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A Modified Approach to an Analytical Solution of a Diffusion Model for a Biotechnological Process

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Abstract: Biotechnological processes are objects with distributed parameters characterized by a complicated structure of organization and interdependent characteristics. Partial differential equations are used for their behavioural description with modelling in relation to diffusion phenomena considered in this paper. Furthermore, an application of the theory of partial differential equations to obtain a direct analytical solution of the model is considered. This is in contrast with less direct approaches in the literature. The behaviour of the model developed here accords well with real phenomena.

Keywords: Continuous Biotechnological Processes, Distributed Parameters Objects, Partial Differential Equations.

INTRODUCTION

Biotechnological processes (BTP) are characterized by complicated reactions and interdependent characteristics which lead to complicated mathematical descriptions. In order to develop a more complete and precise model, space distribution of the process variables can be considered and included in the model. This determines the behavioural description of BTP as objects with distributed parameters (ODP), using partial differential equations (PDE) or systems of PDEs. The processes in general have wide application in biology and medicine, for instance, in determining erythrocyte sedimentation rates (Reuben and Shannon 1990).

The modelling of BTP as ODP has not been widely studied. In most studies the authors have chosen some method, for example finite differences or orthogonal collocation, to represent the PDE with a finite number of ordinary differential equations. Bourrel et al. (1998) have merely considered the processes in steady-state. Babary et al. (1993) and Julien et al. (1995) have applied the orthogonal collocation method. Dochain et al. (1997) and Jacob, Pingaud et al. (1996) have exploited the methods of both finite differences and orthogonal collocation. Jacob, Lann et al. (1996) have also applied the method of lines and the orthogonal collocation method. The PDE have been approximated by a system of ordinary differential equations in all these studies. To overcome the approximation errors in such approaches one possible way is to use the PDE directly. Hence an elaboration of some new methods and approaches for the description and control of biotechnological process is appropriate.

The twofold aim of this paper is both to model substrate space distribution for a specific class of biotechnological processes, and to obtain an analytical solution of the PDE in the model.

STATEMENT OF THE PROBLEM

A class of fixed bed biotechnological processes is considered wherein the active biomass is kept within the vessel, while the substrate and product flow through it (Babary et al. 1990, 1993). This type of bioreactor is called a biofilter (Figure 1). The problem is to describe the process as an object with distributed parameters and thus to obtain a model of a specific class of BTP.

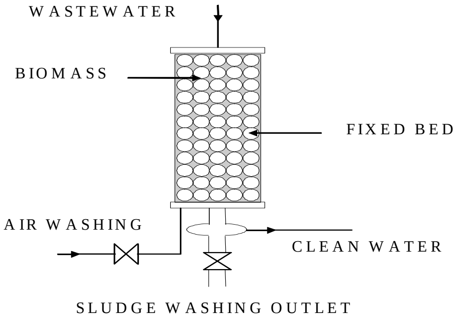

Figure 1: A fixed bed bioreactor

The non-uniformly distributed media elements on the apparatus cross-section, as well as the presence of turbulent diffusion, are expressed as follows (Schmalzriedt et al. 1995):

$$\frac{\partial c}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}\left(ru_r c\right) + \frac{\partial}{\partial z}\left(u_z c\right) = \frac{1}{r}\frac{\partial}{\partial r}\left(D_{eff} r \frac{\partial c}{\partial r}\right) + \frac{\partial}{\partial z}\left(D_{eff}\frac{\partial c}{\partial z}\right) + \\ + reaction + mass\ transfer\ gas/liquid \tag{1}$$

where c is a differentiable function to describe concentration; r, z are radial and axial co-ordinates, respectively; D_{eff} is the turbulent diffusion coefficient, and u_r, u_z are radial and axial components of the rate vector.

In fact Equation 1 represents the equation for the material balance of the concentration. The material balance of the substrate S can be considered in the following two cases:

- when the diffusion of substrate S is regarded as negligible, and
- when the diffusion of S is accounted for in the axial direction.

The first case when diffusion of the substrate S is regarded as negligible has been presented previously (Pencheva et al. 2003; Pencheva 2003). In this paper, the latter, more complicated, case is discussed.

MODELLING OF THE SUBSTRATE

When the space distribution of the substrate S is considered at this stage, the diffusion in one direction, (for example, axial), is given, while the variables do not change in the other direction (Babary et al. 1990, 1993). According to Babary et al. (1990, 1993), the turbulent diffusion coefficient D_{eff} is considered to be a constant and the mass transfer from a gas to a liquid phase is not examined. As was demonstrated in Pencheva et al. (2003) based on (Babary et al. 1990, 1993), the axial component of the rate vector u_z can be expressed as:

$$u_z = \frac{F}{B} \tag{2}$$

where F is the flow rate, constant in the considered direction, via the bioreactor cross-section B. The reaction in the system when the substrate S is modelled is presented as follows (Farlow 1982):

$$\text{reaction} = -k\mu(S)X \tag{3}$$

where X is a differentiable function to describe the biomass concentration [g/l], $\mu(S)$ is a specific growth rate of the biomass, and k is a yield coefficient. This relation describes the biochemical mechanism in the system, expressed as the substrate decrement due to biomass accumulation in the culture medium.

When the biomass X is modelled, the reaction of the system can be presented as follows:

$$\text{reaction} = (\mu(S) - k_d)\, X \tag{4}$$

where k_d is a death coefficient of the biomass, $[h^{-1}]$. The kinetics for the specific growth rate of the biomass are assumed to be:

$$\mu(S) = \mu_{max}\frac{S}{k_S + S} \tag{5}$$

where μ_{max} is the maximum value of $\mu(S)$ $[h^{-1}]$, and k_S is a saturation constant [g/l].

Thus, on the basis of Equations 1–3 and Equation 5, the following parabolic model is obtained for the substrate space distribution, when the diffusion phenomena are considered:

$$\frac{\partial S}{\partial t} = D_{eff}\frac{\partial^2 S}{\partial z^2} - \frac{F}{B}\frac{\partial S}{\partial z} - k\mu_{max}\frac{S}{k_s + S}X \tag{6}$$

The other basic biochemical variable when modelling BTP is the concentration of biomass. Due to the fixed bed reactor, the cell biomass is uniformly distributed in the cultural medium. Therefore, the variation of biomass will be examined in relation to time only:

$$\frac{dX}{dt} = \left[\mu_{max}\frac{S}{k_s + S} - k_d\right]X \qquad 0 \le z \le H \tag{7}$$

Hence, Equations 6 and 7 constitute the mathematical model which describes the BTP in a biofilter as an ODP when the diffusion phenomena are taken into account. When BTP are described as an ODP, the initial conditions should be specified and in this case they can be given as follows:

$$S(z,0) = S_0 e^{-z^2/b} \quad \text{and} \quad X(0) = X_0 \tag{8}$$

where S_0 and X_0 are the initial concentrations and b is a constant.

The families of curves, which represent the numerical solution of the model in Equations 6–7 by the method of lines are given in Figures 2 and 3 for the substrate and biomass, respectively. The results indicate that the model described by Equations 6 and 7 predicts behaviour similar to a real biotechnological process.

SOLUTION OF THE MODEL

There are two fundamental approaches when BTP are examined as an ODP: in the first one, the PDE, which describe the mathematical model of the processes, are approximated by ordinary differential equations. Most authors have chosen some method, for example, finite differences or orthogonal collocation, to represent the PDE with a finite number of ordinary differential equations (Babary et al. 1990, 1993; Dochain et al. 1997; Jacob, Pingaud et al. 1996; Jacob, Lann et al. 1996; Julien et al. 1995). In this way BTP are presented in a standard form and conventional control theory can be applied. However, the application of this approach leads to the introduction of approximation errors. Other authors (Balakrishnan 1976; Pencheva 2003) have applied the theory of semi-group linear restricted operators, but in this paper the theory of PDE is used directly.

