box completed the circuit through the diode and the meter. By adjusting the resistance we were able to get the forward and reverse resistance of the diode in the range of the meter. We next needed to provide a switch to periodically reverse the current. After some thought Tom had a bright idea. The motorised unit that Bill and I had built the previous year to rotate the foils in the Exponential Pile could be modified to provide a reversing switch. We added a cam and a pair of 'Microswitches' and set it to reverse the current every 15 minutes. The result was perfect; it produced two traces on the recorder, one for the forward current and one for the reverse.

The next problem was more difficult. The diode was very temperature dependent, so it would be necessary to control the temperature when it was placed in the pile. Tom asked me to make a small oven in which we could place the diode and control its temperature. I found a piece of Aluminium tube 2 inches in diameter and 3 inches long. On this I wound a heater of Constantan resistance wire. I first placed a layer of paper on the tube then wound a single layer of wire. The whole thing was fixed in place with 'Durofix' glue.

While I was making the oven Tom had found an 'Electroflow' temperature controller. This was another 'meter' type device. It had a mechanical 'chopper' which once per minute sensed the position of the meter arm, and operated a switch when the meter was above the preset level. We made a thermocouple, to measure the temperature, from Copper and Constantan wires. The thermocouple was attached to the inside of the oven and the other end to the controller. Using a 'Variac' and a transformer we applied power to the heater via the controller. After half an hour we had the device controlling, but were not sure of the temperature because the controller was calibrated for Iron-Constantan, and did not match our thermocouple! A simple Mercury in glass thermometer was used to verify the temperature, which was then set at 30degC.

Tom had already obtained permission to place this experiment in the GLEEP pile. There were very few experimental holes in the pile; an unfortunate decision made during the hurry to get the first pile working. We were allowed to use the hole on the opposite side from the GLEEP control room. The first task was to move all our equipment close to the pile and the hole. Next I had to increase the length of all the wires so that we could place the oven at the centre of the pile. We were now ready to go. By modern standards it must have looked a mess; a crude oven containing the diode, and an untidy bunch of wires all stuck together by sticky tape.

As soon as Tom was informed that the pile had shut down, we removed the plug from the hole in the pile. The oven, with its long trailing leads, was then pushed gently into the hole using a long rod. We then had to estimate the distance to get the oven at the centre of the pile. We then blocked, as best we could, the hole without damaging the wire connections. When we switched on our equipment, everything was working perfectly and the temperature of the oven was soon controlling at 30degC.

We had to wait some time for the pile to start up again. This was because other people were installing equipment. Tom was worried that the temperature control may be lost if it got too hot when the pile was working. He did not know what the internal temperature would be, or whether it would be cooled by internal ventilation. However, when the pile was in operation, our experiment was working perfectly. We watched it carefully for several hours, to ensure that there were no problems. The current through the diode was being recorded, and all was well. Then, as nothing dramatic was happening, Tom decided that we could leave it overnight.

I can't remember now how long it took, but the current through the diode slowly but surely changed. The forward resistance increased, and the reverse resistance decreased until the two lines merged on the chart. The diode effect had therefore been destroyed.

Tom was very pleased at the result. I am sure that it was what he expected. I confess, that I did not know what would happen, and was very surprised. I never knew whether Tom ever published that result. The only reference to it I found many years later in a book by John Cockroft.

[When I was in the RAF in the early 1950's, I found that the same type of diode was used as a first detector in microwave Radar systems. A burst of radiation could therefore render the system inactive.]

While the experiment was in progress, Tom gave some thought to how we should manage the equipment when it was removed from the pile; it would of course be very radioactive. The result was primitive but otherwise quite effective. I obtained a large steel 'ammunition' box, cut holes in each end and fixed a metal rod through the centre of the box. With a handle to turn the rod, we could wind up the wire bundle as it emerged from the pile and capture all the radioactive material in the box. This worked perfectly, and the task completed very quickly. The box was then sealed and sent for disposal.

The Early Days.

Tom was bursting with ideas, and seemed to want to do everything at once. One of the important materials used in a pile was the Graphite moderator. We needed to measure all the properties of the material, and see how they changed with irradiation.

Ron Dugdale was given the task of measuring the electrical resistivity. I helped him to set up the equipment and took most of the measurements. The Graphite sample was a 5mm diameter rod with four circular flanges; two at each end. We passed an electric current through the outer contacts, and measured the voltage between the inner two. I remember being very thrilled to learn how to use a real 'Potentiometer' instrument, instead of the primitive ones that I had used at college.

Soon another member of the group arrived. His name was George Kinchin; another Cambridge graduate. He was to measure the properties of magnetic materials. I assisted him in building an 'Inductance Bridge', and helped him with the measurements.

One of the worries about Graphite was its dimensional stability. As most piles of that time were very large 'piles' of Graphite blocks, it was very important to know how it would behave when irradiated. Tom had some special samples made for this purpose. They were one inch cubes of Graphite. These were sent to a precision engineering company, where they 'spot ground' the surfaces of the cube, and then polished them until they looked like mirrors. It was then possible to measure the dimensions of the cube using a 'Comparator'. This was a very special instrument that could compare, to a high degree of accuracy, the sample with a metal standard. The standard was an assembly of precise 'slip gauges' which could be made up to be close to the sample size. The Comparator was borrowed from the Engineering Standards group, and had to come with an expert operator. Tom had this installed in a temperature controlled room, which was a basement under the floor of Hangar 8.

Initial measurements, aftèr irradiation in the Bepo pile, showed that the changes were very small. Tom therefore decided to send some of the samples to Chalk River in Canada, where they could be put in a Reactor with a much higher Neutron flux. I made a special metal box, which was lined with thick felt, to transport the samples. These were then sent to Canada by 'Diplomatic Bag'. I don't know how Tom managed this, but it was to ensure that the delicate samples were not even looked at by Customs! I'm not sure whether Tom had considered how they would be returned when they were radioactive. It is interesting that I never knew if they had been returned.
By the middle of February our new accommodation was ready. This was rather splendid and all brand new. On the north west side of the hangar we had three rooms on the ground floor, and one on the first floor. Also we had the two basement rooms under the floor in the middle of the hangar. (One was already in use for the Comparator measurements). Fortunately another assistant arrived just in time for the move. His name was Jack Oswald. Tom had ordered the new furniture, and had made plans of how the space should be used. We all worked very hard to install this and move the

equipment from the temporary lab, and also from Ron Dugdale's lab in Hangar 10. It was a shame for Jack, whose introduction to the group was moving furniture.

The largest lab. (G07) was home to Tom, George, Jack and myself. Ron was in G04, and Ken in G02. The lab. on the first floor (105) was for John Simmons who had not yet arrived at Harwell. 105 was the only lab. with an adjacent office. An interesting feature in each of the ground floor labs. was a 'Galvanometer Pillar' in the corner of the room. This was a solid pillar about one foot square and four foot high. Its foundation was independent and isolated from the building, making it a vibration free support suitable for a galvanometer or other sensitive instrument. These were purpose built at the request of Tom. I never saw anything like it in any other building.

Inside the GLEEP Pile

At the beginning of 1949, my old school friend Ralph Thomas joined Harwell. He was put into the GLEEP group, and was placed in a lab. which was quite close to where I worked. We often went to lunch together.

One day Ralph told me that he had obtained permission to go inside the GLEEP Pile. The only condition was that he had to take someone with him; so he asked me. The next time the pile was shut down, Ralph collected me and we went to the control room where the pile manager gave us torches and a radiation meter. I don't remember any comments as to why we wanted to go inside! We climbed up to the top of the pile and found the access hole. It was a 'trap door' in the roof of the structure. The heavy cover had been removed and this revealed a hole about 2 foot square. It was dark inside. Ralph had been told the location of the light switch, and turned on the light. We climbed down a vertical steel ladder and found ourselves standing on the top of the graphite pile. There were various structures on the top of the pile, but the most obvious one was the 'Shutoff rod' mechanism. This was a horizontal shaft that held the cables from which the shutoff rods were suspended. The shaft could be rotated by an electric motor to raise the rods from the pile prior to start up. I moved to the side of the pile and peered over the edge into the inky blackness. There were no lights down there. Using my torch I could see scaffolding in the gap between the pile and the concrete shield. I looked back up to the small hole through which we had entered this strange world. I suddenly felt extremely claustrophobic and panicky. What if someone closed that hole and turned on the pile?............ Ralph was already climbing down the scaffolding to a lower level. I followed and found that it turned out to be just a single scaffolding plank. It seemed very precarious! We were now just above the vertical centre of the pile. I could see the ends of the horizontal fuel channels, and just below me was one of the connecting tubes that linked an experimental hole from the shield to the interior of the pile.

We managed to walk on the wobbly planks around three sides of the pile. When we reached the control face, we were blocked by the tubes carrying the horizontal control rods. I looked at the radiation monitor; it was reading 60 R (Roentgen) and as this was worryingly high, I suggested that we had seen enough and should get out.

As we climbed out of the narrow hatch I breathed a sigh of relief; it had been an interesting but possibly foolhardy experience. When the pile was operational it required five feet of concrete to protect people on the outside! We went straight to the control room to inform the manager that we were out.

It is interesting that we wore no special protective clothing; just a white lab. coat and cloth overshoes. The manager had insisted on the overshoes to protect the inside of the pile!

Graphite Growth

Once we were installed in our new lab. Tom gave me two new experiments to look after. They were both to measure the change in length of a Graphite rod while it was being irradiated in the Bepo pile.

The first was a 'pneumatic' method: A Graphite rod 4 inches long and 2 inches in diameter was held in a jig with a very small gap between the end of the rod and a Graphite end piece. The 'end' had a hole in the centre through which air could be blown, and three pairs of holes spaced at 120 degrees. Each pair of holes was connected to a manometer to measure the pressure difference caused by the air flowing through the narrow gap. Another manometer and a needle valve was placed in the air supply line to control the air flow through the device. The gap was maintained by springs and referenced to three Molybdenum rods. I had to attach seven Nickel tubes to the end piece. This was done by Copper plating the Graphite surface, using a filter paper wet with Copper Sulphate solution. The tubes were then soldered to the Copper. I was very glad that I had gained some experience at glass blowing, as I was able to make the manometers myself.

The whole device, complete with its manometers and lengths of plastic tubing, was very bulky and unwieldy. I found it hard to believe that we could install this in the centre of the Bepo pile.

The second experiment was an 'optical lever'. A graphite rod 4 inches long and ½ inch in diameter was compared with a Molybdenum rod, and the difference used to tilt a small metal mirror. The tilt could then be measured using a telescope looking at an illuminated scale reflected in the mirror. It was easy to set this up in the lab. with a short optical path, but the thought of installing this in the Bepo pile was quite daunting. It would need additional mirrors to bend the optical path, so that one was not looking directly into the heart of the pile.

I enjoyed setting up and testing both these experiments, but could not believe that we would manage to set them up in the pile. Fortunately, before we got that far Tom decided that the changes in length would be too small to measure in real time. The direct measurements of the 1 inch cubes had shown very small changes.

I spent about a month working on these two experiments; it did seem a waste of my time, but it was a very interesting exercise.

Graphite. One thing I did learn at this time was that Graphite is not isotropic! That is, it is not the same in all directions. When it is manufactured, coke is ground, mixed with a binder and extruded into long bars. The bars are then 'Graphitised' at very high temperature in an oven. This drives off the volatile components and leaves just pure Graphitic Carbon. As the crystals are flat plates, they are partially aligned by the extrusion process. This means that the physical properties are different in the two directions: 'parallel' and 'perpendicular' to the direction of extrusion. This did mean that our measurements had to made in both these directions.

The 'Master – Slave Manipulator

One morning Tom arrived at the lab. carrying a large box of Meccano. It was well used and I believe that it was his own personal collection. He said that he had an interesting little job for me. – To build a Master – Slave manipulator. At first I did not know what he meant, so he made a rough sketch on a piece of paper. Two mechanical arms, so linked that the 'Slave' arm would exactly duplicate the movements of the 'Master' arm. If we placed a radiation shield between the two arms, we could manipulate highly radioactive material in complete safety. After a brief discussion about the arm, and the size that we would need, he was gone; I did not see him again for three days.

