Joseph Rotblat: The Nuclear Physicist

John Finney

"I don't know if you have met Rotblat, a Pole who has been here about nine months. He is an extremely able man, one of the best I have come across for some years."[1] So wrote the discoverer of the neutron, James Chadwick, to John Cockcroft at the Cavendish Laboratory, Cambridge, in 1940. Over the ten years or so that Rotblat spent working with Chadwick and in the Liverpool University Physics Department, Chadwick's initial assessment only grew. So much so that Chadwick tried hard to dissuade Rotblat from taking the Chair in Physics at St Bartholomew's Hospital in London in 1950. Rotblat's moving the focus of his work to medical applications would, he said, be a great loss to nuclear physics. Moreover, it would mean, argued Chadwick, that Rotblat would never be elected a Fellow of the Royal Society.

In the light of this very positive assessment of Rotblat's work in nuclear physics from one of the "greats" of the field, it is perhaps a little surprising that, apart from his work on the atomic bomb in the early 1940s, his contributions to the early developments of nuclear physics are little appreciated. Both his early nuclear physics and later medical physics achievements tend to be overshadowed by his tireless work aimed at ridding the world of nuclear weapons. But his achievements in nuclear physics were also major. They deserve to be noted and recognized.

What were his main achievements as an early nuclear physicist?

1) Letter from J. Chadwick to J. Cockcroft 8/1/40. Cockcroft's papers, 20/5. Churchill Archives Centre, Churchill College, Cambridge. Quoted in Andrew Brown: *The Neutron and the Bomb*, Oxford University Press, 1997, p. 185.

Joseph Rotblat: Visionary for Peace. Edited by Reiner Braun et al.

ISBN: 978-3-527-40690-6

The Warsaw Years

Nuclear physics was a very young science when Rotblat began his research life in the Radiological Laboratory in Warsaw in 1932. This was the year in which Chadwick had published his discovery of the neutron, uncharged particles that, together with the charged proton of about the same mass, make up the nuclei of atoms. It was a time when the field was essentially uncharted, and techniques to begin the mapping of the area had to be developed from scratch. The field was wide open; no one knew what there was to be discovered, let alone how to go about making those discoveries. Artificial or induced radioactivity was discovered in 1934 by the Joliot-Curies. There were other big players in the field, one of the foremost being Enrico Fermi and his group in Rome. Already by the middle of 1934, Fermi's group had bombarded most of the elements in the periodic table and measured the lifetimes of over 40 artificial radioisotopes. The facilities of the Warsaw laboratory, with only a relatively small amount of radium available to use to produce neutrons for bombarding other atoms, were nowhere near those available to the likes of Fermi. Nevertheless, the Warsaw laboratory focused on using neutrons to produce artificial radioactivity and to study related nuclear phenomena. As Rotblat commented: "We had to compensate for the lack of facilities with ingenuity . . ."

And there was plenty of that. Indeed, the first nuclear physics paper Rotblat published was to turn out to be, in his own judgment, one of his main achievements. At the time, many thought that a neutron could undergo only elastic collisions with a nucleus – it would bounce off the nucleus with no change in energy. Against this view, Niels Bohr had hypothesized that the bombarding neutron and the bombarded nucleus could form a "compound nucleus" which could then break up, with a neutron ejected with a different amount of energy from that of the incident neutron. As there was a change in energy between the incoming and outgoing neutron, this was called an *in*elastic collision. Rotblat's first paper demonstrated experimentally that this inelastic scattering process indeed occurred. In so doing, he added an important building block to the young, growing nuclear physics edifice.

This paper has a particularly interesting acknowledgement that must be unique. The work used a block of gold, which was obviously not easily available. Perhaps as a further demonstration of the ingenuity that Rotblat said they needed to compensate for lack of facilities, the paper acknowledges: "The block of gold weighing 963 grams was kindly prepared for us by the Polish State Mint and the gold was lent by the Bank of Poland." Perhaps one of the earliest collaborations between commerce and science?