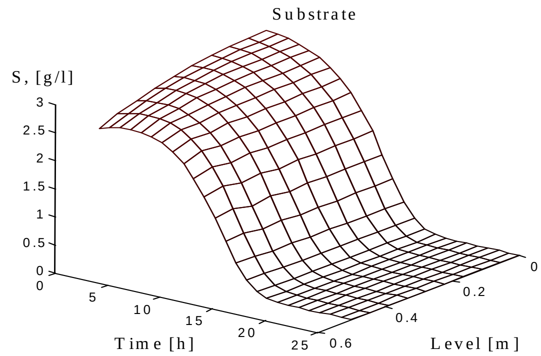

Figure 2: Numerical solution of space distribution of substrate concentration

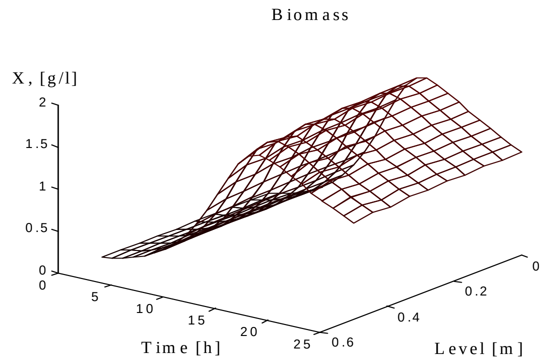

Figure 3: Numerical solution of space distribution of biomass concentration

Equation 6, which describes the concentration of the substrate S, is in fact a non-homogeneous non-linear equation of convective diffusion. So to obtain an analytical solution of this equation a new modified approach, based on existing methods, has to be developed. This approach is based on a transformation of the equation for convective diffusion into the simpler equation for heat conductivity. This modified approach consists of the following steps (Pencheva 2003):

Step 1. According to the theory of PDE, in order to obtain a solution of a given non-homogeneous equation, one first needs the corresponding homogeneous equation to be considered under non-homogeneous initial conditions.

Step 2. For a solution of the corresponding homogeneous equation a modified approach is then used, consisting of the following steps:

Step 2.1. transformation of the initial equation of convective diffusion to the much simpler equation for heat conductivity, using the following relation:

$$S\left(z,t\right)=e^{\frac{u\left(z-\frac{ut}{2}\right)}{2D_{eff}}}f\left(z,t\right) \tag{9}$$

where $f(z,t)$ is a solution of the heat conductivity equation.

Step 2.2. solution of the equation for heat conductivity.

Step 2.3. solution of the initial equation for convective diffusion based on *Step 2.2.*

Step 3. The final step involves obtaining a solution of the initial equation for convective diffusion as a non-homogeneous equation examined under homogeneous initial conditions. Additional difficulties spring from the fact that the non-homogeneity in the equation introduces a non-linearity as well. The general solution of the non-homogeneous equation is the sum of the results from *Step 2* and *Step 3.*

The homogeneous equation, which corresponds to (6), can be given in a general-type formula:

$$S_t = D_{eff} S_{zz} - u S_z \quad \text{where} \quad S_t = \frac{\partial S}{\partial t}, \quad S_z = \frac{\partial S}{\partial z} \quad \text{and} \quad S_{zz} = \frac{\partial^2 S}{\partial z^2} \tag{10}$$

Therefore, by the application of the transformation (9), the solution of (6) is contracted to the solution of the heat conductivity equation. On the basis of the theory of PDE, the following solution of heat conductivity equation is then obtained:

$$f(z,t) = \frac{1}{2\sqrt{\pi D_{eff} t}} \int_{-\infty}^{+\infty} \varphi(\xi)\, e^{-\frac{(z-\xi)^2}{4D_{eff}t}}\, d\xi \tag{11}$$

where $\varphi(\xi)$ is the initial condition for the heat conductivity equation, which overlaps with the initial condition of the corresponding homogeneous equation (10) which, in turn, corresponds to (6). When the initial condition is as described in (8) and the solution obtained for the heat conductivity equation is replaced in (9), the solution of (10) is:

$$S(z,t) = e^{\frac{-\frac{F}{B}[z-\frac{Ft}{2B}]}{2D_{eff}}} \cdot \frac{S_0}{2\sqrt{\pi D_{eff} t}} \int_0^H e^{-\xi^2 - \frac{(z-\xi)^2}{4D_{eff}t}}\, d\xi \tag{12}$$

The relation (12) represents a solution of the homogeneous equation (10), corresponding to the non-homogeneous equation (6), considered under non-homogeneous initial conditions. In terms of the theory of PDE to obtain a solution of the non-homogeneous equation (6), it is necessary to examine the non-homogeneous equation (6) under homogeneous initial conditions. Consequently the general solution is presented as a sum of the two cases and is given as follows:

$$\begin{aligned} S(z,t) = {} & \frac{S_0}{2\sqrt{\pi D_{eff} t}} e^{\frac{-\frac{F}{B}[z-\frac{Ft}{2B}]}{2D_{eff}}} \int_0^H e^{-\xi^2 - \frac{(z-\xi)^2}{4D_{eff}t}}\, d\xi \quad + \\ & \int_0^t \int_{-\infty}^{+\infty} \frac{1}{2\pi\sqrt{D_{eff}(t-\tau)}} [-k\mu_{max} \frac{S}{k_s+S} X(\tau)]\, e^{-\frac{(\xi-z)^2}{4D_{eff}(t-\tau)}}\, d\xi\, d\tau \end{aligned} \tag{13}$$

If the following assumption, which is meaningful from a biotechnological point of view, is also accepted:

$$\frac{S}{k_S + S} \le \frac{S_0}{k_S + S_0} = \mu_L \tag{14}$$

then the solution of (13) comes down to the following final form:

$$S(z,t) = \frac{S_0}{2\sqrt{\pi D_{eff} t}} e^{\frac{-\frac{F}{B}[z-\frac{Ft}{2B}]}{2D_{eff}}} \int_0^H e^{-\xi^2 - \frac{(z-\xi)^2}{4D_{eff}t}}\, d\xi - \frac{\mu_L k \mu_{max}}{\sqrt{\pi}} \int_0^t X(\tau)\, d\tau \tag{15}$$

The solution of (15), when the values of the biomass numerical solution are given, is shown in Figure 4. Although the values of the constants used for the numerical solution represented in

Figure 2, and those used for the analytical solution (Figure 4), are the same, it can be seen that both figures do not correspond closely. The differences are due to the assumption (14), which allows an analytical solution to be developed, but partly eliminates the non-linearity of the model.

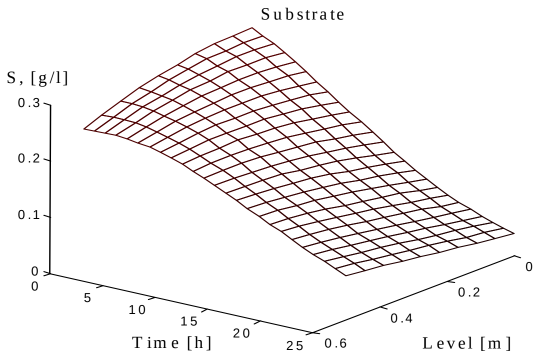

Figure 4: Analytical solution of space distribution of substrate concentration

This type of family of curves, which represents the analytical solution in Equation 15, illustrates that the model obtained behaves similarly to a real biotechnological process. Moreover, it represents the effective application of the modified mathematical approach using the theory of partial differential equations to obtain an analytical solution of the model.

The basic aim of this paper is to present a modified mathematical approach using the theory of partial differential equations for obtaining an analytical solution of the model with the rendering of the substrate diffusion. It is interesting to note that after the comparison and the statistical evaluation (Pencheva 2003), it is found that the differences between the results obtained with and without the rendering of the diffusion phenomena are less than 7% for the substrate and less than 15% for the biomass. At the same time, rendering of the diffusion phenomena leads to a more difficult mathematical description. Therefore, where it is not essential, diffusion phenomena in the system can be regarded as negligible without loss of generality.