I spent the first morning making drawings of how I thought it should look. To duplicate a human arm would have been very difficult; far too many motions which would have to be transferred to the slave arm. I thought that it would simplify matters if we concentrated on the shoulder, and just one other joint; a combination of elbow and wrist. The hand was a little easier. For the Master end just a wooden 'file' handle, which the operator could use to push the arm around. The Slave hand could be a pincer like jaw that could be operated remotely.

The shoulder proved to be quite simple; a horizontal rod, free to rotate, with the arms fixed at each end. Each arm would be hinged to tilt along the direction of rod, and connected to the other arm by a simple parallel link. This would give two directions of motion to the arm with little complexity. The elbow/wrist was much more complicated; to transfer the motion of the hand in two dimensions by mechanical links seemed quite daunting. I struggled with this for a whole day before I found a solution. The 'Bowden' cable used on most bicycles to transfer the motion of the handle to the brake calliper, would be ideal. I was not sure how much friction there would be in the cable, but it was a very simple solution. Bowden cable could also be used to operate the hand.

By the next time I saw Tom, I had built one arm from Meccano and produced several drawings showing how the final system would look. Tom was very pleased, and without much discussion, told me to get on and build a working model. He said that he had some ideas about the business end (the hand) and would see what was available. I expressed some doubt about where to build the model; there was very little floor space left in the lab. and I thought that it would cause too much congestion. Tom took me along to Ken Donaldson's Lab. which was largely empty. Ken reluctantly agreed to host this large device.

The first task was to build a large supporting frame. Tom had suggested 'Kee-Klamp' fittings. These are a range of connectors, (elbows, corners, joints, and feet etc.) which could be used to join steel tubing, and make a supporting frame of any size. The tubing was 1½ inch diameter galvanised steel. As this was quite difficult to cut I had to take it to the Hangar 8 workshop, where they quickly produced all the lengths required. I had already obtained all the necessary fittings from the stores, so it was an easy task to fit all the pieces together. The fittings were fixed to the tube by 'Allen' screws, so with a simple key, it was a easy task to add or remove parts to the structure. The finished frame was about 5 ft. high, 3 ft. wide and 6 ft. long. It was so heavy I had to get Jack to help with the final assembly, and the positioning of the frame in the centre of the lab.

I had positioned two extra fittings on the top rail at each end of the frame. This was to carry the tube from which the two arms were suspended. This was not fixed, but free to rotate. I had already made the two arms from Meccano, and these were fixed to the tube using hinges, so that the arm was free to move in a direction which was along the axis of the tube. A simple link was then fitted between the two arms to provide a parallel motion.

It was quite pleasing at this stage to see the first part of the mechanism working. The Master arm could now be rotated from side to side, and could also be pushed backwards and forwards. The Slave had no choice but to follow.

The next stage was the Elbow. The stores carried a range of Bowden cables, and all the necessary fittings. This proved to be quite complicated, and it was useful that I was familiar with the system. I had repaired my bicycle brakes not long before. I tried several different arrangements before I got it right. It was then quite easy to control the Slave arm by just pushing the Master to the required position.

Ken was very helpful at this time, as were many other people who dropped in to see this strange contraption. I got lots of advice, not all good but it did help. I must admit that I was a little amazed at the interest that was shown, even by complete strangers.

One problem that did arise, at this point in the construction, was that the Meccano arms were not stiff enough. This meant that flexure of the arm could mean that the two arms were not quite synchronised. The mechanism felt decidedly spongy. I worried about this, and even considered rebuilding the arms from larger metal sections. However, this would increase the weight of the structure, and make it more difficult move. A very simple solution, which was suggested by a casual visitor, was to fix wooden batons inside the Meccano frame. Wood is rigid and very light. I had wooden strips cut to the exact dimensions, and screwed them on to the inside of the Meccano sections. The result was amazing; the arms were now quite firm and the motion almost perfect.

Tom, on one of his many trips away, had visited a place that made artificial limbs. He returned with the end of an arm, and some plug in fittings. One was a wooden 'hand' with a moveable thumb, which we thought was not much use, but the other was like a large pair of pliers which could be operated by pulling a wire. I quickly fitted the wrist and the pliers to the end of the Slave arm, and used another Bowden cable to transfer the control to the Master side of the frame. To complete the system I fitted a wooden table just below the Slave arm, to provide some workspace.

The result was very pleasing. After a little practice I could pick up an object from the table, and move it to another location. Tom was very pleased, and suggested a test to prove how useful it could be.

The Test: Pickup a container from a tray on the LHS of the table, Unscrew the lid and tip the contents into another tray on the RHS. (The container was a standard aluminium can in which we placed specimens for irradiation in the Bepo Pile. It had a screw lid with a rectangular boss.)

In order to perform this task we needed a second 'Hand'. This was easily provided by a small bench vice, which I attached to the centre of the table. To operate the vice, I removed the existing handle, and replaced it with a long rod which was extended to the Master end of the frame.

After a lot of practice, I could pickup the container - place it in the vice - unscrew the cap - pickup the container again and tip the contents into the second tray. The real problem with this was that the action was several feet in front of you. This was also to be made more difficult by the placing of a radiation shield in between the Master and the Slave ends. We simulated this by putting a wooden screen between the two ends. It was then necessary to provide some optical means of looking over the screen.

Ken was very helpful here, and after a number of trials we came up with a workable solution: Two large mirrors to look over the screen, and a pair of low power Binoculars to bring the action closer. It was also possible, but unnecessary, to use four mirrors to get a better viewpoint.

It did take time, but I was soon able to perform the Test without problem using the optical system.

What happened next took me completely by surprise. Tom told me that **we** were to give a demonstration of the system to a group of engineers. He said **we** but he meant **me!** The engineers were from the Harwell Engineering Division, and were more than a little rude and amused at the Meccano with its crude construction. However, when I performed the test that Tom had set, they were quite impressed and strangely silent.

Only afterwards did I discover that the engineers had been working on this problem for two years, and had produced nothing but several designs on paper. I had built our system in just two months. I think that Tom had done all this just to embarrass them, and spur them into action.

To be quite fair, the Engineering Division did eventually produce a very elegant design which was to become standard throughout the UKAEA.

Ron Dugdale

At the beginning of May, Tom asked me to go and work with Ron Dugdale. Ron's assistant, Alan Perks, had just been conscripted into the Army to do his National Service. I was quite shocked; Alan had only been with us for a short time, and was now having to leave. I would be eighteen in October, and was very concerned about what would happen. I had thought that I would be exempt because I was studying part time, however it was to prove more complicated than that!

On the first day Ron spent a long time explaining what he was doing. His main task was to study radiation damage in metals, by measuring electrical resistance. A secondary task was to provide a Temperature Standard that could be used by the rest of the group.

Ron was a very different character from Tom Fry. Tom was bursting with ideas and wanted to do everything at once. He could not sit still and talked all the time. He was a very clever extrovert, but

often jumped into a new experiment before he had thought it through. He was a 'maverick' character, who broke all the rules and usually got away with it.
Ron, however, was a quiet man; softly spoken and thoughtful. He did not do anything without full consideration of all the facts. I enjoyed working with Ron, and learnt a lot of new skills. It was interesting to see a more considered approach to a problem. When deep in thought, Ron would smoke his pipe; a large curly 'Sherlock Holmes' one. It was part of his character.

The Temperature Standard

For the Temperature Standard, Ron had obtained advice from the National Physical Laboratory. From this he had constructed a Platinum Resistance Thermometer. (PRT) This was made from Platinum wire wound on a Silica tube, and was contained in a Pyrex tube filled with Helium. Two wire leads were connected to each end of the PRT. The resistance was measured with a Wheatstone Bridge. This was arranged to eliminate the lead resistance, so that only the PTR itself was measured.

The Muirhead Wheatstone Bridge had 6 decades, so it could measure to one part in a million. Ron had extended this by the addition of an external Resistance box, so that it could measure to one part in a 100 million. At this level of accuracy a special galvanometer was necessary. This used a 'Galvanometer Amplifier'; a primary galvanometer reflected a light spot onto a split solid state photocell. The output from the photocell was then connected to a secondary galvanometer, which reflected another light spot on to a scale in front of the operator. The very sensitive galvanometers were installed on the special anti-vibration pillar in the corner of the lab. The bridge compared the unknown resistance with a 1 Ohm Manganin resistance standard. This was maintained in a temperature controlled oil bath at 30degC. I had never before measured anything with such a high degree of accuracy. I found it to be fascinating!

NPL had suggested that we calibrate the PTR at three temperatures: The melting point of ice - 0 degC, The boiling point of water – 100 degC, and the boiling point of Sulphur – 444.6 degC.

The Ice Point. This was simple to set up, but difficult to get right. We used a 2 gallon Thermos flask filled with powdered ice and distilled water. The ice, which came from a factory in Reading, had to be checked for pùrity and powdered to a snow like consistency. This was done using a device we called the 'Ice machine'. It consisted of a large 'Jack Plane' (as used to smooth wood) fixed upside down on a metal frame. The ice block was then rubbed over the sharp blade of the plane and the resultant 'snow' allowed to fall directly into a Thermos flask. The powered ice was added to distilled water, and the mixture chopped up using a one inch diameter glass tube. The result was a mass of ice melting in water. Too little water – and the temperature could be below 0 degC, Too much water – and the temperature could be above 0 degC. It was very tricky to get it just right.

The Boiling Point of Water. For this we used a standard device. This was an all glass construction. It consisted of a bulb to boil the water, a tube to insert the thermometer, and a condenser to reclaim the evaporated water. The condenser was water cooled from the mains supply. Before it could be used, it was necessary to thoroughly clean the glass vessel, using many different chemical solutions. The bulb was then half filled with distilled water, and set up over a Bunsen burner. It was at this point that we encountered the first problem. Because everything was smooth glass and so clean, there was nowhere for the steam bubbles to form. This resulted in over heating, and 'bumping' as the steam was eventually released. The bumps were so violent that we were worried that the glass may break. Ron made a quick call to NPL for advice. The cure was so simple; a short length of Platinum wire was cut into small pieces about 5 mm. long. When these were placed in the glass bulb, steam bubbles formed on the sharp ends of the wire and the problem disappeared.

The next hurdle was that the boiling point was only 100 degC at the standard atmospheric pressure of 760 mm. This meant that Ron had to buy a Fortin barometer, so that we could apply a correction for the ambient pressure. As the barometer was calibrated in Inches, we needed to convert the reading to millimetres. I remember being sent to the library to get the precise conversion factor. I was amazed to find that it was exactly 25.40000 mm. per inch.

The Boiling Point of Sulphur. Right from the beginning I could tell that Ron was not at all keen on this device. To have a flask of boiling Sulphur in the lab. created all manner of problems, some real and some imagined. It seemed very unpleasant and nasty. The very thought of the smell and the danger of fire was enough to put anyone off the idea. I built the apparatus, but it lingered in a corner of the lab., and was never used. Ron thought that we could manage to do the calibration without that measurement.

The first use of the PRT. This was to calibrate a thermocouple for George Kinchin. The thermocouple was made from Copper and Constantan wires, and had a 'Cold Junction' in a small Thermos flask filled with ice and water. We took measurements at several temperatures and calculated the parameters for a cubic equation to fit the thermocouple voltage output. George was very pleased at the result.

Education

For two years I had been studying at evening classes. I was lucky in that the Physics courses were taken at Reading University, and my progress was good. However, I was not at all happy about my progress in French, which I was studying at a school in west Reading. I was desperate to abandon this, but was told that I could not Matriculate without a pass in one foreign language. Only at the last minute I was informed that, as there had been a change in regulations, I could take a 'Simple French' exam instead! However, this meant that I would have to take an extra subject. I quickly, and rashly, decided to take Mechanics. I had previously dropped this subject in 1947, because I was studying four evenings per week and this was too much. I had only one month to prepare. In June 1949 I took the Matriculation examination at Imperial College in London. Much to my amazement, I passed in the French but failed the Mechanics exam. I am sure that this could have been easily resolved as I had Credits in other subjects in the Oxford School Certificate examination. However, this was all to no avail as I was overtaken by other events.