Rotblat's Warsaw research during the five or so years before he joined Chadwick in Liverpool produced 15 papers on different aspects of nuclear physics. Some of these took further the work on inelastic collisions. Another examined the production of artificial radioactivity by fast (high energy) neutrons. Being a relatively inefficient process, the signal that had to be detected experimentally was very weak and so difficult to measure with the techniques then available. Again, Rotblat "... had to compensate for the lack of facilities with ingenuity ..." and devised a clever, but inherently simple, way of effectively increasing the weak signal that needed to be measured. In other experiments, a method was found for measuring the ranges in air of particles emitted in the disintegration of nuclei. From these data, the energy released in the nuclear processes concerned could be determined, as could the probability that a bombarding neutron would be captured by the bombarded nucleus (the neutron capture cross-section). Bombardment of nickel uncovered induced radioactivity in nickel and cobalt, phenomena that Fermi's team with their greater resources had failed to find. Another example of what ingenuity could do. In fact, reading these early papers gives interesting insight into the subtle reasoning that was used, both to design clever experiments and to interpret the results.

Just as Rotblat's first published nuclear physics paper on inelastic scattering reported a major advance, his final piece of work before leaving Warsaw was also a celebrated one. In early 1939, Otto Frisch and Lise Meitner had discovered the fission process, in which a neutron incident on a uranium nucleus caused this very heavy nucleus to break up into smaller fragments. Following an interesting and subtle argument – which according to Rotblat was "a fairly simple intellectual exercise" – he reasoned that this fission process would produce more neutrons than were required to initiate the fission process itself. He was able to perform an experiment to test his reasoning very soon after the discovery of the fission process for an intriguing reason. The gold that was important in many of his experimental measurements had to be taken back to the Bank of Poland vaults every evening. The commuting involved led him to use another heavy element instead. As this element happened to be uranium, he was very well placed to undertake, essentially immediately, the crucial experiment to confirm his prediction about excess neutron production. It was done and dusted within a week.

As is well known, he also realized the potential implications of this discovery for the production of a terrifying new weapon.

Liverpool

Ludwik Wertenstein, the director of the Warsaw laboratory, obtained funds for Rotblat to spend a year abroad. Invitations from both Joliot in Paris and Chadwick in Liverpool followed. Given the choice between spending a year in Paris or Liverpool, surely no young man could choose other than Paris? Interestingly, Rotblat chose Liverpool for a reason that reflects on his attitude to science and its importance. By this time, it was becoming clear that real further progress in his area of interest required more intense particle beams than could be produced from the disintegration of radium. The way forward was seen to be the cyclotron, a machine that accelerated charged particles to high energy. These high-energy particles could then be used to either bombard other nuclei directly or produce other particles through an intermediate interaction. Although the Warsaw laboratory had been able to compete effectively with Fermi's group in the discovery of radionuclides, a better source of particles was needed if it was to develop further. Rotblat saw the Liverpool cyclotron as being in the "right" stage of building. If he could be there for the critical completion and commissioning periods, he would be able to bring back this expertise to Warsaw to help establish a world-class nuclear physics facility in Poland.

So Liverpool it was.

This was 1939. It was just before war was declared, and at a time when the Liverpool laboratory's research and staff were about to be disrupted by diversion to measurements related to the development of the atomic bomb. Before this happened, however, Rotblat was able to complete an imaginative piece of work that particularly impressed his new boss Chadwick. Rotblat's previous measurements in Poland involved activating the sample and then transferring the newly radioactive sample to a detector – usually a Geiger counter – in order to complete the measurements. If the lifetime of the artificial nucleus was reasonably long, this was in principle no problem, but if it was short compared to the time taken to perform the measurement, then by the time the sample had been transferred to the counter, the activity would have fallen below the threshold at which it could be measured effectively. Thus this technique was inherently limited to examining radioactive nuclei with lifetimes of at least seconds.

Rotblat's first Liverpool experiment involved the adaptation of an electronic circuit that converted the signal emitted from the radionuclide into an electrical signal. The circuit itself could be tuned to give a pulse of a given length (in time) for every particle detected. By varying this time period, it was possible to set up the detector system to discriminate between particles arriving at slightly different times. This opened the way to studying radionuclides with very short lifetimes indeed. The one on which this system was developed by Rotblat – an isotope of polonium (^{214}Po) – had a half-life of less than a thousandth of a second (1.4×10^{-4} s), though this "coincidence method" was expected to be effective for lifetimes between a tenth and a ten millionth of a second. Thus the way was opened up to detecting artificial isotopes with very short lifetimes. This development in instrumentation was also particularly useful in determining absolute intensities of sources – particularly weak ones – and in measuring the efficiency of the more traditional Geiger counters. On the basis of this work, Chadwick offered Rotblat the Oliver Lodge Fellowship. This was the most prestigious fellowship the department had to offer, and it promised to double his income.