CONCLUDING COMMENTS

The following conclusions can be summarised from the foregoing:

§ The equation of material balance of the variable S, which describes the variation of the substrate in the biotechnological processes in a biofilter, with regard to diffusion phenomena, has been derived. The distribution of biomass concentration in the culture medium is uniform because of the fixed bed bioreactor.

§ The numerical solution of the mathematical model of substrate space distribution, presented by the method of lines, demonstrates that the model displays behaviour similar to a real biotechnological process.

§ By applying the developed modified approach within the theory of PDE, the analytical solution of the mathematical model of the substrate space distribution has been found.

§ The analytical solution achieved also shows the efficiency of the direct application of the theory of PDE without resorting to other, less direct, mathematical methods.

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Atomic Australia and Nuclear New Zealand

ANNA BINNIE

INTRODUCTION

The following four papers in this issue of the Journal and Proceedings of the Royal Society of New South Wales were presented at a session entitled 'Atomic Australia and Nuclear New Zealand' at the Australasian Association for the History, Philosophy and Social Studies of Science Conference in Dunedin, New Zealand, in December 2005. The papers were originally presented in two sessions. The first focussed on two individuals, Oliphant and Marsden, who were instrumental in the introduction of nuclear science to Australia and New Zealand, respectively. It should be noted that both scientists had been students of the legendary Antipodean, Ernest Rutherford.

The second session focussed on two effects of nuclear science in Australia and New Zealand. The first looked at the British tests at Maralinga, not from a political perspective, but from the perspective of the soldiers who were stationed at there before, during and after the tests. The final paper discussed effects of the 'Atoms for Peace' initiative on New Zealand science and society, and the lead up to the rise of the anti-nuclear movement in New Zealand.

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Oliphant, the Father of Atomic Energy

ANNA BINNIE

Abstract: Sir Marcus Oliphant, perceived by several generations of Australians as the kindly public face of Australian physics, may be regarded as the individual who introduced the concept of an atomic bomb to the World. Oliphant did not discover fission, nor did he work on the fission process, but he was responsible for bringing together the people and the information required for the development of both the atomic bomb and civil atomic energy. Yet he was a man noted later for speaking out publicly against nuclear weapons, so how can these two statements be reconciled?

Keywords: Sir Marcus Oliphant, atomic energy, atomic bomb, Australia

INTRODUCTION

Oliphant had been living in Britain at the outbreak of the war and he had no hesitation about becoming involved with the work of war. It was his radar work during the war, his position as Professor of Physics at Birmingham University, and his Cavendish network of colleagues that gave him access to those in positions of authority that would bring about Britain's commitment to develop the atomic bomb. It was also during the war that Oliphant insured that Australia had knowledge of the developments of the British bomb project. After the war, Oliphant returned to Australia and became an advocate of the civil uses of atomic energy. He especially espoused the development of an atomic power station and a desalination plant in the Port Pirie region of his native South Australia. He later became involved with the Industrial Atomic Energy Committee and it was through his impatience and the actions that resulted from this that lead to the establishment of the Australian Atomic Energy Commission. While he was never a Commissioner and was never employed by the Commission, his influence in the development of Atomic Energy in Australia is such that he can be considered as father of atomic energy.

THE MAUD COMMITTEE

In 1927, Oliphant arrived at the Cavendish Laboratory in Cambridge as an 1851 Exhibition Scholar[1]. Oliphant was to spend the next ten years at the Cavendish working with Ernest Rutherford and associating with the other gifted young men such as James Chadwick and John Cockcroft, both of whom would both play major parts in the development of atomic science. This association would result in what can best be described as a brotherhood of Cavendish men and would include all Cavendish alumni.

In October 1937, Oliphant took up a position as Professor of Physics at Birmingham University. As an experienced researcher, Oliphant wanted to follow research directions started at the Cavendish. He was determined to have his own accelerator so he could continue his research into nuclear physics. The cyclotron, a new type of accelerator developed by Ernest Lawrence at Berkeley in California, could deliver much more energy to the accelerated protons than either the Cockcroft-Walton or Van der Graaff designs of linear accelerators. In fact, Oliphant wanted a bigger version of Lawrence's machine [2]. This interest in the cyclotron would bring Oliphant into contact with Lawrence, with whom he would form a working relationship in the years to come.

At the outbreak of the Second World War, Oliphant and many of his team at Birmingham were working for the Admiralty on radar. This work was a highly secret operation and those scientists resident in Britain who were foreign nationals or those regarded as being enemy aliens were left to do their own research. Two of these scientists who had made their way to Birmingham University were Otto Frisch and Rudolph Peierls. In early March 1940, Oliphant received a short note from Frisch and Peierls, entitled 'On the Construction of a

"Super-bomb" based on a Nuclear Chain Reaction in Uranium'. The notion of using the fission reaction to power a bomb had already been discussed in scientific circles but it was thought that such a device would require several tons of the rare uranium isotope, uranium-235. The Frisch-Peierls note described that a fission explosion could be achieved using only a few kilograms of pure metallic uranium made up of the uranium-235 isotope. The note continued to discuss the possible method of obtaining this isotope in sufficient quantities (thermal diffusion of uranium hexafluoride gas), the construction of the bomb and possible radiation effects of fission products after its explosion [3]. The note is significant in that it was short; it was written in a non-technical style so that a non-physicist could readily understand most of its content but it contained enough technical information to allow physicists to make their own calculations in verification.

The memorandum had arrived on Tizard's desk by the 19^{th} March with a covering note from Oliphant. The covering note suggested that a Committee be established comprising G.P. Thomson, Patrick Blackett, Oliphant and Tizard [4]. Tizard in turn sent a copy to Thomson who wanted to discuss the contents with Oliphant and Cockcroft [5]. On the 10^{th} April, Thomson, Oliphant, Cockcroft and another ex-Cavendish physicist, Philip Moon, met under instructions from Tizard, at the Royal Society headquarters with the purpose of determining if such a 'super-bomb' could be constructed [6].

By June this small committee of essentially ex-Cavendish physicists had grown to include the Nobel Laureate Norman Haworth and another ex-Cavendish man, C. Ellis. The Committee had become known as the MAUD Committee. Both Frisch and Peierls were excluded from the Committee but were included in the Technical Sub-committee [7]. Oliphant would himself be excluded from the MAUD Committee in 1941 when it would undergo a reorganisation. Oliphant was then relegated to the Technical Sub-committee [8]. However, Oliphant, unlike other members of this Sub-committee, would not be working directly on research into the bomb.

The MAUD Committee produced its report on 30 June 1941, recommending that a bomb was feasible and that atomic energy could also be a useful source of electrical power [9]. A minority report produced by Blackett suggested that the full-scale plant to produce the bomb be set up outside Britain, possibly in the US or Canada. This minority report was taken up by the Ministry of Aircraft Production [10]. The MAUD Committee ceased to exist in December 1941 but its work had been taken over by the Tube Alloys Project that had been established in October that year to develop the British atomic bomb.

While those around him were involved in the uranium and fission work, Oliphant continued with his work on radar, specifically on magnetrons. Collaboration had been established between Britain and the US in the development of more sophisticated magnetrons. In August 1941, Oliphant went to the US essentially to continue work on this partnership. However, before he left Britain he was approached by Thomson who asked him to investigate why the US had not responded to the contents of the MAUD Committee Report which had previously been sent to the US [11]. At this time Britain wanted to establish a joint uranium project that included exchanges of information [12]. When Oliphant was finally able to free himself from radar work to follow the mission entrusted to him by Thomson, Oliphant was shocked to discover that the MAUD Committee's report had languished unread in the safe of Lyman Briggs, the head of the National Bureau of Standards in Washington and Chairman of the Uranium Committee [13].

Oliphant now attempted to enthuse Briggs, but failed. He then attempted to interest Vannevar Bush and James Conant (Bush was President of the Carnegie Institution and Chair of the National Defence Research Committee and Conant was a member of the Uranium Committee) in the findings of the MAUD Committee, with a similar result to that experienced with Briggs. Oliphant was not easily deterred. He now went to Berkeley to visit Ernest Lawrence with whom he had been corresponding for a number of years. The result of this visit was the production by Oliphant of a summary of the MAUD Committee report [14] and the inspiration to produce enriched uranium through electromagnetic separation using Lawrence's cyclotron as a mass spectrometer [15]. Lawrence took Oliphant's summary and met with Conant and Arthur Compton. This meeting ultimately led to a restructuring of the US Uranium Committee and ultimately to the establishment of the Manhattan Project [15].