The training officer at Harwell informed me that they had decided not to support people who wished to study part time for an external degree. This was because experience had shown that few managed to complete the course. A new course, which was just about to start at the Oxford

Technical College, would lead to a new qualification. This was the Higher National Certificate in Applied Physics. He wanted me to join this course which featured 'Day Release'. This meant that I would get one day off a week, during the term time, to attend. He also noted that as I was just coming up to 18, I would be subject to
National Service. If I joined the 'Day Release' course at Oxford, the conscription would be deferred. Note - deferred, not cancelled! To me this seemed like Blackmail.

The National Certificate course in Applied Physics only started in 1947, and at that time was only available at the Regent Street Polytechnic in London. This meant that if I had known about it, I could have started 2 years before! My evening studies for the last 2 years, while not a waste of time, were irrelevant. I had just been marking time!

It seemed to me that I had no choice; I agreed to join the course at Oxford in September.

The course was 3 years to the National Certificate, for which I would study Physics, Chemistry and Mathematics, and a further 2 years to the Higher certificate for which I would study Pure Physics, Applied Physics and Mathematics. It transpired that local industry decided the nature of the Applied Physics. This turned out to be Harwell, so the course was Nuclear Physics.

Establishment

When I was first offered the job at Harwell with the Ministry of Supply, my position was described as temporary. After two years I was given the opportunity to make this permanent. Much to my amazement I had to be interviewed by a board of five people. I did quite well, and my position was subsequently made permanent. It made no difference to me, but I was now Established!

Radiation Damage

Ron's main task was to measure radiation damage in metals. We made 1 Ohm resistances in various metals. The technique was to connect the two lead wires to each end of the resistance wire. The leads were of the same metal, but in a thicker gauge. An Argon arc welder was used to fuse the wires together into a bead of metal, so that all three wires emerged from the bead at different angles. This produced the most stable resistance. If the bead did not look right, we abandoned it and started again. It did take some time to get the perfect resistance.

The Argon arc welder was home made and very simple; a glass tube closed at one end by a Carbon electrode, with a side tube to supply a steady stream of Argon to prevent oxidation. The wires formed one electrode and the Carbon the other. The DC mains of 200 volts was used in series with an ordinary incandescent lamp bulb. The lamp bulb could be changed to vary the current in the arc. A foot switch was used to terminate the arc. Dark goggles had to be used to view the progress of the arc.

Platinum with its high melting point required a different solution. An Oxygen/Gas flame was used to melt the wires. Argon was not required as the Platinum does not oxidise. Again very dark goggles had to used. It took a lot of time and practice to get it right, but we eventually ended up with a set of very precise resistances.

The resistance was then wound onto a Silica tube in the same manner as the Platinum resistance thermometer.

We measured the resistances with the bridge to see how stable they were over a period of time. Magnetic materials like iron and nickel were completely unstable. Any movement through the Earths magnetic field was enough to change the resistance. Copper also proved to be useless because it oxidised so easily when exposed to the air. A thin layer of oxide on the surface (which was an insulator) was enough to make a large change.

By far the most stable was Platinum. I made three identical resistors, and measured them over a period of a year. The variation was only 2 or 3 parts in 100 million. These were measured at the Triple Point of Water (+0.01 degC), which proved to be a very reliable and consistent temperature standard.

The Triple Point Cell

Ron had taken some advice from the National Physical Laboratory on how to construct a Triple Point Cell (TPC). They had suggested that it was an easy standard to create and maintain. Much easier than the 'Ice Point' which required constant maintenance to keep it at 0 degC.

The TPC consisted of a closed glass vessel about 2 ½ inches in diameter and 12 inches long. From one end a concentric tube ½ inch in diameter was inserted using a 'ring seal'. The internal end was sealed about 2 inches from the bottom, and the top left open 3 inches above the vessel. During preparation, access to the vessel was via two thin tubes which were prepared to be easily sealed. One tube was in the form of a small funnel, to ease the loading of the Water. At first we placed the thin tubes on the sides of the vessel, but they were very prone to being damaged in use. The best place proved to be the bottom of the cell.

This was far too complicated a shape for us to make, so it was constructed by the glass workshop at Harwell. It was made in Pyrex glass.

The next step was to thoroughly clean the inside of the vessel before the Water is loaded. This proved to be quite a difficult and tedious task. I had to follow a long list of instructions on how to clean glass. I am not sure that I remember all the sequence, but it included – Alcohol – Caustic Soda – Hot Chromic Acid, all rinsed out with Water. It was then rinsed several times with distilled Water. Finally it was ¾ filled with 'Analar' (very pure) distilled Water. The funnel tube was then sealed with a flame.

Next came the removal of the air. The remaining tube was connected to a vacuum pump and the air removed. This caused the Water to boil, which helped to expel the air. The tube was then sealed. The TPC was now complete.

I made three TPC's, and all proved to be successful.

To use the TPC it first had to be placed in an ice bath and the temperature reduced to 0 degC. A freezing mixture was then prepared by dissolving 'Dry Ice' (solid CO_2) into a beaker of Acetone. The Acetone remains liquid and the temperature reduced to -80 degC. This cold liquid is then poured into the inner tube of the TPC to a depth of 4 inches. After a short while ice forms around the tube inside the closed vessel of the TPC. The freezing fluid is then removed. The TPC now contains only Water, Ice and Water vapour; the internal temperature is then at the Triple Point of Water (0.01 degC).

To maintain this condition it is necessary to keep the ice bath at 0 degC. Too cold (if the ice is not pure) and the internal ice can grow and form a barrier between the Water and the Water vapour. Too hot (if there is too much Water in the ice bath) and the internal ice sheath can melt.

After a thorough testing, Ron decided that we would take all our measurements at the Triple Point. This had proved to be a very constant temperature, and easy to generate.

The Green Television

While I was working for Ron he was building a Television set. I was very interested in this as few people at that time owned such an expensive device. I was also very interested in how it worked, and we spent a lot of time discussing the various parts of the circuit. When it was completed he took me to his room in 'B club' to see the finished item. It did look a bit of a mess, as it was made from a kit which included odd bits of government surplus electronic equipment. The screen was a 6 inch diameter cathode ray tube from a wartime radar set. The screen was monochrome and green! It did work very well, and I remember, one lunchtime, watching the current test match. With a green screen it looked very good.

The Study of Radiation Damage

For the studies of Radiation Damage, Ron had chosen a Copper Gold alloy (Cu_3Au). This had a faced centred cubic structure and had proved to be a very stable resistance.

I made a new CuAu resistance and annealed it at a high temperature in a furnace. This was then measured over a period of several weeks to prove its stability. It was then ready to be placed into the Bepo pile to be irradiated by neutrons.

Because of the unknown conditions in Bepo, Ron decided that we needed to seal the resistance in a glass tube. Ordinary glass contained a lot of Sodium, which would become very radioactive, so we were advised to use Lead glass. As this was rather unusual I had to go to the Glass Blowers workshop to receive instruction on how to manage this. It did prove to be very simple; it needed a little extra care, and the necessity to use only an oxidising flame.

I placed the resistance in the glass tube, filled it with dry Helium, then sealed it with a flame. Ron had organised with the Bepo manager a special hole which only we would use. It was an 'E' hole, high up and to the rhs of the Bepo experimental face. The next time Bepo was shut down, we were shown, by one of the engineers, how to use this facility. We had to climb a ladder to a high up platform to reach the hole. The engineer removed the shielding plug, and then withdrew a long

Graphite bar. This was about 4 inches square and 3 feet long. It was hollow like a thick walled tray. We placed our sample in the tray, and it was then pushed back into heart of the reactor. The engineer then replaced the plug.

One month later, when the reactor was next shutdown, I went to retrieve our sample. I found that the shielding plug had been removed for me, but I had to withdraw the tray and extract the sample. With tongs I placed the sample into a lead flask so I could carry it back to Hangar 8. The first thing that I noticed was that the Lead glass tube, which was normally a pale blue colour, was now amber! The whole thing was radioactive, but not a real danger. I broke open the tube and transferred the resistance to the measuring rig. I had previously prepared the Triple Point Cell, so it did not take long to make the measurement. That completed, I sealed the sample into a new Lead glass tube, and took it to Hangar 10 where I placed it back in the reactor for another month. This whole operation was completed inside one day, while the reactor was shut down.

This procedure continued for about a year, so I was able to draw a graph of resistance against radiation time in Bepo. I only obtained one reading per month, so it was slow progress. The resistance first decreased and then began to increase in a smooth curve. It was thought that the radiation damage first ordered the structure of the metal; i.e. made it more perfect! Then continued damage caused more disorder, and increased the resistance.

Of course in between these measurements we did do other things.

Diamonds

One day Tom came into the lab. and asked Ron to undertake a new study. It seemed that the Diamond merchants of Hatton Garden in London had heard a rumour, probably from a USA source, that radiation can change the colour of Diamonds. As some coloured Diamonds are very expensive, they wished to know how to tell the difference between a natural colour and a radiation induced colour. Tom gave Ron the letter from a Hatton Garden merchant and asked him to investigate.

The letter, which came through the ordinary post, contained a Diamond which to my untrained eye looked to be about 0.5 carat. It was not in any special container, but just retained in a cleverly folded piece of paper. We were quite amazed; the Diamond was not an uncut stone but a finished item of jewellery. It looked very expensive. Tom suggested that the first step was to put it in Bepo and see if it changed colour.

I sealed the stone in a glass tube and placed it in the reactor during the next monthly change. After a month I collected the container and took it back to the lab. I was horrified! The stone looked completely black! For an anxious moment I thought that we had changed the Diamond into Graphite. (both are different crystalline forms of Carbon) Ron was a little more cautious. We placed the stone in front of a very bright light, and it then appeared to be a very dark green. We then placed the stone in a high temperature furnace. The dark colour disappeared, and the stone was returned to its original colour.

Ron then found a method of putting the stone into the reactor for a short period. This could be done while the reactor was working, so we were able to choose the length of time of the irradiation. It was found that we could make the stone any shade of green that we liked, but only green. Ron wrote a short report and sent the Diamond, now an attractive shade of green, back to Hatton Garden. They were delighted and replied almost immediately. They sent a large number of Diamonds for further testing, and were even more keen to have an answer to the question: How to tell the difference between a naturally green stone and the artificially coloured one. It transpired that a naturally green Diamond was much more expensive than the more normal one.
Ron then set up a series of experiments to try and expose this difference. While he was looking at the optical transmission using a spectrometer, I was asked to measure the electrical conductance. This proved to be very difficult as Diamond is a poor conductor of electricity.

To hold the Diamond I made a cell out of Polystyrene, which is a near perfect insulator. The stone was placed in a hole with a conical bottom, and was held there by a helical spring. Through the base of the cone I fitted a pointed screw, which could be advanced until it touched the stone. I then had to measure the current through the cell, which was not easy. The current was so small that I had to resort to a technique, that was used by Madame Curie, to measure the ionisation current caused by a radioactive material. A sensitive Electrometer was connected across the cell; this was charged from a battery, and the subsequent leakage through the cell measured by timing the decay. The Electrometer was of the quartz fibre type, similar to the simple Dosimeters used to measure radiation.

I made a lot measurements, and convinced myself that I had obtained a meaningful result. However, I did not manage to observe any changes in the conductance.

The next thing I looked at was fluorescence and phosphorescence. The first was easy; just look at the stone when it was illuminated with ultraviolet light. Phosphorescence however was much more difficult to observe; it is the glow left over after the UV light was removed. This was often short lived, so difficult to observe. For this I had to make a special rotating shutter – a Phosphoroscope! This would allow the sample to be bathed in UV light, when it was hidden from the observer, and observed when the UV light was cut off. The shutter was attached to an electric motor which could be rotated at a variable speed. This enabled the observer to see how the phosphorescence varied with different time delays.

I must admit that I had a great deal of fun in making this piece of apparatus, and used it to observe many different samples; most of which were not Diamonds!

All this work proved to be very disappointing, as we did not seem to be able to find the differences for which we were looking. The only obvious difference in the irradiated Diamonds was that they were faintly radioactive.

The Lost Diamond

As we had received many Diamonds from the merchants of Hatton Garden, Ron kept very strict records of where each one was stored, and what tests had been carried out. One day he lost one, and was very upset. He had been using a furnace in a 'General' lab. in Hangar 8, when he dropped a

Diamond onto the floor. He could not find it! The lab. was used by many people, and was very untidy and dirty. He called me to help, and we spent a long time, on hands and knees, searching. We did not find it! Ron was quite distressed; he could hardly go back to the Diamond merchant and say - "Sorry, I've lost your Diamond".