In 1939, the month before the coincidence technique was published, the cyclotron produced its first beam. The window was now open to lots of new nuclear physics, such as Rotblat's study of radioactive bromine. Stimulated by other published work which was not in agreement with his own results, a preliminary report of this work was finally published in 1941. The first paragraph of that paper told a story in itself:

> It was intended to carry out the investigations in some detail, but the work had to be abandoned in the spring of 1940 for more urgent duties, and it seems unlikely I shall be able to resume it for some time.

The "more urgent duties" were of course related to the development of the atomic bomb. The bromine work was never resumed.

The Bomb

The 1939 experiments of Rotblat, Joliot, Fermi and Szilard demonstrated that fission of uranium produced more neutrons than it took to initiate the process. A chain, or divergent reaction was therefore possible in principle. However, uncertainties remained. There was no agreement about whether the process could be engineered to work. Late in November 1939, in a meeting with Chadwick, Rotblat suggested that, for an effective bomb, the chain reaction would have to be propagated by fast rather than slow neutrons. The latter would be unlikely to produce the catastrophic outcome required. Rotblat thought he had no significant response from Chadwick and left the meeting discouraged.

Whether Rotblat seeded this idea into Chadwick's mind or whether it was there already is unclear. Whatever the genesis of the insight, a few days later Chadwick found Rotblat to discuss the experiments that needed to be done to answer the outstanding scientific feasibility questions. Accurate measurements were needed of many of the quantities that Otto Frisch and Rudolf Peierls had only been able to estimate in their highly influential 1940 memorandum on the feasibility of a uranium bomb. The critical experiments were ones that could be done using the cyclotron and Rotblat was eminently capable of undertaking them. Little was known about the energies of the neutrons that would be produced by fission. Little was known about the fraction of neutrons that would be captured without producing fission. The fission cross-section for fast neutrons was unknown, though contemporary calculations of the critical mass of uranium required for a runaway chain reaction suggested that one was unlikely to be sustained in this way. Rotblat was also concerned that the inelastic scattering of the neutrons might slow them down so much that the chain reaction could not be sustained: it was important to find out "how fast the neutrons will slow down". So Chadwick gave Rotblat and two assistants the job of answering these questions. In a letter dated December 5, 1939 to Sir Edward Appleton, the Secretary of the Department of Scientific and Industrial Research, Chadwick set out the technical issues concerning the feasibility of an atomic bomb as he saw them:[2] "I think it would be desirable to get some information on the mechanism, and if I can get enough uranium dioxide I will do so. I have here a Polish research man who is very quick."

And very quick he was. The work was completed by Rotblat, Flanders and Wilson by mid-1941. The Maud report, written in July mainly by Chadwick, summarized all the work done under his direction relating to the use of uranium both as a bomb and a source of power. This work was critical in stimulating a serious bomb program. Moreover, the slow neutron measurements made contributed to Fermi's realization of controlled nuclear fission in December 1942, with its clear relevance to fission as a source of power. With accuracy essential if an effective weapon was to be produced, related work continued on the cyclotron. Rotblat considered the measurement of the energy spectrum of fission neutrons from uranium as among his major achievements.

During this intense period of work on the cyclotron, Rotblat had a scientific insight which he never published. In June 1940 a paper written by McMillan and Abelson appeared, reporting their discovery of a new radioactive element heavier even than uranium. This new element itself decayed into another heavy element with a very long half-life of the order of a million years. Rotblat reasoned that this element – which came to be called plutonium – would probably be fissile under neutron bombardment and therefore

2) Letter from J. Chadwick to E. Appleton 5/12/39. Cabinet Office Files 21/1262, Public Record Office, Kew, London. Quoted in Andrew Brown: *The Neutron and the Bomb*, Oxford University Press, 1997, p. 183.

might be an alternative to uranium as a nuclear fuel. Although Rotblat wanted to make this new element with the cyclotron and measure its fission properties, the uranium work had to take priority. So Rotblat's plutonium ideas were dropped, to be taken up later by others.

The Post-War Period

Rotblat joined the Manhattan Project and moved to Los Alamos in early 1944. As is well known, when it became clear to him that the Germans were not in the race for building a nuclear weapon, his rationale for being involved was no longer valid and he famously left the project. Chadwick saw some scientific advantages in Rotblat returning to Liverpool as his close knowledge of "all branches of nuclear physics" would prove useful in the post-war period. Rotblat therefore returned with instructions to restart the cyclotron.