FOREVER AN AUSTRALIAN

While in Washington, in August 1941, Marcus Oliphant was invited to a dinner party hosted by Dr Darwin, the grandson of Charles Darwin, and his wife at which the Australian Minister to the US, Richard Casey, was also a guest. It was in this capacity that Oliphant was introduced to him. Oliphant initially discussed radar work with Casey but later mentioned a new scientific project that was currently being undertaken in Britain [16]. It was obvious from Casey's replies that he knew nothing of the MAUD Committee or the uranium project, so Casey asked for a note on this matter.

The next morning, 26th August, Oliphant sent Casey a four-page letter, effectively summarising the findings of the MAUD Committee which at this time was secret. Oliphant, in his covering note, suggested that Australia should 'do some work on the energy machine, so that if and when she wishes to exploit it she will have something with which to bargain' [17]. The other significant aspect of this note was the stress for the peaceful uses of the 'Uranium Energy Machine', but he did mention the requirements for a bomb and the possible radioactive after effects of such an explosion [17]. Oliphant even suggested that this form of energy could use Australian uranium:

'It is possible to make a machine in which the production of energy is less violent than in the bomb and which could be used for the commercial production of power. Such a machine could be realized at the present time ... by mixing uranium oxide with "heavy water", or deuterium oxide, or possibly also with carbon or beryllium ... Such a machine should be capable of producing 100,000 horsepower for very many years without any fuel whatsoever. It would be of the greatest possible importance to Australia, with her isolated coal-fields. I am confident that the scientific and engineering problems will be overcome and that Australian uranium, will prove as valuable to the country as oil-wells have to America' [17].

Casey made at least two copies of this note. The original was sent to Prime Minister Robert Menzies, (1894–1978), and what is remarkable is that very little was done with the information it contained. Political turmoil hit Australia within weeks of the despatch of the note, when the general election brought not only a change in Prime Minister but also a change in the governing party and consequently the memo was virtually forgotten. The new Prime Minister was John Curtin. Curtin took office a few months before the Japanese entered the war and hence had other more pressing matters to consider.

Casey sent the two copies of Oliphant's note, on 17th September, to David Rivett, as 'Secret by Safe Hand'. Rivett was then the Executive Officer of the CSIR [17] and the covering letter gives the impression that Rivett and Casey were on familiar terms, Casey stated:

'... I gather he (Oliphant) came from Adelaide in the first place and has been working in England for the last fifteen years. He seems to be regarded as a man of some note. Darwin speaks of him with great respect. He has been working on radio-physics for the British Admiralty lately and is in this country in this connection. ... Oliphant began to speak more generally of new applications of scientific knowledge to war purposes and in due course asked me if I was aware of the work that is being done in England in connection with Uranium. ... I said that I was unaware of this – and pressed him for further information – whereupon he told me about it. I asked him if he would let me have a short memorandum on the subject, which he did the next day. ... I have since discussed it with Munro – and he tells me that you will undoubtedly have been relevantly informed by Sir John Madsen' [18].

Rivett responded to Casey on 8th November, stating ' ... I am rather hoping that Madsen will come back with something in his head and in his bag about all this, and, in the meantime, I am treating the file as very strictly confidential' [18]. Sir John Madsen (1879–1969) was Professor of Electrical Engineering at the University of Sydney and was involved with the Australian Radar project and the CSIR (Council for Scientific and Industrial Research). Australia was also at war with Germany at this time. Rivett and the rest of CSIR were too much involved with the Australian radar project to be concerned with some new research project that at the time was still of a theoretical nature and under a military classification. According to Tim Sherratt, Rivett did not just ignore the note, he 'began to seek more information through his scientific contacts, and tried to arrange for increased Australian involvement in the work. He was, however, unsuccessful' [19].

In December 1941 Japan attacked the US Naval Base at Pearl Harbour in Hawaii, bringing the US into the Second World War. Within months the Japanese military moved south to occupy most of South-East Asia. Once Singapore fell to the Japanese in February 1942, Oliphant saw Australia as being under threat, and immediately offered his talents to the service of his country, especially in the area of radar research. On the 14^{th} Feb 1942, Stanley Bruce (1883–1967), the Australian High Commissioner in London, sent a memo to the Prime Minister, John Curtin, stating that Professor Oliphant was offering his services to Australia and 'In addition to RDF his knowledge covers other branches of Scientific Warfare' [20]. RDF stood for radio direction finding, later called radio location, and is now known as radar. The other branches of Scientific Warfare referred to his knowledge of atomic energy. Rivett was swift to reply and on 18^{th} February sent a note to the Prime Minister's department stating, 'Am strongly recommending Minister accept offer' of Oliphant coming to Australia. The following day, Rivett sent another note to the Prime Minister's Department stating 'Madsen and White welcome proposal' and on 20th February Rivett sent a further memo to the acting Australian High Commissioner in London, Mr McDougall, asking Oliphant to bring materials for magnetron research with him [20]. Frederick White (1905–1994) was then Chief of the Division of Radiophysics in CSIR.

On the 24^{th} February, McDougall responded to Rivett that the British Admiralty, saying 'Tizard wholly concurs desirable Oliphant go to Australia' [20]. What Oliphant had hoped to achieve is unknown but he was now to be reunited with his family whom he had sent to the safety of Australia two years before. Events moved swiftly with Oliphant finishing up at Birmingham and leaving the United Kingdom 19^{th} March. Australia House wrote to CSIR on 31st March informing them of Oliphant's departure [21]. The journey was not as swift as Oliphant had expected since Oliphant is next heard from in Capetown on 23^{rd} April requesting to return to Britain, 'owing to transport delay and possibility of no return from intended destination'. The request was refused by the Australian High Commission in London. What now followed was what could best be described as a comedy of errors. Rivett had decided that Oliphant was not required because the local group had made considerable head way on the radar project. Rivett then informed the Australian High Commission to allow Oliphant to return to the UK. However, the telegram recalling Oliphant 'missed' him.

During his entire journey, Oliphant had not been in contact with his family who by this time were quite naturally concerned about his welfare. His wife Rosa sent a letter to Rivett that arrived on 11^{th} May stating that she was worried that she hadn't heard from Oliphant for two months. On 13^{th} May Rivett replied suggesting that Oliphant was on his way back to UK since Rivett believed that Oliphant had received his message in Bombay. Letters were now passed between the CSIR and the Navy in an attempt to discover where Oliphant actually was [21]. The search for Oliphant ended on 26^{th} May when Oliphant, who was in the Physics Department at University of Western Australia in Perth, sent a telegram to Rivett 'please instruct authorities here urgent priority air passage for me plane leaves six am Perth time tomorrow'. Oliphant arrived in Melbourne on 29^{th} May. That night Oliphant went to Sydney with Madsen and White, where he started work at the National Standards Laboratory on 30^{th} May [21].

Rivett and the CSIR may not have wanted Oliphant for the radar work and Oliphant certainly did not want to remain in Australia but he was part of the radar team and the CSIR was going to make use of his expertise. This arrangement was to be short lived with Oliphant and his family leaving Australia within months of his arrival. Before Oliphant left Australia, he made a short visit to Wellington in New Zealand to address a meeting of New Zealand scientists who were working on radar.

Oliphant initially wanted to leave Australia with his family on 19^{th} August but was forced to remain until October. On 27^{th} August Oliphant had presented to the CSIR a paper entitled 'Report on Uranium as a Source of Energy' [22]. This was Oliphant's attempt to encourage the CSIR to ensure that control of uranium ore deposits was vested in the Commonwealth government [23]. Oliphant himself claims that he did not suggest that the government should control the uranium deposits, but that 'if there was uranium in the country that it would be wise not to let it go overseas unless they decided that they didn't want to use it themselves' [24]. Regardless of whether Oliphant used the term 'control' or not, he still attempted to alert the scientific community of the need for uranium and indirectly of the potential uses of atomic energy.