The next day Ron swept the floor of the whole lab., and placed the huge pile of debris into a very large 3 litre beaker. He then sat down at his desk, and carefully teased out the more obvious rubbish like wood shavings and bits of paper. Next he poured Chromic acid over the remainder and boiled it to remove all the organic matter. After washing and filtering, the residue was now down to reasonable proportions. When dried he had about a cup full of what looked like sand and very small stones. He poured the remains onto a sheet of white paper, and carefully spread it out. There in the middle of the sandy deposit was the elusive Diamond.

Ron was delighted – his perseverance had won the day.

Another Change

At the end of 1950 Tom Fry asked to see me. He told me that John Simmons assistant, Terry White, had been conscripted to do his National Service, and John needed some help. I was quite shocked as Terry had been with us for less than a year. Tom wanted me to move to John from the beginning of the new year. I discussed this with Ron and he seemed quite happy about the move. He felt that his work was now at the stage where he could manage on his own. I was sad to leave Ron, as I had enjoyed my time with him. However, I was quite pleased at the prospect of some different work. My conscription had already been deferred for more than a year, and I had high hopes that it would never occur.

The Wigner Group – 1951

At the beginning of 1951 I was moved to work with John Simmons. John was in room 105 on the first floor, just above Ron Dugdale's lab. It was a modest sized lab. with an adjacent office.

John was the oldest member of the group and probably the most experienced. I never knew his exact age, but then he was in his mid thirties. He was a Senior Scientific Officer, and very different from the other senior members of the group. He had come up the hard way, having first obtained a Higher National Certificate in Mechanical Engineering. He had worked for a time at Avery, the company that made weighing machines and large weighbridges. However he soon became dissatisfied with the work and decided to study Physics. Having obtained a degree from Birmingham University just before the war, he was quickly absorbed into the Scientific Civil Service. He was at TRE Malvern during the war, working on Radar systems, and Later at RAE Farnborough.

John was a very different character from the other people that I had worked with. While undoubtedly clever, he was a very nervous individual. At that time he smoked incessantly. Not just cigarettes, but also a pipe. It seemed to me that he just could not do without tobacco. In fact if he ran out of cigarettes, he could not work and had to go and buy some. The floor of the lab. was covered in stubbed out cigarette ends and ash. The room stank of tobacco smoke. I think that this put me off smoking for life!

On the first day John took me into his office and gave me a quick account of what he was doing. He was building a 'Positive Ion Accelerator'. This would enable him to study radiation damage produced by heavy ions, which would cause more serious damage than the neutrons used by the rest of the group.

The equipment would consist of a long glass tube connected to a vacuum system. At the one end would be an 'Ion Source', and at the other end the target. Between these would be connected a high voltage source to accelerate the ions. A magnetic lens would focus the ions onto the target.

John had been working on this for about a year. While I am sure he had put a lot of thought into the design, he had very little to show for it. He had brought a vacuum system with him from Farnborough, and obtained a collection of five inch diameter glass vacuum tubes and fittings to make the main assembly. The high voltage supply unit was half built.

My first task was to complete the high voltage unit. This was a 'Cockroft Walton' generator; a ladder of capacitors and solid state rectifiers which was driven by a high voltage transformer. This was supplied by a rotary converter which provided 250 volts at 2000 Hz. by using 2000 Hz. instead of the mains 50, allowed the use of smaller capacitors in the generator. It is interesting that 2000 Hz. was used in many Radar systems, with which John was very familiar. The generator was housed in a standard 4 foot electronics rack. This was quickly completed and tested. It produced in excess of the 40,000 volts required.

I then built the frame to house the ion source and its power supply. This was to be at 40,000 volts above ground, so it was standing on four Tuffnel insulating pillars. The ion source required a variable 5,000 volt supply; as this assembly was 40,000 volts above ground potential it had to be completely isolated. This was obtained from a 12 volt lead acid battery powering a 'Vibrator' driven transformer and rectifier circuit. The vibrator was a standard electromechanical switching device which provided a 12 volt square wave output, at 110 Hz., to feed the transformer. [N.B. this is what was used in the days before Transistors were available]

Mixed amongst these tasks, I had produced drawings of the various mechanical parts needed for the vacuum system. Several of these were round brass plates which would connect the various glass tubes. These were being manufactured in the workshops in Hangar 8. One of the brass plates had a 3 inch hole in the centre which required something to be mounted at the centre of the hole. I had drawn this as a three legged 'spider' with a central boss. The workshop had done as the drawing requested and milled the complicated hole from the solid brass. This was spotted in the workshop by Dr. Bretscher, the head of the Nuclear Physics Division. He grabbed the finished item and confronted John Simmons. He complained that this structure should have been prefabricated, instead of being milled from the solid, which was more time consuming and expensive! This was the second time that I had faced Bretscher with something that he disapproved. He was not unkind to me, but requested that we think more carefully before designing something in a complicated way.

Bruno Ponticorvo

The next door lab. had been taken by Bruno Ponticorvo. He was a very senior physicist who had been involved in the early research in Nuclear Physics in Italy during the 1930's. I believe that it had been a hard choice, between him and Dr. Bretscher, to decide who would be the head of the Nuclear Physics Division. Bruno lost that race, but he was given a free hand in his choice of study. He had chosen Cosmic Ray research. Bruno was very different from most of the other scientific staff, who were often very casual, scruffy, and eccentric. A handsome man, he was always very smart and looked as if he had just stepped out of a tailors shop window. He was a quiet man and always very polite. In his youth he had been a professional tennis player. I only remember three people working for him: John Jelly, Ted Cranshaw and an assistant called Peter Robinson. Peter became a good friend and we often went to lunch together. It came as a big shock when we heard that Ponticorvo had defected and gone to Russia. He took his family on holiday to Stockholm, (I believe that his wife was Swedish) but immediately took the next plane to Helsinki and thence to Moscow. This was only a few months after Klaus Fuchs had been arrested and charged with passing secret information to Russia.

The Change

What happened next took us all by surprise. In the spring of 1951 Tom Fry called a meeting of the whole group. This took place in John's office, because at that time Tom did not have an office of his own. He told us that Eugene Wigner (the American physicist after which our group was named), had visited Harwell. In discussions with Tom and John Cockroft, he had warned about the neutron induced changes in graphite which could cause severe problems in a graphite moderated nuclear reactor. He was not allowed to give any detail (because the US had banned the disclosure of what were deemed to be military secrets), but said we should look with some urgency at two things: The

Dimensional changes and Stored Energy contained within the graphite. He emphasised that both could get us into a lot of trouble.

Tom then told us that Cockroft had instructed him to drop all other work, and concentrate on graphite. We were already measuring the dimensional changes, and starting to measure the stored energy using a 'Bomb Calorimeter'. However the changes induced in the BEPO irradiated graphite were very small and difficult to measure. The new Plutonium Producing reactors at Windscale would operate at a much higher power, and hence had a considerably greater neutron flux. This would make much larger changes in the graphite. One of the Windscale reactors had just started, and the other was nearing completion.

We had already discovered that the changes could be reduced, or even removed by heating to a sufficiently high temperature. Tom therefore decided that we must irradiate the graphite at a range of temperatures. This involved the construction of a 'Thermostat' which could operate in the hostile environment at the centre of the new Windscale reactor. John Simmons was given the job of designing the Thermostat, and my job to construct and test.

The meeting was over and that was it – all change. I was quite upset that the work on the accelerator was to be shelved (it was never revived), as I was getting quite interested in the design. However, John seemed almost relieved to have the change! I had already perceived that he was not happy about that task.

While John was in detailed discussions with Tom, I was instructed to gather and pack up all the equipment for the accelerator, so that it could be put into storage. I was asked to leave the vacuum system, which could be useful for other experiments.

The next morning when John came in we were faced by an almost empty lab. He seemed strangely excited by the new task, and we retired to his office so that he could explain what needed to be done. What he told me quite shocked me – I had envisaged a Thermostat similar to the one that I had built for Tom Fry two years before. However, this was going to be very different. It would have to operate at the centre of the Windscale reactor for a minimum of one year. It should be able to be controlled at temperatures up to 450degC and it must be possible to change a sample container without removing the assembly from the pile.

Perhaps the most staggering thing about this Thermostat was its size! The Windscale reactor was much bigger than anything I had seen before. The charge face was over 60 foot square, with horizontal holes loaded with Uranium fuel and taking the air cooling. This was about three times the linear size of the Bepo reactor. The length of the fuel channels was comparatively short, only about 30 feet. I think that this was because of the difficulty of getting the heat out of the fuel using only air cooling. The reactors would operate at a power level of 100 Megawatts, and all that heat blown straight up the chimney and wasted.

Our Thermostat would be loaded, and operated from the top of the reactor, which meant that it had to be 30 feet long to reach the centre of the pile. It would also need a 7 foot long shielding plug to connect to the outside.

The main problem with the construction was a material one. The environment inside the reactor was very hostile. The materials needed to withstand the radiation and the high temperatures involved. The induced radioactivity would also mean that it needed to be made of materials that would decay in a reasonable time, so that it could be safely removed when necessary.

John had already made a few decisions. The main body of the Thermostat would be made of Aluminium, which has a half life of only 2.5 minutes. A heating coil of Nichrome tape which would be insulated with Mica sheet. While John was looking at the other details of the design, I was given the task of trying to see how feasible it was to wind the heater.

I obtained a length of Aluminium tube 2.5 inches in diameter, a reel of Nichrome heater tape and a stack of Mica sheets. Amber Mica was available in large sheets about 10x12 inches. After a little practice I was able to split this into very thin sheets, which I was able to wrap around the tube. I then needed to make some small clamps, attached to the tube to hold the ends of the heater tape. With the tube mounted horizontally on 'Vee' blocks I managed to wind a heater about 12 inches long, carefully spacing the winding with a gap equal to the width of the tape. When completed this looked very neat, and a far cry from the heater that I had wound for Tom, which was insulated with paper and stuck together with Durofix glue!

John was not in his office, so I decided to apply power to the heater to see how it would behave. I connected it to a 'Variac', placed a thermometer into the tube, and applied a small AC voltage. The tube very quickly got hot and was registering over 300 degC. I was a bit surprised to find that some parts of the heater had moved! The winding now did not have equally spaced turns. It seemed that when hot the heater tape expanded, became loose on the tube, and moved. I next placed the tube in a vertical position, as it would be in the reactor, and cycled the temperature up and down several times. I was dismayed to find that some of the turns had moved downwards, and now were in danger of touching an adjacent turn. It was obvious that we needed to fix the winding in some way.

When John returned he did not seem all that surprised at what I had found. He had suspected that this might be a problem. He suggested that I try to interleave a strip of mica into the winding, so that adjacent turns were over and under the strip. He then left me to try again as he was busy with the rest of the design.

I cut some mica into strips half an inch wide, and did a few tests to see how many strips would be necessary. It obviously had to be an odd number, and one would not be enough. I started with three, but this left big gaps between the strips. I eventually settled on five; this gave a very tight winding, and looked secure. I then removed the original winding and started again. It was much like weaving a basket, with the heater tape going over and under the mica strips. It did take a lot longer, but it was quite pleasing to do. The finished winding looked very neat.

When I returned to the heating tests there was no obvious movement of the winding. John was very pleased with the result, and was happy that we could easily obtain the required temperature.

John had now obtained the necessary dimensions from the Windscale engineers, and made a number of decisions about the design. We retired to his office so he could explain what was required.

The specimen carrier would be an aluminium tube 2 inches in diameter. This would be filled with helium and sealed. This would have to be lowered into the Thermostat (and later recovered) using a cable with a special 'grab'. This did mean that our Thermostat must have a 2.5 inch hole all the way from the top of the reactor to the centre of the heater. Ron Dugdale was designing the carrier, so this was one area that we did not have to think about.

As the Thermostat tube would have to be 30 ft. long, it had to be made up from several parts. The lower section would be 6 ft. long and contain the heater. Three other tubes would make up the total length, and the whole assembly joined together by flanges, welded to the ends of each tube, which could be bolted together. The heater section would be 3 ft. long, and covered by an aluminium shield 5 inches in diameter. The vertical hole in the reactor was 6 inches in diameter, but as it was made up of a matrix of graphite blocks, there may be sharp edges or even steps in the wall. John had been warned that it was necessary to ensure that all edges on our assembly were bevelled, so they could not catch on any obstruction.