In addition to his work at Liverpool, on his return to the UK Rotblat played a key role in the wider development of nuclear physics in the UK. The new British prime minister, Clement Attlee, recognized that the emergence of the atomic bomb had "rendered much of our post-war planning out of date". In addition to the bomb itself and its possible implications with respect to Britain's position in the post-war world, there was the tantalizing possibility of nuclear energy from controlled nuclear fission. The Advisory Committee on Atomic Energy was therefore set up, with Chadwick as a member.

A healthy and advanced nuclear physics research infrastructure was considered important to the UK's future, and an early meeting of the Advisory Committee proposed that a Nuclear Physics Subcommittee be set up to "make recommendations regarding the programme of nuclear physics to be pursued in this country as a whole". It was in two areas of the work of this committee that Rotblat took leading roles: in the development of more powerful particle accelerators and of improved photographic emulsions for detecting elementary particles.

Since the earliest cyclotrons had begun to operate, one of their key inherent limitations had been realized. As a particle is speeded up to a significant fraction of the speed of light, the effect of relativity is that the particle mass increases. This in turn means that it takes the particle longer to travel round the cyclotron, resulting in its getting out of step, or phase, with the accelerating potential. The practical consequence for the cyclotron was that particle energies were limited to about 25 MeV (million electron volts). By 1945, a way round this problem had been proposed: the frequency of the accelerating voltage could be varied so as to compensate for this increase in mass. Chadwick and Rotblat both wanted such a machine – a synchrocyclotron – to be built in Liverpool.

Rotblat took on much of the responsibility for the planning of this new machine. By late 1946, the Nuclear Physics Subcommittee approved the ambitious proposal that had been put to it, and gave the go-ahead for a synchrocyclotron in Liverpool. Interestingly, they suggested that the possibility of an even more powerful machine should be investigated. There was a good scientific reason for this, though it may not have been appreciated at the time. In 1947 Cecil Powell, using photographic emulsions to detect particles (of which more later), had discovered a new elementary particle through studies of the cosmic rays from outer space that hit the earth. This π-meson was quickly accepted to be the particle that the Japanese physicist Yukawa had predicted in 1935, and hypothesized would be responsible for the strong interaction between protons and neutrons. Now that this particle had been discovered, there was a clear need to study it further, and for this a more reproducible and intense source of π-mesons was needed. Although the originally planned synchrocyclotron was designed to produce protons with energies of about 250 MeV, this was not comfortably above the threshold for π-meson production. There was a need to build a machine that could produce particles at even higher energies.

Rotblat set about pushing the limits of the machine design in the characteristic fashion that underlined his practical skills and engineering expertise. The maximum energy of the accelerated particles is determined mainly by the size of the largest steel casting that could be produced for the magnet. The original 250 MeV design called for pole pieces of 120 inches in diameter. Direct discussions between Rotblat and the steel manufacturers resulted in increasing the diameter to 156 inches, with the resulting machine capable of producing 400 MeV protons. It was this design which was finally decided on. The "dynamic team" of Rotblat and Mike Moore – the young engineer who had solved many of the problems of the first cyclotron and had been a leading member of the team that ran the old machine – set about solving the outstanding problems. In addition to the scientific and engineering ones, these included somehow procuring the materials (for example 1500 tons of steel) and power that were in very short supply in the immediate post-war period.

One of the major, very practical, problems concerned the radiation shielding of the machine. Whatever the material chosen, large amounts of it would be necessary and it would almost certainly also be in short supply. Rotblat's creative imagination worked again. Close to the university was a derelict piece of land that was earmarked for the new Metropolitan Catholic Cathedral. Although work had started on the crypt, the building had been stopped by the Vatican as the plans indicated that the new building would be larger than St. Peter's in Rome. Walking the site, Rotblat realized that the sunken crypt and the ground topography would be a significant help in solving the radiation protection problem. The university Estates Department was instructed to open negotiations with the Catholic Church to try to secure a lease on the consecrated ground concerned.

Experimental physics might be simply thought of as doing something to something and measuring the results with something else. In the kind of nuclear physics experiments we are concerned with here, high-energy particles are produced by a *source* (for example a cyclotron). These collide with a nucleus of a particular element or material (the *sample*) and the results of this collision process are measured by a *detector* system. Clearly each of these three elements of the experiment must be up to the job – it is no good having a superb source and a poor detector or vice versa. Ideally, source, sample and detector must be matched to get the best out of the experiment.