The CSIR Minutes of Executive Meeting 23^{rd} October 1942, under item 2 Uranium, Sir David Rivett referred to secret correspondence in connection to uranium [25], which could only be related to the British request for uranium to be used in the Tube Alloys project. At this meeting Marcus Oliphant was also appointed as an advisor to the Radiophysics Division of CSIR [25]. This was the division of CSIR that would ultimately be responsible for research into atomic energy.

Oliphant was finally given permission to leave Australia from Melbourne on 27^{th} October [26]. On 31st October 1942, Rivett sent a cable to the Australian High Commission in London, informing them of Oliphant's return [27]. Rivett may well have thought his problems with Oliphant were over but on 28^{th} November Oliphant cabled Rivett with a request for money and a fast passage from Durban. Oliphant and his family did not get their fast passage and were there until the 14^{th} January. He arrived in the UK on 1st March 1943 [26].

THE MANHATTAN PROJECT

When Oliphant returned to Birmingham in early 1943, his work on radar was virtually complete. The work on Tube Alloys was continuing but Oliphant was not a member of this project. Yet he did manage to glean that progress was very slow. The processes devised for the enrichment of uranium were not producing a large enough yield quickly enough. Now Oliphant suggested an alternate proposal, that of electromagnetic separation using a cyclotron [28]. He sent his proposal to Edward Appleton, who was secretary of the Department of Scientific and Industrial Research under which Tube Alloys operated. Appleton sent his note onto the leaders of the Tube Alloys project with the subsequent request that Oliphant join the project [29].

Britain had earlier been decided to move some of the Tube Alloys work to the safety of Canada. Scientists in the US were working on their own uranium project. Negotiations between Britain, Canada and the US resulted in the Quebec Agreement, which was signed on 19^{th} August 1943 [30], and it should be noted that Oliphant accompanied the British delegation for these discussions, returning to Birmingham in September [31]. Australia was kept informed of the developments concerning the lead up to the Quebec agreement by Oliphant, who had briefed Stanley Bruce in London on 16^{th} August. Oliphant again stressed that Australia should secure its uranium deposits [32]. As Oliphant was well aware of the secrecy of his mission to the US, one wonders what was Oliphant's motivation in attempting to keep the Australian Government informed of these events.

With the agreement signed, all the Tube Alloys personnel were transferred to continue work in Canada or seconded to the US project, now called the Manhattan Project. In November 1943 Oliphant was posted to Berkeley to work with Ernest Lawrence on the electromagnetic separation of uranium isotopes. Oliphant, during his posting to Berkeley, returned to Britain for visits during February and March 1944 and again from November 1944 to early March 1945. He left Berkeley and the Manhattan Project in March 1945 [33].

While Oliphant was working at Berkeley, he attempted to get other Australians working on the project. In part, he must have realised that the knowledge gained by these physicists could be utilised in post war Australia. Oliphant went so far as to nominate whom he wanted to join him and January 1944, Oliphant sent his request to David Rivett stating; 'Would you release Burhop for the duration to take part in urgent semi-theoretical work on tube alloys problems . . . On account of his past experience Burhop could advance materially the use of the new weapon' [34]. Burhop kept his superior informed of his work at Berkeley, writing to Rivett in June; ' . . . My own feeling is that this project is very important for the future of Australia and the present time is a golden opportunity to get knowledge of the techniques that, it seems, will prove vital for the future of the country. In my opinion there are in Australia several people who have had the right type of training that would make them suitable to pick up the various techniques involved and would enable them to make a significant contribution to the work' [35].

As is now well known the collaboration between the three nations did produce an atomic bomb. In fact it produced three; one was made from enriched uranium and two were made from plutonium. The first bomb exploded was a plutonium bomb. As a result the Second World War ended on 15th August 1945. With the end of the war both in Europe and in the Pacific, many of the scientists working in Canada and the US wanted to return to their homes and families.

AUSTRALIA WANTS ATOMIC ENERGY

Shortly after Oliphant returned to Britain in 1945, he became involved in another new project, that of setting up a British atomic energy research establishment. Cockcroft had been the Director of the Canadian Experimental Atomic Energy Plant during the war and had also returned to Britain at the conclusion of the war [36]. By April 1945, Cockcroft and Oliphant toured a number of sites that were being considered as possible locations for this new establishment. The site most favoured and hence recommended was a disused airfield at Harwell near Oxford. By July, the British Atomic Energy Research Establishment had a director, Sir Edward Appleton, and the support of the newly elected Labour Prime Minister, Clement Attlee. Harwell was to be the location of an experimental reactor which had been designed by the Graphite Group that had been formed in 1944 in Montreal [37].

Australia wanted access to atomic energy information, which it had been denied during the war. As soon as the war was over Australia again made overtures to Britain for this information. Ben Chifley, Australia's Prime Minister, sent a cable to Stanley Bruce in London on 6^{th} September 1945 stating:

'Repeated attempts made throughout war have failed to obtain for Australia information on research . . . on utilization of atomic energy. This development is of very considerable importance both in regard to its wartime application and its peacetime possibility as a source of power . . . my Government would appreciate an opportunity of contributing to the research and . . . If the United Kingdom Government is willing to release information to us . . . request you endeavour to ascertain if Professor H.S.W. Massey or Professor O.M.L. Oliphant would be permitted to come to Australia to communicate this information' [38].

Chifley had thought that by supplying Britain with uranium ore during the war, Britain would in return provide Australia with information on atomic energy, but this information was not forthcoming. Chifley received a reply, on the 26^{th} September, from Evatt, who was in London and had been in contact with Oliphant. Again Oliphant informed the Australian government that the British government was in the process of establishing atomic research facilities that would research both military and peaceful uses of atomic energy. Oliphant had recommended that since Britain would have the necessary facilities, Australia should seek to send scientists to be trained in Britain.

The process for establishing the United Nations Atomic Energy Commission commenced on 3rd October 1945 when President Truman announced to Congress that he was about to initiate talks with the UK and Canada 'on the international control of atomic energy' [39]. The notion of 'control of atomic energy' was a euphemism for maintaining the status quo and not sharing atomic secrets with anyone. These discussions with the UK and Canada were only relevant because Canada had a reliable source of uranium ore and the US had none, and the UK had been involved in atomic energy from the beginning and was badgering the US to share the knowledge and technology that the US had developed during the war years based on the information that Britain had first shared with the US.

On the 26^{th} March 1946 Ben Chifley received a cable informing him of Oliphant's expected visit to Australia [40]. Records from the National Archives of Australia indicate that Oliphant had agreed in March to be part of Australia's delegation to the United Nations Atomic Energy Commission [41]. I suspect that it was during this visit that Oliphant and Chifley met and not at the Commonwealth Prime Ministers' Conference that was held in Britain in May 1946, as has been stated in the Oliphant biography written by Cockburn and Ellyard.

On the 4^{th} February 1947, Chifley sent a note which had been drafted by Coombs, to Atlee that stated:

'Professor Oliphant has made it clear that he could not take up a position here until his present obligations in the United Kingdom are complete. And it is understood that this may take another two or three years. Furthermore, he is anxious that if he should accept appointment this should be done with the goodwill of his fellow scientists in the United Kingdom and the United Kingdom Government to whom he feels a considerable debt of gratitude. Furthermore, he points out that the work he would do here should be regarded as part of the general British Commonwealth contribution to the development of knowledge in the field of atomic physics and that he should have continued opportunity for consultation and collaboration with fellow scientists working in the United Kingdom' [42].

Oliphant had wanted to continue playing a part in applied research into atomic energy and was not prepared to forego that type of involvement on his return to Australia.