The heater tube would have a thick wall so that we could embed the thermocouples in slots underneath the heater winding. The insulation for the thermocouple wires would be twin bore alumina tubes. These were available as a flattened tube in 3 inch lengths. Four thermocouples were required, two at the centre of the heater and one close to each end. One thermocouple at the centre would be used to control the temperature, and the other three to measure the temperature and its distribution. The thermocouple wires would be Nichrome and Constantan.

The heater winding was to be 2.5 ft. long, and would have a 'tap' 10 turns from each end. This would mean that we could apply extra heat to the ends of the tube to provide a uniform temperature along its length. The power leads to the heater would be nickel, housed in silca tubes outside the heater winding.

This meant that we had 4 wires for the heater, and 8 wires for the thermocouples, making a total of 12 wires to extend to the control panel outside the reactor! All the wires to be 20 SWG. The wires would lie outside the tube and pass through slots in the connecting flanges. The insulation would be small bore silca tubes, which were available in 3 ft. lengths. Every 3 ft. the wires would pass through twin bore tubes of pipeclay, which was fairly rugged and could be clamped to the aluminium tube. Where the wires passed through the spiral hole in the shielding plug, they were housed in normal flexable electrical insulation sleeves.

All of this unusual structure and materials was to ensure that the assembly survived in the hostile environment inside the Windscale reactor.

John had calculated the approximate level of radioactivity that the assembly would attain during one year in the reactor. Ignoring the aluminium, which would decay quite rapidly, he found that the heater end would be 300 Curies per foot, and the rest 100 Curies per foot – a staggering level of radiation!

We made quick sketches of the required mechanical parts, and I took them to the 'Drawing Office'. John must have applied a lot of pressure, as only two days later I received a call from them to ask me to go and check the drawings. There were a few queries, mainly about dimensions, which were quickly resolved. The drawings were then put into the engineering workshop in Hangar 8 for manufacture.

John then asked me to make a list of all the things hat we would need to assemble the Thermostat. I ordered from the stores: Thermocouple wires, Nickel wire, Mica, Alumina tubes, Pipeclay tubes and a very large quantity of 1.5 mm. bore silica tubing.

Calibrating the Thermocouples

While the hardware was being manufactured, I was given the job of calibrating the thermocouple wires. I had done similar work when I was working for Ron Dugdale, but this had to be extended to much higher temperatures. John suggested that we use the melting points of Tin, Lead and Zinc. 231, 327 and 419 degC.

I went to see Ron Dugdale to get some advice. He was very helpful and provided me with a small furnace, in which to heat the metals, and a Potentiometer to measure the thermocouple output. My next port of call was the main stores, where I obtained a small quantity of the three reference metals. I think that this was 'Analar', a very high purity grade. Each metal in turn was placed in a graphite crucible and melted in the furnace. The thermocouple wires, of Nichrome and Constantan, were passed through a short length of twin bore silica tubing to form the 'Hot' junction, the tip of which was arc welded. The two 'Cold' junctions, where the thermocouple wires were joined onto copper wire, were placed in glass tubes and immersed in a Thermos flask filled with crushed ice.

The technique was to melt the metal, immerse the hot junction in the crucible, and switch off the furnace. Readings of the thermocouple output were then taken as the temperature cooled through the melting point. When this was plotted on a graph, we had a cooling curve which exhibited a small plateau due to the latent heat of fusion. I did this several times and found it to be quite reproducible. I was thus able to obtain the thermocouple output, in millivolts, for each of the three metals. I plotted these numbers on a graph and drew a smooth curve through the four points on the temperature scale: 0, 231, 327 and 419 degC.

John then asked me to fit a cubic curve to the data, such that the thermocouple output E = at + bt**2 + ct**3. I had three unknowns a, b c, and three equations, one for each temperature. This did take me the best part of a day, but when I had the three coefficients, I was able to calculate the value of E at ten degree intervals. When plotted on the same graph there were minor differences in the curve.

As the hardware for the Thermostat had not arrived, John asked me to add a new point on the graph at 100 degC as there was a large gap between 0 and 231 deg. (I think that this was just filling in time). I went back to Ron Dugdale, and with his help, compared the thermocouple with his Platinum Resistance thermometer. I had helped Ron calibrate this the year before.

I now had four points and three unknowns, and did not know how to proceed. I asked John if I should add another term to the equation, making it a quartic. He was amused and very much against this, pointing out that if you had enough terms in the polynomial you could make it fit anything, including all the errors! [I wonder what he would have thought of modern Cosmologists who have to resort to 14 dimensions in order to fit their extraordinary theories]. He suggested that I calculate a 'Least

Squares' fit to the cubic function. That is: To find a cubic curve where the sum of the squares of the deviations from the data points was a minimum. I did not know how to do this, but John pointed me to the 'Rubber Bible' (Handbook of Physics and Chemistry) which described the procedure in great detail.

I spent another day at the calculating machine, and this resulted in a new cubic curve that fitted very closely to all the data points. I was very pleased and felt that I had learnt a lot from this exercise. [The Facit calculating machine that I used was a mechanical device, operated by winding a handle. It required a degree of expertise to use it quickly].

The Control Panel

I was quite shocked when John told me that we had a 'deadline'. We had less than four weeks to finish the assembled Thermostat. He wanted to load it into the Windscale reactor No. 2, before it started up. This was so we could overcome any problems before the reactor became extremely radioactive.

To speed things up he wanted me to design the control panel before we had measured the required power levels on the finished product. We made a projection from the data obtained from the trial heater. That done he left me to select the components and design the hardware. I quickly decided on four panels mounted in a standard electronics rack. The top panel would house an Electroflow temperature controller, similar to the one that I had used with Tom Fry. The next panel contained the three Ammeters showing the current to the three parts of the heater. Next came the power supply panel. This was three 'Variacs' and three low voltage transformers, which could adjust the current to each of the heaters. The bottom panel contained just a terminal box, where it could be linked up to the Thermostat assembly. I made the necessary drawings and put them into the workshop for assembly.

Building the Thermostat

As soon as the hardware arrived I set about assembling the heater. First I had to fit the thermocouples into the milled slots in the thick walled furnace tube, two at the centre, and one at each end of the heated tube. Here I hit my first problem; the wires had to be over forty feet long, and as the reels were only 6 inches in diameter, the wires had a permanent curl, which made handling them rather difficult. After some trials I found a solution. I took the reel down onto the hangar floor and put one end into a vice, unwound the desired length and holding the free end in a pair of pliers, stretched the wire to just beyond its elastic limit. This resulted in a very straight and kink free wire, which was easily wound up to a diameter of 18 inches without causing any permanent set.

Having fitted the thermocouples, I set about winding the heater with its mica insulation and 'basket weave' strips. This was a much longer section than the trial version, and proved to be quite tedious and took a long time. I remember working through a whole weekend to get it finished in time. Connecting the Nickel leads to the Nichrome heater tape did prove to be a problem. I had to use a high temperature 'Silver' solder, which was quite tricky to do in situ.

Having completed the business end of the Thermostat, I insulated all twelve wires with Silica tubing and the short section of pipe clay tubes, which were then clamped to the outside of the Aluminium tube above the heater section. The last part of the assembly was fitting the protective tube which covered the heater.

Testing

Just in time, the completed control panel had been delivered to the lab. I quickly connected this to the Thermostat, and set the temperature to 350 degC. After a few trials I managed to adjust the temperature of the end parts of the heated tube to be the same as the centre. The power levels were all right, and there was plenty of adjustment left for setting other temperatures.

When I showed it to John he was very pleased, but asked one awkward question! Had I checked the level of the current in the heater 'tap' leads? Each lead was taking the current in the centre part of the heater, plus the current in the end part of the heater! If they were in phase (it is an AC voltage), the currents would add and could be double! If they were out of phase they would subtract and show only the difference! I had to admit that I had not thought of that. A check showed that one was all right, but the other was not. This was quickly cured by reversing the output leads from one of the transformers. [Why didn't I think of that!]

Windscale

Because the whole Thermostat was so large, John had decided that we would complete the final assembly on top of the Windscale reactor. This would involve connecting the two extension tubes to the Thermostat, threading all the twelve wires through the slots in the tube flanges, and fitting the Silica & pipe clay insulation sleeves. At the time this sounded like a good idea. However, it was a decision that we would live to regret.

The 'deadline' was now approaching, so we were in a bit of a panic. John organised the transport to take the extension tubes, and the control panel to Windscale, and asked me to gather all the tools, materials, and equipment that we would need to make the assembly. We would take the business end of the thermostat with us in John's car.

On the appointed day, I was ready to go as soon as I arrived at Harwell in the morning. However, John was not ready, and had a number of other things to sort out before we left. In the end we did not leave until late afternoon; to make the 300 mile journey to the Windscale works in Cumberland. In the days before motorways this would take about 10 hours! We were in John's new car (an old style Ford Anglia), and I was in the passenger seat clutching the 6 foot long thermostat underneath my arm. I was dismayed when John told me that we had to go to his home in Wantage, because he had forgotten his suitcase! This delayed us another hour, and meant that we were caught up in heavy traffic through Oxford. (No bypass in those days)

By the time we got to Lichfield it was dark and quite late. John said that he was to tired to continue, and we would have to stay the night. In the main street the George hotel was full, but we managed to find space in the nearby King's Head. However, we had to go back to the George to eat in the rather nice restaurant. All these delays meant that we were late to bed. I have a vivid memory of a sleepless night, listening to the traffic passing through the main street all night long! In the morning we were away early and soon making good progress. I was relieved to find that the Thermostat was still in the car, which we had left in the car park overnight!

We arrived at the Windscale works mid afternoon, and after a little formality we were guided to the No.2 reactor building. I was a little surprised when I found that it was necessary to go though the Men's changing room to get inside the building. There was no Women's changing room! We had to put on white coats and overshoes before we were taken to the foot of the reactor, where there was a metal frame stairway to the top. The building was 150 ft. high, and the pile about 100 ft. In front of us was the huge concrete duct which carried the air cooling to one side of the pile. We were told that there was a similar duct on the other side. Above the duct was a metal frame carrying the horizontal control rods. Our guide left us, and John and I then climbed the 130 steps to the top. The only feature at the top was two rows of vertical steel tubes attached to a metal frame. These were the shutoff rods. The top of the reactor was a mess of pipes, cables and access holes covered with metal plates. There was little unoccupied floor space. Fortunately our Control panel and the extension tubes for the Thermostat were already there. There was a space along one side where we decided we could complete the assembly. This was bounded on one side by a short steel fence, beyond which was a 100 ft. drop to the concrete floor.

John next had to go and see the reactor manager to decide in which hole we were going to put the Thermostat. He left me to collect all our stuff from his car, and carry it to the top. It took me three trips up the 130 steps, before I had everything that we needed. I lay the Thermostat and its extension tubes in a line, and supported them on the 'vee' blocks that I had thoughtfully provided. I had just bolted all the tubes together when John arrived. He looked exhausted from the climb, and suggested that we had done enough for one day. It was late, we were both tired and in no state to start the delicate operation of threading all the wires through the insulating tubes. We then left the site and made our way to the hostel at Greengarth (a few miles away) where we had booked rooms.
After an early meal we retired for the night, both completely exhausted.

The next morning we were up early and back at the site by 9 am. John had to go and see one of the engineers about the shielding plug which would form the top part of the assembly. He also had to organise the crane which we would need to lift the whole Thermostat and lower it into the reactor. He gave me a piece of paper which identified the hole in the top of the reactor that we were to use. I was told that there was an ionisation chamber in the hole, which I could remove.

When I got back to the top of the pile I was all alone. In fact I was mystified that there seemed to be so few people about in that building. I was surprised that there appeared to be little in the way of security! I quickly located the hole, which was closed by a steel plate fixed by only two bolts. Through the centre a cable was passed through a cable gland. I unbolted the plate and carefully lifted it away and pulled the cable slowly upwards. It seemed to be very light. After removing many yards of cable the end came in sight. It was just bare wires! The ionisation chamber was not there. I must admit that I panicked a bit. Would I get the blame? However when I looked at the end of the cable, it was obvious that it had been hanging on the wires. There was no real support for the ionisation chamber! I found a powerful torch in my toolbox, and shone the beam down the hole. I could see nothing; the beam seemed to just disappear into the inky blackness of the Graphite hole.