As often happens in experimental physics, advances in one element of the experiment stimulate advances in another. And the best experimentalists are often those who can deliver these advances in an imaginative way. We have already noted Rotblat's work on the production of artificial radioactivity by high-energy neutrons that required improving the effective sensitivity of the detector in order to obtain adequate results. Similarly, his work developing the coincidence counter on his arrival in Liverpool might be thought of as a response to the need to measure much shorter time intervals that was possible using the existing detector systems. In the early post-war period, Rotblat played a further key role in developing particle detector systems that were to make possible more sophisticated particle scattering experiments that the developing field and the more powerful accelerator sources made necessary.

He was put in charge of a small panel, set up as a subcommittee of the Advisory Committee on Atomic Energy, to interact with the photographic companies to develop more efficient photographic emulsions for detecting particles. The originator of the use of photographic plates to detect elementary particles was Cecil Powell in Bristol, who had published a paper in 1939 that showed that photographic plates could be used to measure the energies of neutrons. Chadwick invited Powell to Liverpool, and a collaboration was set up which was to develop and exploit the use of photographic emulsions to detect and track not only neutrons but other nuclear particles as well. Realizing the potential of this detection technique from the work early in the war, on his return to Liverpool Rotblat decided to capitalize on the use of photographic emulsions and set up an organization to do this effectively. As a look at the published papers soon reveals, the work was tiring, intensive and extensive, entailing the microscopic measurement and appropriate correction of sometimes thousands of particle tracks for a single study. Clearly too much for a single observer: "some half a dozen ladies" were trained to make the measurements.

Earlier work using photographic emulsion particle detection, including use in the critical experiments on uranium in 1940–41, had indicated the improvements that were needed on the emulsions. Under Rotblat's chairing, the work of the emulsions panel resulted in these major improvements being realized. Working to a program outlined by the panel, Ilford and Kodak produced a number of different kinds of "nuclear research emulsions" to meet the different requirements of the experimental nuclear physics community. Offering a range of sensitivities and grain sizes to meet various demands, the photographic detection method became a standard experimental technique.

Rotblat's hand can be seen also in the refinement of the use of the technique and in enhancing its reproducibility and reliability. Results could vary depending on whether there was significant water in the emulsion, there could be shrinkage on plate development, and in order to use the technique for reliable energy measurement, accurate calibration was needed of the relationship between track length and particle energy. Several of Rotblat's post-war papers address apparently humdrum instrumental issues like these, but this kind of work was essential if the technique was to produce reliable results. His expertise in the technique is attested to by his writing a major review on the photoemulsion technique in 1950.

Rotblat's contribution to the development of emulsion detection was not however limited to the optimization of the emulsions themselves. The photographic plates had to be placed so as to intercept the beam of particles that is to be detected – in essence some sort of "camera" is needed in which to mount the film. The instrument or "camera" that was developed at Liverpool, and later improved for work on the Birmingham cyclotron, provided the workhorse for a range of important experiments in the 1950s.

Although Rotblat's published scientific output in terms of "hard core" nuclear physics was very limited during this period in Liverpool between 1945 and 1950, he was clearly active on the experimental front, as well as being effectively in charge of the laboratory's research direction in the periodic absences of Chadwick. From Chadwick's move to Cambridge in 1948 until the new department head took over in 1950, Rotblat was fully in charge of the research direction of the Liverpool laboratory. In September 1947, a conference on nuclear physics was held at Harwell, which "celebrated ... the restarting of nuclear physics research in Britain after the war". Reports on research both in the UK and abroad were given, with Rotblat reporting on an extensive range of work at Liverpool, largely based on the (recently improved) cyclotron. These included elastic and inelastic collisions of protons, deuterons, and neutrons with a range of nuclei. This and other fundamental and new research was to see the light of day in a series of papers published between 1950 and 1952. The power of the photographic emulsion detection technique is clearly evident from these papers, which illustrate what was now possible in this developing field in terms of measuring the energies of a range of different particles, cross-sections of nuclear processes, and, given certain model assumptions, obtaining information on spins and parities of different nuclear states. The whole field was growing, and Rotblat was at the heart of it.