Atlee responded to Chifley's request on 4^{th} March and stated:

'. . . In so far as his work was concerned with fundamental physical research of a non-secret character, we should hope that he might have the fullest opportunity for consultation and collaboration with fellow scientists working in the United Kingdom . . . There are as you know, aspects of atomic energy which much of our knowledge in this country is derived from the work we did during the war in conjunction with the Americans and the Canadians. Professor Oliphant who played such an important part in that work, will know that the war-time partnership has placed hither to certain limits on our freedom to co-operate on atomic energy with other countries, even within the Empire. You will remember that I explained the position at our meeting here last May' [42].

This reinforced the conditions that the U.S. had placed on both the United Kingdom and Canada concerning the sharing of knowledge and information on atomic energy and related technologies.

Oliphant by this time had the ear of the Australian Prime Minister and over the next decade would continue to have this type of familiarity with Chifley's successor, Robert Menzies. During the period 1946 to 1950, there would be much negotiation between Oliphant and the Australian officials who were attempting to bring him out. In August 1950 Oliphant finally arrived in Australia [43]. He took up the position of Director of the Research School of Physical Sciences at the Australian National University.

INDUSTRIAL ATOMIC ENERGY COMMITTEE

Australia had, more from good fortune than by design, become involved in the international politics of atomic energy and its control by its membership of the first Security Council of the United Nations and as such a member of the United Nations Atomic Energy Commission. This was a position that Australia wanted to maintain. It was a new technology and at the time there was no reason to suppose that Australia could not join the elite technologically advanced atomic club. After all, many of her sons had been involved in the development of the atomic bomb and were now working on the development of atomic energy.

John Dedman, as the Minister responsible for the CSIRO, wrote on 27^{th} June 1949 to the Minister of Defence (one notes with some amusement that the Minister of Defence was also John Dedman), stating that 'The executive of CSIRO has recently advised me that it is difficult for it to formulate future policy on many different aspects of atomic energy with which the Commonwealth Government may be concerned without collaboration of your Department of Defence and of the Department of Supply and Development' [44]. He suggested that a group of officers from the CSIRO, the Department of Defence and the Department of Supply should meet 'with the view to advising the three Ministers concerned as to the interdepartmental machinery which should be set up to advise Cabinet on policy matters' [45] concerning atomic energy. By 26^{th} July a group representing the CSIRO, the Department of Defence and the Department of Supply and Development met at CSIRO Head Office in Melbourne [45].

This meeting recommended the formation of an Atomic Energy Policy Committee. Initially this committee was to have representatives from the Departments of Defence and of Supply and Development, a representative of CSIRO and three technical experts, under the chairmanship of Marcus Oliphant [46]. Oliphant had 'agreed with the view that Defence and other aspects of Atomic Energy could not be separated' [46]. However, in a note sent to the Secretary of Defence by the Acting Secretary, it became obvious that the Minister of Defence 'did not wish Defence to be associated at this stage with CSIRO on the committee, although he did say that Defence could be added later.' The rationale for this Ministerial decision was evident later in this note, 'He (Dedman) mentioned that the government was desirous of setting up an atomic pile in South Australia for the generation of electrical energy as a counterpart in that State to the Snowy River Scheme' [46].

This committee was later renamed as the Industrial Atomic Energy Policy Committee and was established on 19^{th} August 1949 by Chifley. It was to advise the government on the possible industrial applications of atomic energy and to suggest a program for its development. It was answerable to the Minister responsible for the CSIRO [47]. Oliphant was to be the Chairman and the other members of the committee were representatives of the Departments of Supply and Development, Treasury and the CSIRO and 'three technical men, familiar with the physical, chemical and minerals problems that will require consideration'[48].

Oliphant initially was involved with the works of the committee by correspondence but was to take a more active role on his return to Australia in 1950 [23]. Menzies, who by this time was Prime Minister, endorsed Oliphant as chairman but also included his own nominees, one of whom was Professor Philip Baxter. Oliphant was an active chairman and made independent submissions to Menzies concerning the development of atomic energy in Australia. When Oliphant discovered in February 1951 that Menzies did not see Mr Clement Attlee, the then Prime Minister of the United Kingdom, to discuss 'cooperation in the field of atomic energy' [49], Oliphant went so far as drafting a note to Attlee stating that 'Detailed exploration of uranium ores at Radium Hill in South Australia has proved that at least 600 tons of uranium is recoverable as oxide' [49] and that since a joint program of development would be useful to Australia, 'authority be given for technical discussions' between Oliphant and Cockcroft, who could then make recommendations in the development of atomic energy in Australia [49].

This draft letter, based on a report that Oliphant had prepared on behalf of the Industrial Atomic Energy Policy Committee, which recommended the adoption of an atomic energy program in Australia, was sent to Menzies, by Oliphant, with the instructions that Menzies ought to send it to Attlee. Menzies obediently cabled this letter, unaltered, to Attlee who responded that there were issues of security due to the constraints of the tripartite agreement and that not all information available to Britain could be freely passed on to Australia [49].

Specifically Attlee's reply stated 'We have to regard our commitments under the tripartite agreement between the United States, Canada and ourselves. Complete separation of power and military programs for the use of atomic energy is not possible and a worthwhile program for industrial power could not be carried out without the use of classified information. ...In these circumstances we should in the first place need to have from you assurance that any Australian project in the industrial field would be dealt with as 'classified' to the extent that this is necessary under the rules agreed with the United States and Canada.' The response concludes with 'This need not, however, hold up essential preliminary work such as ore mining operations' [48, 49]. Quite clearly Britain was unwilling to share information but it still wanted its uranium ore.

Oliphant was shown a copy of this response and in return responded, on 28^{th} May 1951, with a willingness to accept the notion of secrecy of any information made available from Britain. He concluded: 'Assuming that the Government agrees to 'classification' of work on atomic energy, I assume that the project must be transferred to a Ministry which has the necessary machinery for dealing with classified information' [49]. Even before Oliphant had a chance to write a reply to Attlee's response other members of the Industrial Atomic Energy Policy Committee were being brought secretly into the discussion.

The first shot was fired by Harold Breen, on 23^{rd} April 1951 when he sent a copy of Menzies' letter to Attlee, with Attlee's response, to the Secretary to the Department of Defence, with a cover note stating that 'No member of the Committee was aware of the first cable' [50]. The Secretary of Defence responded saying that the Defence Department had no official representation on the Committee. By 4^{th} May, Breen had met with two other members of the Committee, Martin and White, who were in general agreement as to what should be done. They produced a report that was critical of Oliphant's views on atomic energy, suggested that the Committee would need to be reconstituted. The cover note to this report was written by Breen and sent to Menzies on 7^{th} June 1951. Breen refers to the issue as the 'Oliphant-Uranium matter'. The final paragraph of the cover note states: 'I am particularly anxious to know if any Australian scientific help may be needed by the United Kingdom in Australia in the near future because of a certain event which is being planned and which may occur in Australia. You are aware of this possible project. White and Martin do not know' [50]. This is a reference to the forthcoming British atomic tests which were to be held in Australia commencing in 1952.

Oliphant's reply of the 28^{th} May drew a 'slap on the wrist' by the Secretary of the Prime Minister's Department, suggesting that Oliphant should meet with the Industrial Atomic Energy Policy Committee and present a report. Oliphant did what he had been asked [48]. The Committee met and recommended that it be disbanded and replaced by a new committee 'constituted under one of the Departments of the Defence group' [51]. The machinations of the Secretaries of the Departments of the Defence Group resulted in The Industrial Atomic Energy Policy Committee being reconstituted under the Department of Supply. Howard Beale sent a letter on 4^{th} April 1952 inviting the respective Departments to nominate their representatives. Oliphant, however, did not hear about the changes to the new committee until almost three weeks later when he received a letter from Menzies asking him to act as a consultant to the committee. Oliphant objected vociferously [51]. The committee remained in existence until November 1952 when it was reduced in size and changed in composition to allow for the easy transition for the new Commissioners who would run the new organisation once the Atomic Energy Act 1953 was enacted [52].