I suppose that we all do something silly in our lives, however, what I did next was completely stupid! I had a hank of string in my toolbox; I tied one end to the ring at the bottom of the torch, and lowered the torch down the hole. It worked fine; I could see the ring of light illuminating the hole just in front of the torch. After an estimated 30 ft. I had seen nothing unusual, so I started to pull the torch out of the hole. Much to my dismay it encountered an obstruction and stuck! I quickly tied the free end of the string to a nearby pipe, and tried very gently to dislodge the torch. It did not want to come. I could feel the string stretching as I pulled.

At this point I really did panic! I was standing on top of a brand new multi million pound Plutonium producing reactor that had not even started, and I had managed to get a very large torch stuck in the middle of it. I had borrowed the torch, so I knew very little about what it contained. The heavy waterproof casing I guessed was Aluminium or an alloy, which would not cause too much harm. However, the batteries could contain Cadmium, which I knew to be a prolific absorber of neutrons! The reactor was due to start tomorrow, and I would be for the 'high jump' if it was delayed by my stupidity. I looked nervously about me, but all was quiet and there was no one in sight. I continued to jiggle the string in the desperate hope that it would free the stuck torch. After what seemed like an hour, but in reality was only a few minutes, the torch eventually became free. I breathed a sigh of relief, and with care slowly pulled the offending torch out of the hole. I wrapped the torch and all the string in a ball and hid it away in the bottom of my toolbox.

After this I felt shaky and quite weak. I found a place to sit down and allowed myself to recover. I never told anyone about my stupid action.

John did not arrive for another half hour. By that time I had recovered, and started to thread the Silica tube insulation on to the wires leading to the Thermostat. It was not an easy task! I was working on my knees, in a cramped space and with poor lighting. The slightest kink in the wire would make it harder to pass it through the 1.5 mm. bore tubes. John was not a lot of help. His large hands made it very difficult to do delicate work. However, he passed me the tubes and other parts as I needed them. By midday we had only got as far as the centre of the first extension tube, and I felt exhausted. We decided to take a break and go and get some lunch. We were back in less than an hour, and refreshed, the work proceeded at a faster pace. John had booked the crane for 4 pm. However, when the Rigger arrived on the top of the pile we were no where near finished. John then had to make a quick decision. He decided to abandon the construction, and try the unfinished assembly in the hole.

The crane Driver was already in his seat high above our heads, and the Rigger was waiting. We quickly cobbled the wires together, and fixed them to the tube with sticky tape! With a sling attached to the top, the assembly was quickly hoisted into a vertical position. The Rigger then directed the Driver, using signals that were hard to understand, and with great precision carefully lowered the Thermostat into the hole. There was no problem, but when John asked them to remove the assembly, I noticed that he was very agitated. (He explained later, that if the Thermostat snagged in the hole, the 10 ton crane would rip it apart.) After the assembly was placed back on the floor, the Rigger, somewhat bemused, departed.

I was a bit dismayed by what had happened, but John had now made up his mind; we would dismantle the Thermostat and take it back to Harwell. It would be a lot easier to build the whole assembly in more favourable conditions, and ship it to Windscale in one piece. [I could have said "I told you so" but did not dare!] The following morning we were on our way back home.

The second assembly

Back at Harwell, in the familiar territory of Hangar 8, I managed to find a 30 ft. long unoccupied space along a wall. I borrowed three tables which allowed me to support the assembly at a reasonable height. I then began the reconstruction. At first I was worried that I may have to rewind the heater, but after a struggle, I managed to straighten the wires well enough to pass through the Silica tubes. It took me three days, in the relatively peaceful environment, to complete the task. I think that John was just a little bit over optimistic in thinking that we could complete the assembly in one day.

Fortunately the second control panel had arrived. [The long term plan was to put a Thermostat in each of the two Windscale reactors.] I quickly connected this to the assembly, and gave it a thorough test. It was all working perfectly. In the meantime John had located a 30 ft. long steel tube into which we carefully packed the assembled Thermostat. It was dispatched to the Windscale works on a lorry, together with the new control panel.

A week later John and I were back at Windscale. It had now been decided that the Thermostat would be installed in the No.1 pile, which was due to shutdown for a routine service. When we got to the pile building, we found that the Thermostat had been unpacked and was on the top of the pile together with the new control panel. My first task was to check that the assembly was in good working order. I connected it to the control panel and immediately found that there was a problem! The bottom heater was not working; it was open circuit! I quickly removed the protective cover from the heater and found, much to my dismay, that the Nickel wire lead had come adrift from the end of the Nichrome heater winding. This was a disaster; the joint was Silver soldered and not an easy thing to mend. I was not prepared for this and did not have the materials or the equipment to carry out the repair. Fortunately one of the pile engineers managed to find a portable gas torch, and the necessary Silver solder and required flux. The repair was awkward to get at, but in the end it all went well. I also checked the other joints to make sure they were sound. Another test and everything seemed to be all right.

The reactor had been shut down so the next stage was to insert the Thermostat into the prepared hole. This time John and I were not allowed to take part in this operation. The pile engineers supervised the whole thing, and did it all with great skill. First the Thermostat was lowered into the hole, and tied off, leaving about 4 ft. sticking out of the hole. The crane then picked up the 7 ft. long shielding plug and placed it just above the top of the Thermostat. The 12 wires, now in their flexible insulating sleeves, were threaded through the spiral hole in the plug, and then the two parts were bolted together. Finally the whole assembly was lowered into the hole. The wires were then taken under the decking to the control panel. That job done, the engineers departed and John and I were left on our own to connect the system to the control panel.

We set the temperature to 350 degC and switched on the power. It took about half an hour before the desired level was reached. I then measured the temperature, using a portable potentiometer, and adjusted the power levels until the centre, the top, and the bottom readings were all 350 degC. John was very pleased; it had been a long haul and a considerable effort, but all now seemed to be working as planned. The next stage was when the reactor started, and that was going to be some time that evening.

It was now late afternoon so John suggested that we go back to the hostel to have a meal and a rest. We returned in the evening and went directly to the control room to see what was happening. The reactor was up and running, and the power level was the expected 100 MW. We then went to the top of the pile to check the Thermostat temperatures. Everything was all right and it was controlling perfectly. However, John was slightly worried because we did not know whether the Thermostat would be overheated by the reactor, or cooled by the air flow! He had been unable to get anyone to express an opinion on this matter. We returned every four hours to make the checks. In between we returned to the hostel, drank coffee and sat in the lounge chatting. I learnt more about John and his early life in that one night, than I had in all the time that I had known him. We did not have any sleep that night. The next day we made our last visit at midday, and John was quite happy that all was well. The Thermostat was still working, and it had not failed or fallen apart. We went back to the hostel, had lunch and straight to bed. I was exhausted. The next morning we returned to Harwell.

The Second Thermostat

After two days off to recover, I was faced with the task of building the second Thermostat. I must admit the prospect of starting again was a little daunting, however the work went well and proceeded rapidly. In less than three weeks the new unit was sealed into the 30 ft. long tube, and was dispatched to the Windscale Works.

At this point a new member joined the group. He was Francis (Dinky) Howell; he was a lot older than the rest of the group, and had been an RAF pilot during the war. A great character, highly amusing and a good organiser. Tom had given him the task of supervising the irradiation of samples in the Windscale Piles. He was soon joined by Jean Griffiths, who was to help in that task.

Dinky arranged for the second Thermostat to be placed into the No.2 reactor during the next shutdown, and I went along to test and set up the new system. The temperature was set to 250 degC. I also went to the No.1 reactor to check that the first Thermostat was all right. On the same visit I helped Dinky and Jean place samples in an empty fuel channel of the reactor.

The Routine

For the rest of the year, monthly visits to Windscale became routine. It was Dinky, Jean and either Alan Perks or Beryl Bird. I always went along to check the Thermostats, but got involved in the other operations as well.

Ron Dugdale had designed the container to put samples into the Thermostats. It was a sealed Aluminium tube containing a Helium atmosphere. It had a top fitting which could connect to a special grab lowered down the hole. The main shielding plug contained a secondary plug, 2 ½ inches in diameter, which could be removed during a shutdown.

By comparison, putting the samples into an empty fuel channel seemed very primitive. The hole we were allocated was near the centre of the reactor, so we had to wait until the platform had been set at the correct level on the Charge Face. The engineers removed the shielding plug from the hole, revealing four fuel channels. A wooden trough was then placed to connect to the chosen channel. With a long pole with a hook at the end we pulled out a Graphite 'boat' in which the samples were contained. We removed the 'old' samples and put in the new.

The top of the pile was very dull; just a messy collection of pipes and cables set against the drab grey concrete. However, the Charge Face was very different; it was impressive on a scale that I had not seen before. The size of the active face was about three times the linear size of the more familiar BEPO reactor at Harwell. It was also brightly painted, and all the holes numbered. The platform was even more remarkable; it was about 60 ft. long and 15 ft. wide, and it could be set to any level on the face of the pile. There were railway lines along the length of the platform on which ran a huge charging machine. This was supposed to be able to load the Uranium fuel into the reactor channels. However, I never saw this in action! When I was there the fuel was always being loaded by hand, using a similar method to what we were using to insert our samples. Access to the platform was via a lift which stopped at the platform level. This, for safety reasons, was not usable when the platform was in motion. On one occasion we were the last to finish on the face, and the platform was being lowered before we got to the lift. We had to wait some time before the platform reached its rest position at the bottom. Looking up from the bottom we had a view of the most impressive industrial site that I have ever seen; It was awe inspiring.

In between the visits to Windscale we all had other jobs. The samples had to be measured, and this task was divided between various members of the group. The most important was the Dimensional Change, but also measured was Young's Modulus, Thermal Expansion, Electrical Resistance, Thermal Conductivity, Rigidity Modulus and Stored Energy.

My task was to measure the Rigidity Modulus. We had no apparatus to do this so I had to make it myself. John Simmons made a sketch of a very simple way of taking this measurement. I constructed the apparatus to do this by torsion. The specimen was a rod ½ inch in diameter and 4 inches long. This was twisted by the application of a weight to a lever. The rotation was measured by attaching two small mirrors to the rod and observing, with a telescope, the movement of a distant scale when reflected in the two mirrors. The mirrors were a fixed distance apart on the rod, and the measurement gave the degree of rotation between the two mirrors. The apparatus worked well and gave very reproducible results.

Education

During this hectic year I had still been studying at the Oxford Technical Collage one day a week. However, I frequently missed days and my studies were often interrupted by the many trips to the Windscale Works. In July I took the National Certificate examination and passed with good grades. In September I started the Higher National Certificate course in Applied Physics. This required three lectures: Mathematics, Physics, and Applied Physics, and also two practical periods; all in one day. The subject of the Applied Physics course was normally dictated by local industry, and as Harwell was a major local employer, the subject chosen was Nuclear Physics.

The Wigner Group – 1952-3

At the beginning of 1952 the work continued with the monthly trips to Windscale, and the same pattern of measurements. During this time I learnt a lot more about the Windscale reactors and their purpose.

The Windscale Piles

A very good description of the Windscale Piles is given by K.E.B. Jay in a book published by HMSO in 1954 'Britain's Atomic Factories'.

The main purpose of the piles was to produce Plutonium for military use in Atomic Bombs. The engineers at Risley, working only from the nuclear parameters derived by Harwell, had to design the piles to produce the required amount of Plutonium per year. Although the primary use for the Plutonium was military, it could also be used in future designs of a new breed of reactors. To achieve the required production rate the engineers decided on two reactors, each operating at 100 Megawatts. The choice of cooling for the piles was limited to three designs: Water cooling, while efficient, required a high level of purity of the water, and also there were safety concerns if the water supply failed. The most efficient system would be closed circuit high pressure gas cooling. However, this required a sealed high pressure vessel, which would be expensive to build and would delay the construction. The last option was simple air cooling. This would be much cheaper, faster in construction, and simpler in operation. As they were under immense pressure to complete the project, they chose air cooling. The 100 Megawatts of heat would be blown straight up a chimney and wasted. With hindsight this was not a very wise decision. However, there was a lot of political pressure to build and test an Atomic Bomb, as we were far behind the USA and Russia in this field.