Bart's

From the earliest days in Liverpool, the possible medical applications of nuclear physics had been recognized by both Rotblat and Chadwick. Some of Rotblat's experiments at Liverpool had begun to explore specific medical possibilities. For example, he made what has been thought to be the first major step in nuclear medicine in the UK with the use in 1948 of radioiodine in the location of a thoracic goitre. The distribution of lead in an organism was studied using the photographic emulsion technique he was instrumental in optimizing. One of the earliest papers he authored from St. Bartholomew's Medical School was very much a nuclear physics paper with strong medical implications – the use of nuclear emulsions to locate a radioactive atom by tracing the origin of the tracks emanating from it.

Although his work at Bart's focused on medical applications, he continued to be involved in fundamental nuclear physics for over a decade. The Liverpool work he had undertaken since returning from Los Alamos was published in the first three years of his time in London. He also worked collaboratively with others on the cyclotron in Birmingham. A series of fundamental nuclear physics papers on this latter work continued to be published between 1953 and 1964. The state of the field had by this time changed significantly, not only from his earliest days in Warsaw when the field was only just beginning to be charted, but also from the early days of the Liverpool cyclotron. The continued development of particle sources, detectors, and the arrival of computers enabled more complex problems to be addressed and sophisticated theoretical models of nuclear processes tested by precise experiments. The fundamental work he was involved in during this period covered a wide range of problems relating to nuclear interactions. Nuclear probes with low charges (for example protons, deuterons, ^{3}He and ^{4}He) could come close enough to light nuclear targets to sample the potential due to nuclear forces. The experiments also used extensively the emulsion technique he had been instrumental in optimizing, as well as further improvements to the plate camera, which may have been one of the best of its kind in the early 1950s.

Although this fundamental work was not central to his primary nuclear medicine interests of the time, he himself did consider this "systematic study of energy levels and other properties of nuclei, by the bombardment of various targets with high energy beams of protons, deuterons, ^{3}He and ^{4}He particles … and using the photographic emulsion technique" as another of his main achievements.

An End Note

I met Rotblat first in 1997, and worked with him in Pugwash from late 1998 until his death. Then I knew little of the details of his scientific work, apart from a consciousness of that which was related to the bomb, but the sharpness and creativity of his mind was obvious and impressive from the first time we talked. Chadwick tried to prevent him from going to Bart's to focus on medical applications, telling him that he would be a great loss to nuclear physics and would never become a Fellow of the Royal Society. Looking at the work he did even after leaving Liverpool, his contributions to nuclear physics continued to be significant. He was not lost to nuclear physics; rather he added the medical applications to his portfolio of work. And of course he was elected to the Royal Society, thus proving Chadwick wrong on both counts.

On welcoming him to the Warsaw Radiological Laboratory in 1932, his mentor Wertenstein, commenting on the examination Rotblat had just taken and thought he had failed, told him that the examiner "was impressed by the originality of your reasoning". This originality was demonstrated throughout his life, from the early highly imaginative work under poor conditions in Warsaw ("We had to compensate for the lack of facilities with ingenuity" – remember his borrowing nearly a kilogram of gold from the Bank of Poland!), through his scientific work in Liverpool, to his contributions to nuclear physics in the 1950s and early 1960s. His responsibilities in the Liverpool laboratory on returning from Los

Alamos were wider than pure science, and here again "the originality of your reasoning" resulted in advances in techniques that others have exploited and built upon. It also led him to imaginative solutions to constrained problems, perhaps illustrated rather nicely by his idea of locating the Liverpool synchrocyclotron in the crypt space of the then unbuilt Catholic cathedral. And this suggestion came from a citizen of a Catholic country!

The originality of his reasoning was fully exploited also in his work within the Pugwash movement. "You should do well with us," commented Wertenstein in that first interview. He certainly did do well with them. But he also did well with us all – whether we are nuclear physicists or citizens of the world.

Acknowledgments

I thank Andrew Brown for his biography of James Chadwick (*The Neutron and the Bomb*, Oxford University Press, 1997) and for a copy of the transcript of his interview with Joseph Rotblat in 1994; John Holt for a copy of his reflections on Joseph Rotblat in Liverpool; Adrian Allan, Liverpool University Archivist for supplying copies of a number of documents relating to Joseph Rotblat's years in Liverpool; Bill Toner for enlightening me on certain aspects of nuclear physics, discussions on the scattering camera, emulsion development and the Birmingham experiments; and University College London Library for help in providing copies of Joseph Rotblat's scientific papers.