OLIPHANT AND NATIONAL SECURITY

It has already been noted that Oliphant had a somewhat relaxed approach to security. His reputation was further damaged by two different 'spy scandals'. The first was the revelation, in March 1946, that Alan Nunn May had acted as a spy for the Soviet Union. Nunn May had been an undergraduate in Oliphant's Physics Department in Birmingham. What added to the scandal was that Oliphant knew Nunn May's family who lived near the Oliphants in Birmingham [53]. The second scandal was the famous Klaus Fuchs affair. Fuchs was arrested in Harwell in early 1950, as a Soviet agent. Fuchs had worked at Birmingham with Rudolph Peierls and Otto Frisch and later on the Manhattan Project [53]. Both spies were Birmingham men and Oliphant was their Professor, so now Oliphant was tarnished by guilt through association.

The Australian Security and Intelligence Organisation, ASIO, had the responsibility of vetting all Public Service appointees. It also established files on individuals who may have posed a security risk; the outspoken Oliphant had such a file established. The file contains allegations of a trivial nature which indicate that Oliphant held strong views and was willing to express them. In 1953 there were two assessments made of Oliphant; one dated 17^{th} August stated, 'we have an unconfirmed report that he expressed horror at the dropping of the bomb on Hiroshima, a civilian target, and accused the American Government of a breach of faith in that regard; his contention being that they had promised that if the bomb was produced, it would be used only on a military target . . . I would also quote the opinion of Professor J.P. Baxter of the Atomic Energy Commission, who said "I have known Mark for years, and cannot conceive of him harbouring a disloyal thought"'[54]. The opinions expressed by Oliphant were shared by many loyal Australians. Another quote from the vetting process for the Australian Atomic Energy Commission stated 'extensive enquiries failed to reveal any evidence of Professor Oliphant's interest in, or membership of, any organisation of security interest' [54].

Two later notes from Oliphant's file indicated that he was under some form of casual surveillance. On 11^{th} June 1956 Oliphant received gifts from Peter Kapitza. Kapitza had been a fellow Cavendish student and had returned to his native Russia just before Stalin closed the borders of the USSR thus effectively making Kapitza a captive in his homeland. It was quite natural for Oliphant and Kapitza to correspond and even exchange gifts. A later entry included that on 10^{th} January 1957 Petrov stated that Oliphant was known to him. Petrov had been a minor diplomat in the Russian Embassy in Canberra and had defected dramatically. Oliphant as Professor of Physics at the Australian National University had attended diplomatic functions and hence this comment by Petrov had little impact.

One insightful entry in Oliphant's file, dated 14^{th} July 1954, stated 'there is evidence of rivalry existing between Professors Messel and Oliphant . . . a campaign is on the way to discredit Oliphant and have him removed from his post which would be taken over by Messel' [54]. If Oliphant was aware of this rivalry, he certainly did not exhibit any malice towards Messel. Meanwhile Messel was busy establishing the first university fundraising foundation in Australia, at the University of Sydney.

Finally, Oliphant was not just concerned with atomic energy. He was also an advocate of other forms of energy production. An article in the Sydney Daily Telegraph dated 19^{th} July 1951 stated that Oliphant ' . . . suggested that Australia could build a solar radiation power station using huge aluminium mirrors to reflect the sun's rays and drive steam power generators . . . ' [55]. Oliphant was certainly a man of vision, he could see the potential of solar powered electricity generation more than 50 years before the first solar pilot steam generating plant was established by David Mills in the Hunter region, north of Sydney in 2004 [56]. Oliphant would continue with his researches and would later become Governor of his home state, South Australia. By the time of his death in July 2000, Oliphant would have regained much of his earlier reputation purely from his great integrity. He was seen as a prominent opponent of the nuclear arms race.

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[56] Lecture Delivered to the Royal Society of New South Wales on 1st September 2004 by Dr David Mills, Head of the Solar Energy Group, Physics Department, Sydney University, entitled 'Low Cost Solar Thermal Electricity'.

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Ernest Marsden's Nuclear New Zealand: from Nuclear Reactors to Nuclear Disarmament

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Abstract: Ernest Marsden was secretary of New Zealand's Department of Scientific and Industrial Research from 1926 to 1947 and the Department's scientific adviser in London from 1947 to 1954. Inspired by his early career in nuclear physics, Marsden had a post-war vision for a nuclear New Zealand, where scientists would create radioisotopes and conduct research on a local nuclear reactor, and industry would provide heavy water and uranium for use in the British nuclear energy and weapons programmes, with all these ventures powered by energy from nuclear power stations. During his retirement, however, Marsden conducted research into environmental radioactivity and the impact of radioactive bomb fallout and began to oppose the continued development and testing of nuclear weapons. It is ironic, given his early enthusiasm for all aspects of nuclear development, that through his later work and influence Marsden may have actually contributed to what we now call a 'nuclear-free' New Zealand.

Keywords: Ernest Marsden, heavy water, nuclear, New Zealand

INTRODUCTION

In the 1990s, Ross Galbreath established Ernest Marsden as having been the driving force behind the involvement of New Zealand scientists on the Manhattan and Montreal projects, the creation of a nuclear sciences team at the Department of Scientific and Industrial Research (DSIR), and the subsequent plans for a nuclear reactor in New Zealand [1]. In an article about New Zealand's involvement in the British hydrogen bomb tests of 1957–58, defence historian John Crawford identified Marsden as advising Prime Minister Sidney Holland against allowing the United Kingdom to test hydrogen bombs on New Zealand territory. Crawford also covered the joint United Kingdom-New Zealand plans for the establishment of a heavy water plant to provide raw materials for the British nuclear energy and nuclear weapons programmes, but it was outside the scope of his article to cover Marsden's initiation and encouragement of the heavy water project [2].

This article focuses on Ernest Marsden as the brains behind New Zealand's nuclear schemes in the 1940s and 1950s, adds the context of his early work in the radiation and nuclear sciences, and examines how his attitude to nuclear weapons development – which he was happy to support in the 1940s and 1950s – changed in his later years. By necessity this article includes some material already covered by Galbreath and Crawford but it also covers new ground. The principal sources for this article are the records of the DSIR, External Affairs Department, and New Zealand Atomic Energy Committee held at Archives New Zealand in Wellington, and Ernest Marsden's personal papers held at the Alexander Turnbull Library in Wellington. Biographical pieces in the history of science in some cases overlook the institutional and wider social context of science. In the case of the present study, however, which concerns both the very small country of New Zealand and a field as focussed as nuclear science, the very reverse is true. In this case, one person significantly shaped both the institutional setting and the wider social environment for his science and we learn much about the context precisely by examining his influence. Ernest Marsden's wide experience, outspokenness and apparent capriciousness towards nuclear weapons development makes him an interesting study, providing some insight into the changing attitudes to nuclear development in the nation of New Zealand as a whole.

ERNEST MARSDEN AND THE NEW PHYSICS

Ernest Marsden was well known in early twentieth-century scientific circles as a result of his hands-on involvement in the birth of nuclear physics. In 1909, Marsden was a 20-year-old undergraduate student at Manchester University, under Ernest Rutherford. Marsden had been assisting Hans Geiger with experiments in which a beam of alpha particles was scattered after passing through a thin metal foil, and in response to Geiger's advice that Marsden was now ready for a research project of his own, Rutherford asked Marsden to see if he could get evidence of alpha particles directly reflected from a metal surface. In a now famous experiment, Marsden observed that instead of passing through, a tiny fraction of alpha particles were deflected straight back from a thin gold foil. Rutherford later described this result as being 'almost as incredible as if you fired a fifteen-inch shell at a piece of tissue paper and it came back and hit you'. After pondering this result for two years, Rutherford came up with a new theory for the structure of the atom. He proposed an atom with a centralised concentration of mass and positive charge – which he called the nucleus – surrounded by empty space and a sea of orbiting negatively-charged electrons [3].