As a result of the air cooling the loading and unloading of the Uranium fuel, which would have to be performed frequently, was quite simple. New fuel was pushed into a horizontal channel, and the spent fuel literally fell out of the rear end of the hole! It fell into a metal skip, which was under water to break the fall, and was moved on a railway to a cooling pond which lay in between the two reactors. From there it was taken to the adjoining Chemical Processing plant, where the Plutonium was separated. The Uranium fuel elements were sealed into an Aluminium (later an alloy) casing. This had fins to help transfer the heat to the cooling air. Each fuel rod was about one foot long, and was mounted on a Graphite 'sledge' to ease the passage through the hole in the Graphite moderator.

The first blunder was encountered when the No.1 pile was started in October 1950. Even when the pile was fully loaded with fuel it would not diverge! That is, it did not reach a critical size! They had overdone the cooling fins on the fuel, which added a lot of neutron absorption. The time consuming cure was to remove the fuel and to reduce the size of the fins. I was later told that this was done by hand!

The second blunder was even more silly. When the pile was in full operation, the turbulence of the air through the pile caused the fuel rods to creep down the channel. This resulted in some fuel elements falling out of the back of the pile! Unfortunately the skips were not in position, so the fuel fell onto the underwater rail lines! How they removed the wayward fuel I do not know, but it did delay the operation of the pile. The cure was to link all the fuel elements in one channel together. This caused even more delays.

The third blunder was really an error of design. In early discussions it had been suggested that the output air should be filtered before passing out of the 400 ft. chimney stack. Terry Price was one person in favour of a filter. However, he was robustly criticised by one of the Risley engineers, who stated that it would be impossible to filter the two tonnes of air a second, which would need to pass through the reactor. Later there was a change of policy and, at Cockcrofts insistence, the filters were installed, at the top of the chimney! I never knew whether it was at the top because the chimney was half built before the decision was made. It was known as Cockroft's Folly. The square filter room at the top of the chimney's was a very obvious feature of the Windscale Piles.

Apart from these teething troubles, the piles worked very well and were soon producing the required Plutonium. The first batch of Plutonium was ready in March 1952.

Secrets

Early in 1952 Tom Fry moved into an office on the ground floor close to Ron Dugdales lab. We were quite surprised when he introduced a man who was to be his secretary. I can't remember his name so I will call him Jim. We were rather puzzled because secretaries were always young women, who were skilled in shorthand and typing. However, Jim was no typist, instead he had a drawing board at the far end of Tom's office, and was very secretive about what he was doing. He was a very pleasant middle aged man, who was a skilled artist. He often showed us beautiful artwork of machine tools, which I felt sure was not the purpose of his residence in Tom's office.

The group 'Tea Break' was an occasion when we all gathered in the general lab. It was a time when we talked about our work, and of course many other things. The girls usually made the Tea, and did not object to the task. (In today's world they would not do that!) One day when the girls were all away, I made the tea. (first and last time) The result was dreadful, and everyone complained. I was teased a lot after that event. In the afternoon I was presented, by Jim, with a certificate stating that I had passed my tea making test. It was a beautiful work of art, drawn on a postcard in pen and black ink. It even had little pictures of people picking the tea leaves, and of a 'Tea Clipper' sailing boat. He had dashed that off since the morning break.

Some time after Jim had departed, Tom asked John Simmons and me to test some new equipment. He took us down to the empty underground room below the Hangar 8 floor. (We had two rooms there, one which was temperature controlled, was used for the measurement of Dimensional Change and Stored Energy) I had used the empty room before, as a dark room, when testing optical equipment and also when I was looking at Phosphorescence for Ron Dugdale. The new equipment was there, and I decided that this was the result of Jim's labours at the drawing board.

It was a pressure intensifier. A double piston device with a twenty to one ratio, which was driven by a simple hydraulic hand pump. The pump could deliver a pressure of 1000 atmospheres, giving a pressure in the final chamber of 20,000 atmospheres. Tom told us that we were going to compress Graphite and irradiate the device in the BEPO reactor, in the hope of producing Diamond! Natural

Diamond was known to be formed in rocks due to high temperatures and pressure. Moissan had produced tiny artificial Diamonds in the laboratory, by dissolving Carbon in molten Iron and cooling the mixture rapidly. Tom told us, that for the time being, the work was secret and we should not disclose it to anyone else.

For reasons that I did not understand, John seemed to be very grumpy about the task. I suspected that he thought that it was a silly idea. However, I cut a piece of Graphite that would fit into the ¼ inch diameter high pressure chamber, and we set about taking a series of measurements. We measured the movement of the piston with a Travelling Microscope, and plotted the movement against the pressure. We cycled this up and down many times. I do not now remember all that we did, or what we found out, but I was amazed how much it was possible to compress the Graphite.

A few days later I arrived to find that the room had been broken into! This was not someone picking the lock, but the door was damaged and looked as if it had been forced with a 'Jemmy'. Of course the site Police were called, but they were of little help. John and I were asked to check if anything had been stolen, but as far as we could see nothing had been taken or even disturbed in the room. It remained a mystery. The only rather weak suggestion of the Police was that one of the Irish labourers on the site, (and there were many) had spent the night there with one of the rather pretty Irish cleaners. However, this did not make a lot of sense as the cleaners all had pass keys and could get into any lab.

Shortly afterwards I remember Tom talking openly about making Diamonds at a group 'Tea Break'. It seemed that it was no longer a secret! I was very surprised at what had happened, and even more surprised when I discovered that the high pressure equipment had been removed from the underground lab. I never saw the apparatus again.

Top Secret

A few weeks later I heard that Tom was setting up a lab. in an empty building. Buildings 151 to 154 were old RAF barracks. 151 was Nuclear Physics and 153 and 154 belonged to General Physics. 152 had been the Medical building, but they had now moved to a new purpose built facility, and the building was empty. Tom set up a lab. at the southern end of the upper floor. He asked Beryl to help him in a new task. She was detailed to gather certain equipment and take it to the new lab. I was very surprised when I found that he had asked for BF3 counters and the necessary electronics. The Boron Tri-Fluoride counter is a neutron counter! Tom was very secretive about the new work, and this made us all very curious. What happened next took us all by surprise; Beryl refused to do the work! She would not say the reason why, but it turned out that the task was top secret, and she did not want to be involved. This, of course, fuelled a wealth of speculation and rumour, including the fact that the work involved Plutonium. Tom eventually found someone else to do the work; a young man who was not from Harwell.

It was widely thought that the task was something to do with the Atomic Bomb. Britain's first test of the bomb took place at the Montebello Islands, 80 miles off the coast of Western Australia, on the 3rd October 1952.

[In 2007 Alison and I visited Tom Fry at his home in Sidmouth. We spent a very nostalgic afternoon looking at old photographs, and recalling the events of 60 years ago. A short while after that meeting I emailed Tom and asked him directly about the top secret work that he did in 1952. I quote his reply: "The secret work was given to me personally by Cockroft. It had nothing to do with the UKAEA, but was for another government department. I do not feel free to give any details." It is interesting that Tom got one thing wrong; at that time the UKAEA did not exist; we worked for the Ministry of Supply! Tom died in 2008, just two weeks before the 60th anniversary meeting at Harwell to celebrate the divergence of the BEPO reactor.]

Windscale Scares

Our visits to the Windscale Works continued throughout 1952. However, Dinky Howell was now in charge of procedures, and this in many ways made things more interesting. We often had times when we were waiting for the reactor to shut down, or waiting for our turn to access the charge face. While waiting Dinky managed to persuade the manager to allow us to visit parts of the site that were not normally open to us. We went into the Blower House, wearing ear protectors, where the huge fans blew the air through the pile. The noise was terrifying.

We were taken round the Cooling Ponds, where the spent fuel from the pile was stored prior to being taken to the Processing Plant. The fuel rods were stored in skips under twenty feet of water, and an over head crane could move a skip to any position in the pond. The fuel rods could be manipulated with very long tongs; and we were shown how the Aluminium can was removed from the Uranium fuel rod. When it was dark you could see the blue glow in the water, caused by the Cerenkov radiation from the extremely radioactive fuel.

Perhaps the most bizarre visit we made was to the Filter Room at the top of the 400 ft. chimney. A lift attached to the side of the chimney took us to the top where we emerged into a very strange place. The room was a gallery, which had no windows, and was about 10 ft. square. It extended all the way round the chimney. The filters, which were about one foot square, were pushed into slots on one side of the chimney and removed at the other side. They were then washed in water, dried and returned to the input point. We were told that when the reactor was in operation, a team of men continuously changed the filter elements. In the roof of the filter room was a trap door leading to the roof adjacent to, and near the top of the chimney. We were allowed to look out of this door, but as it was very windy, we were not allowed to go out and stand on the roof.

In one of the many waiting periods, I managed to persuade Jean to give me a driving lesson in the Ministry car, which was a Vauxhall 14. This took place within the confines of the Windscale Works. I did not do very well and it was several years before I passed my driving test.

Contamination

While working in the pile building we had to wear white coats and cloth overshoes. It was as much to keep the dirt out as it was to prevent radioactive material from leaving the building. On the pile face we wore cotton gloves when we were handling the irradiated samples. The Graphite was very pure and did not get very radioactive. The slight contamination we picked up was easily removed by simply washing the hands. However, on one occasion it did not wash off! We were checked by a Health physicist by putting our hands in a Radiation Monitor. He was not satisfied and we were told to wash again. After we had washed three times it was still not clear, so he insisted that we go to the Health Physics building. There we were instructed to use a very harsh soap and a scrubbing brush to try and remove the contamination. It was very resistant and did not want to be removed. We were then told to immerse our hands in a strong solution of Potassium Permanganate. This, we were told would kill off the top layer of skin which would easily be removed together with the contamination. Jean refused, as it would stain our hands brown. After a lot of argument we settled for a diluted solution. It did work, but only after a lot more scrubbing. It was half way through the night before we were allowed to leave. The contamination, which we knew was not due to the Graphite, was probably fission products from a burst fuel element.

The Hollow Fuel Element

In order to increase the amount of damage to our samples, it was decided to place some into a hollow fuel element, where they would receive a larger dose of fast neutrons. Ron Dugdale arranged for the Graphite samples to be sealed into a ½ inch diameter Stainless Steel tube. This was given to the Windscale engineers who put the tube inside a hollow Uranium fuel element and encased this in a standard Aluminium can. The special fuel element was then placed at the centre of a normal fuel channel close to the centre of the pile.

After one months irradiation we had to recover the sample can. However, the pile engineers insisted that we find the can ourselves. They placed the skip, containing all the fuel elements from the correct channel, into the work bay, which was at the centre of the cooling pond. From there we had to identify the correct fuel element, which we thought would be difficult. After a brief chat about the tools available, we were left to struggle. It was a lot easier than we expected. The skip and all the equipment was under 20 ft. of water, and the area was brightly lit by underwater lamps. First we grabbed a fuel element with very long tongs, and placed it onto a machine which would remove the Aluminium can. Pulling a lever activated a hydraulic ram which pushed the fuel element through a hole which stripped off the can. The remains of the can fell into a container underneath, while the Uranium rod came out the other side and fell onto a 'vee' shaped platform. At this position we could easily see the end of the rod, and able to identify if it was the hollow one. The next step was quite primitive; this was done by the simple means of pulling a chain attached to the 'vee' platform which tipped the rod off and dumped it into another skip.

Of course we had to go through nearly all of the fuel elements before we found the one we were looking for. We were then able to push out our sample can and retrieve it from the hostile environment of the pond.

A near disaster

On one of our visits to Windscale we witnessed what can only be described as a near disaster. During our visits it was necessary to obtain the total Megawatt hours that the pile had run since the last visit.

This was in order to estimate the total Neutron Flux our samples had endured in that time. This task was nearly always given to one of the girls. On this occasion I think it was Jean. It was a tedious job of searching through the charts of the Power recorder, for the whole month. This took place in the Control Room which was usually deserted during a pile shutdown. During this time Jean noticed that the pile temperature, shown on several of the recorders in the Control Room, was increasing! She did not know what to expect, but kept an eye on it while she was working. The temperature continued to rise so she reported this to Dinky Howell. He was concerned and phoned the Pile Manager; who was not at all worried and explained that it was due to the Fission Product heating in the Fuel Elements, which amounted to one Megawatt when the pile was shut down. This was normally kept cool by a small auxiliary blower. However, there were two such blowers, one was in pieces because it was being serviced, and the other one had failed. The manager was just not concerned and considered it to be normal behaviour.

We went back to our work, but Dinky asked Jean to keep an eye on the temperature. Some time later Jean came again, and this time was very concerned because the rate of rise in temperature was increasing. This was not what would be expected! Dinky, now quite worried, phoned Harwell and talked to John Simmons. John very quickly realised that this was not normal and may be due to Stored Energy in the Graphite; he promptly phoned the Windscale site Manager and eventually persuaded him to switch on the main blowers to cool the pile down. This, I believe, probably averted a major disaster like the fire that happened in 1957.

Stored Energy

As soon as we got back at Harwell, Tom Fry called a meeting to discuss the Stored Energy problem. The meeting took place in the general office, and all the senior members of the group were there. John had asked me to join them, and the only other junior member of the group present was Alan Perks. Tom started by describing what we already knew. The energy was stored in the Graphite lattice when it was distorted by presence of interstitial carbon atoms; which had been displaced from their normal positions, by neutron irradiation. When heated to a high enough temperature, the Interstitial atoms could move and return to their normal positions, releasing the stored energy.

Two things that we did not know were: The magnitude of the effect, and the critical temperature at which the energy would be released.

We had for some time tried to measure the magnitude of this effect by using the Total Heat of Combustion of the Graphite. The sample was placed in a 'Bomb calorimeter' and ignited in an atmosphere of high pressure Oxygen. The calorimeter was immersed in a water bath, and the rise in temperature measured. However, this was not a very satisfactory experiment, because of complications. The heat released was about 8000 calories/gram, and with the samples from the BEPO reactor containing only small amounts of stored energy, it proved difficult to get any accurate results. Also the result was uncertain because it depended on the combustion products, which needed to be analysed each time! [I believe that this experiment had been transferred to the Chemistry Division, and little had come of it. I think that Tom felt a bit guilty about that!]
The samples from Windscale now contained much larger amounts of energy, and could be measured in a very different way. I think that it was George Kinchin who suggested a crude but very simple test. He took a small sample of the irradiated Graphite and connected it to a thermocouple to measure

its temperature. The sample was them placed on a 'Hot Plate', with an Asbestos mat in between. The temperature of the sample increased slowly, but when it reached about 100 degC there was a sudden and rapid rise to over 300 degC! There was then a very lively discussion about how much energy had been released. The verdict was some where in the region of 80 calories/gram.

I think that they were all shocked at the magnitude of the effect. Tom quickly realised that it could be a serious problem for the Windscale Piles. He said that it was now urgent that we develop an apparatus to measure the effect accurately.

With little more discussion Tom gave the job to John Simmons. It was a decision that was to change my life completely. From that moment on, I was relieved of all my other duties, and had to concentrate on the measurement of Stored Energy! At that time, I would have been surprised to know, that it was a job that would consume most of my time for the next 10 years!

A New Era

By the time we got back to our lab., John had already decided on what form the apparatus should take. We sat down at his desk, and he made a rough sketch of what we would require. The calorimeter would be a cylinder of Copper with a one inch diameter hole in the middle. The Graphite sample, which he decided would be ½ inch in diameter and ½ inch long, would sit at the centre of the cavity. The Copper block would be heated by a Nichrome tape heater winding, similar to the one we had used on the Thermostat. The assembly required two thermocouples, one on the sample, and one on the Copper block. John then described how it would operate. Power supplied to the heater would cause the temperature of the block to rise linearly at first, but then, as it got hotter, the rate of rise would decrease. The sample temperature would also rise, but lag behind the block, because it is thermally isolated, but would receive heat by radiation from the Copper block. All we had to do was measure the temperature of the sample and the block. When the Stored Energy was released, the sample temperature would show an increase, and may even rise above the temperature of the block. When we thought that all the energy had been released, the apparatus would be allowed to cool, and the procedure repeated with the same sample. The difference between the two curves for the sample temperature would show the rate of release and the total energy released. To reduce the heat loss from the calorimeter, John suggested that we cover it with 'Sil-O-Cel', a fine insulating powder.

John left the details of the design to me. My first port of call was the main stores, where I had to wait while they cut a 3 inch length of 1 ½ inch diameter solid Copper rod. We had our own lathe in a workshop in Hangar 8, so I was able to bore a 1 inch diameter hole in the block 2 ½ inches deep. This was followed by a small hole to take the sample thermocouple, which would be at the top. The open end of the block, which was to be at the bottom, I closed with a Copper disk which was held in place with 3 screws.

The heater winding, using Nichrome tape and mica insulation, was completed very quickly. I had a lot of experience using this method, and all the materials were to hand. I then had to decide how to mount the calorimeter, so it would be easy to load the sample. A simple solution was chosen; the calorimeter was suspended from a retort stand using three Stainless Steel wires, which hooked into small holes at the top of the Copper block. The sample thermocouple was put into a twin bore silica tube that passed through the small hole at the top of the block. This was long enough so that it could be lowered right through the block to enable the sample to be attached. The sample was suspended by the thermocouple, which could then be raised into the block, and held in place by a wire clip. I set the height of the calorimeter above the bench, so that it was possible to place a large Pyrex beaker underneath; this was then raised to enclose the calorimeter, and a wooden block placed underneath. The insulation could then be poured into the beaker, as it was a dry powder which flowed like water. The final task was to connect the second thermocouple to the top of the Copper block, and arrange an ice bath for the cold junctions.

In just three days I was ready for the first test. John decided that we would use an unirradiated sample of Graphite to see how the apparatus behaved. A 'Variac' was attached to the heater, and a small amount of AC power applied. It took a little while to get the rate of rise of temperature to a suitable value. A rate of 5 degC per minute seemed to be about right. Once this was fixed, I measured the rise in temperature of the sample and the calorimeter, taking alternate measurements. It all worked very well with the sample temperature lagging behind the calorimeter, as John had predicted.

The next day I put in a sample that had been irradiated in the Windscale reactor. I plotted the two temperatures on a graph, as I measured them. The result was fantastic! The sample temperature lagged until about 90 degC, and then rose above the calorimeter as the energy was released, then slowly returned to a lagging condition. It all worked as expected, and John was very pleased. A second run using the same specimen, showed only the sample lagging the calorimeter. This meant that all the stored energy had been released during the first run. Note that this would only happen if the maximum temperature reached (400 degC) had been high enough. Only once, I did try a third run, but there was no significant difference between the second and third time.

Using the data obtained from the two runs, I was able (with some help from John) to plot the rate of release of Stored Energy against temperature. The area under the curve gave the total energy released. The curve clearly showed the temperature at which the onset of the release started.

The Routine

For the rest of 1952 I continued taking measurements using the new apparatus. We had a lot of samples from the Windscale reactor, including ones which had been irradiated at elevated temperatures in the Thermostats. All our results were given to the engineers and the Physics group at Windscale, so that they would be able to assess the problem of the Stored Energy in their reactors. I even made a copy of the new apparatus, which was taken to Windscale, and demonstrated, by Ron Dugdale's new assistant.

The Problem

The problem for the Reactor Engineers, was how to safely remove the stored energy from the Graphite. It is interesting to note that this is only a problem when using air cooled reactors like Windscale and BEPO. The inlet air temperature was the outside ambient temperature, so the inlet face was relatively cool, and this was where the majority of the Stored Energy would accumulate. It was not possible to increase the inlet temperature, as it would be in a re-circulating Gas Cooled reactor. (like Calder Hall and others which followed in 1956)

The technique of removing the Stored Energy was a simple process of annealing the Graphite. That is raising the temperature high enough to release the energy slowly and safely. This was done by switching off the air cooling, and running the reactor at a low power to raise the temperature. Provided that there was sufficient instrumentation, so that the temperature was known in all parts of the reactor, it was a safe and reliable operation. This annealing process became standard in the Windscale reactors, and in BEPO.

1953

One problem with our Stored Energy apparatus was that the sample temperature was not controlled, and depended on how much energy the sample contained. It was also not very accurate when measuring samples with a small amount of energy. John proposed a new system, which although much more complicated, would resolve these difficulties.

The Linear Rise Calorimeter

The proposal was for the sample to have a small hole drilled through the centre, which would contain a heater. The heater would be supplied with power to make the temperature of the sample rise linearly with time. When the Stored Energy started to be released, the power to the heater would be reduced, to keep the linear rise of temperature constant. The reduction of power would then be a measure of the energy released. This means that the conditions of the release are precisely controlled, and it would be suitable for small amounts of energy. It all sounded so simple, but in practice it was to prove to be very complicated.

The first obstacle was heat loss from the sample. John wanted to put this in a vacuum, but to keep things simple, decided that for this trial we would just insulate using Sil-O-Cel. The control of the temperature rise would be too difficult to do by hand, so it would have to be a closed loop automatic control system. John seemed to be excited by the whole concept of this experiment, and as he had spent his early years designing electronic systems, he felt quite at home with the idea.

The first item that we needed was a reference source for the linearly rising voltage. We built a simple device which consisted of a multi-turn helical potentiometer, driven by a synchronous clock motor. This was not very elegant, but it was easy to use and did the job perfectly. The power amplifier to drive the heater was quite straight forward. It consisted of six large electronic valves in parallel, and the required drive circuitry. This could provide 1 ½ amps to the heater, which was more than enough to give the desired rate of rise. This was my first introduction to a DC amplifier,
which was very different to the Audio amplifiers I had built before. I found the new ideas to be quite fascinating, and enjoyed the construction.

The next requirement was much more difficult. We needed a special amplifier to cope with the very low voltage that we would get from the thermocouple attached to the Graphite sample. As the thermal voltage from the Nichrome/Constantan thermocouple was only 50 microvolts per degC, we needed an amplifier that could work with an input at microvolt level. At that time the only device that could do this was a Galvanometer Amplifier. Ken Donaldson, who had now left the group, had designed one using an idea dreamed up by Tom Fry. It was a horrible device which was difficult to use and not very stable. The galvanometer projected an image of a Grating on to a similar fixed Grating in front of a solid state photocell. It was similar to the Galvanometer Amplifier that I had used when working for Ron Dugdale, but the Grating gave a much larger gain.

In operation, the thermocouple voltage was compared with the linear rising reference voltage, and the difference used to drive the power amplifier. Once we had made a few adjustments, the control worked well and proved to be very stable.

I was going to do the first test with an unirradiated sample, but John was very impatient, and insisted that we use a sample containing Stored Energy. He chose a sample that he knew to contain only a modest amount of energy. We started the 'run' and took readings every minute. John measured the temperature, and I took the readings of voltage and current to the heater. In between the readings, I calculated the power and plotted the results on a graph. The power increased on a smooth curve, and then decreased as the Stored Energy was released. The power then returned to its expected track, and we let this continue up to 400 degC. John was over the moon and anxious to try the second 'run'. We had to wait over two hours for the sample to cool, but when we started again the power curve, plotted on the same graph, fitted almost exactly on top of the first 'run', except where the Stored Energy had been released.

I was amazed that it had all gone well, but John was exceptionally pleased that his very original idea had been turned into a reality. He realised that, as it stood, there were many areas of the design which could give rise to errors, and had great plans to improve the system. The sample needed to be placed in a vacuum chamber, to provide a more stable environment, and reduce heat loss. The Galvanometer Amplifier needed a complete redesign, and he already had ideas about that. Also it would help if we had a recording Wattmeter.

However, before we could embark on any improvements, my time at Harwell was cut short!

In the Spring I received a letter telling me that I must report for two years **National Service** on the 15th July. I was quite shocked. I was nearly 22 years old and had been deferred for almost four years. I was doing important work, and still studying at Oxford one day a week. I thought that I had escaped. At first I thought that it was a mistake, but after a few enquiries, I found that most of my friends had also been **Conscripted!** This included two who were on the same course as me at Oxford. I was extremely angry, and complained bitterly. However, it was to no avail; there seemed to be no sense or reason for this stupidity. The beginning of the next chapter gives a lot more detail of how I felt about this idiotic decision. John Simmons did not replace me which meant that -
The Stored Energy development work was virtually put on hold for the next two Years!!

Not to be read
or opened