In 1915, on Rutherford's recommendation, Marsden came to New Zealand to replace Thomas Laby as Professor of Physics at Victoria University College in Wellington. In 1922 Marsden turned from research to bureaucracy. He first became Assistant Director of Education, and in 1926 was appointed Secretary of New Zealand's new Department of Scientific and Industrial Research, the DSIR. The people who worked with Marsden at the DSIR described his 'infectious enthusiasm' and 'irrepressible optimism' [4]. As one DSIR staff member said about Marsden and his deputy Frank Callaghan, 'Dr Marsden spends his time giving the moon away and Mr Callaghan spends his time getting it back' [5].

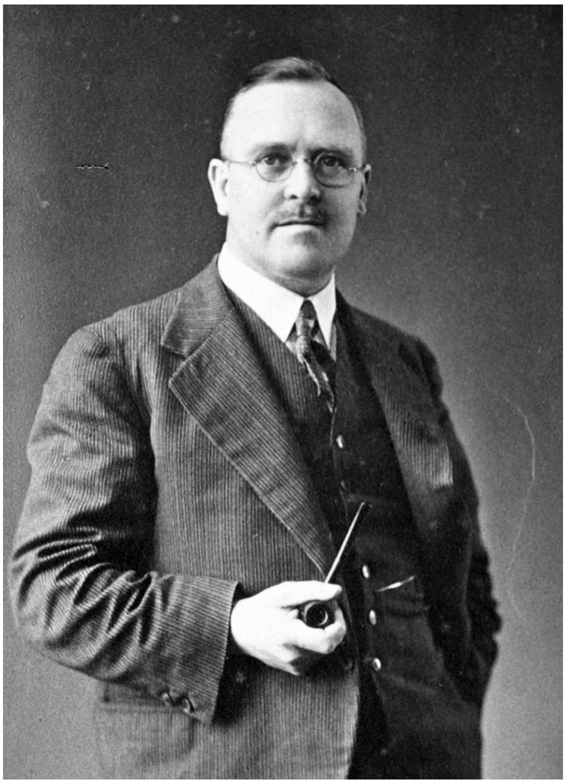

Fig 1. Ernest Marsden, secretary of New Zealand's Department of Scientific and Industrial Research from 1926 to 1947. Photo: Sir C. Fleming Collection, Reference number F-18564-1/4, Alexander Turnbull Library, Wellington, New Zealand.

Marsden used his characteristic enthusiasm, along with his lifelong interest in radiation and nuclear sciences, to initiate a number of projects that kept New Zealand in touch with international developments in the field. In the late 1930s, with a young scientist called Charles Watson-Munro, he conducted a survey of radioactivity in New Zealand soils in an (unsuccessful) attempt to establish a connection between radioactivity and the regional incidence of goitre [6]. He also established a cosmic-ray meter at the DSIR's Magnetic Observatory in Christchurch [7].

In 1939 Marsden pioneered the non-medical use of radioisotopes in New Zealand. An animal wasting disease known as 'bush sickness' had been found to be linked to a deficiency in cobalt. Using a small quantity of radioactive cobalt prepared in Ernest Lawrence's cyclotron at the University of California Marsden worked with Watson-Munro on a series of experiments to determine the role of cobalt in animal metabolism [8].

THE SECOND WORLD WAR AND NEW ZEALAND'S CONTRIBUTIONS TO THE MANHATTAN AND MONTREAL PROJECTS

With the outbreak of the Second World War Marsden was given the title of Director of Scientific Developments, in which role he was charged with mobilizing New Zealand's scientific manpower. Marsden made several wartime trips to the United Kingdom, mostly to advance a secret programme to develop radar in New Zealand. While radar development was initially the Allies' top priority, the United Kingdom and United States soon began attempts to develop an atomic bomb [9]. In December 1943, Marsden was travelling through the United States on his way to the United Kingdom where, in Washington DC, he chanced upon James Chadwick (scientific director of the British nuclear research project), Mark Oliphant (an Australian physicist working on the British nuclear programme) and Danish physicist Niels Bohr, who had been smuggled out of Denmark and was travelling under an assumed name. Following the August 1943 signing of the Quebec Agreement, Chadwick and Oliphant – like Marsden, they had both worked with Rutherford – were in Washington with the top secret task of arranging details of scientific cooperation between the United Kingdom and United States' nuclear research programmes. Oliphant later recalled they were in their hotel lobby waiting for the elevator when they felt taps on their shoulders and turned to find Marsden in full military uniform. They were taken aback to hear Marsden say, 'I can guess why two nuclear physicists are here!' During the elevator journey Marsden put in a good word for New Zealand's participation in the bomb project. He followed this up in London with Sir John Anderson, Chancellor of the Exchequer. Many of the Commonwealth scientists working on the British nuclear research programme had, like Marsden, been students or colleagues of Ernest Rutherford and Marsden was able to successfully trade on his reputation of being involved in the birth of nuclear physics [10].

Following the necessary protocol, the British Government asked New Zealand Prime Minister Peter Fraser for five New Zealand men to join the British nuclear research team [11]. Robin Williams, a young DSIR physicist, recalled reporting to Wellington in July 1944 to find Ernest Marsden 'cock-a-hoop about the fact that he had managed to get a number of New Zealanders in on the atom bomb project' [12]. Robin Williams was joined by Bill Young, George Page and Charles Watson-Munro. Their terms of employment seconded them to the UK DSIR for 'a period of one year or for the duration of the war, whichever is the longer'. Marsden was very keen for New Zealand to launch an atomic research programme when the war finished and following the secondment the men were required to return to New Zealand for at least one year [13]. In late July 1944 Williams and Page arrived in San Francisco to work with Ernest Lawrence and Mark Oliphant on the electromagnetic separation of uranium. Two other New Zealanders were already working at Berkeley, having arrived from the United Kingdom with the British team [14].

In Canada, a team of mostly English and Canadian scientists, led by another Rutherford old-boy, John Cockcroft, had begun a project to develop a heavy-water nuclear reactor. Watson-Munro and Young travelled to Montreal from New Zealand and Ken George reported directly to Montreal from his post as the DSIR's scientific liaison officer in Washington. As part of the Canadian team, they began work on building a low energy atomic pile, using natural uranium fuel and heavy water as a moderator [15]. Marsden, as a scientist turned administrator, was tremendously excited about these new applications of nuclear physics and felt stymied and frustrated in his administrative and managerial role. He wrote regularly to the American-based scientists, asking, sometimes inappropriately, for details of their research. In response to Cockcroft's request for three more New Zealand men, Marsden offered himself, 'in any direction of work, for any period of time' [16]. His offer was ignored and three more young New Zealand scientists were sent to join the Montreal team. The New Zealanders in Montreal, led by Watson-Munro, played a major role in the construction of the Zero Energy Experimental Pile, or ZEEP, the first nuclear reactor built outside the United States, which was completed in September 1945 [17].

WARTIME URANIUM SURVEY

Unable to participate in the North American nuclear research programme, Marsden directed his enthusiasm to a search for uranium in New Zealand. The United Kingdom had initiated a Commonwealth search for uranium in 1942, but had excluded New Zealand, whose geology was not considered promising [18]. In December 1943, while on his fruitful trip through the United States, Marsden had taken matters into his own hands, writing to the Director of New Zealand's Geological Survey to ask him to initiate a search for radioactive minerals in the South Island [19]. The New Zealand War Cabinet approved funding for the uranium survey in July 1944 and a team of DSIR physicists assembled at the Dominion Physical Laboratory in Wellington to start work on the uranium project [20]. In October 1944, a mining engineer and a physicist, carrying a Geiger counter to measure radioactivity, began secretly exploring beach sands along the West Coast of the South Island, from Karamea to the Moeraki River. Surveys of Stewart Island beach and river sands, and of beach sands and dredge tailings at Gillespies Beach, followed [21]. In March 1945, the DSIR chartered the Government ship *New Golden Hind*, and the secret uranium survey was extended. The ship sailed down the South Island's east coast and around Bluff to investigate the eight sounds from Milford Sound to Nancy Sound, but failed to find any promising sources of radioactive minerals [22].

In August 1945 the Manhattan Project culminated in the dropping of atomic bombs on Hiroshima and Nagasaki in Japan. In recognition of the military and economic importance of uranium, the New Zealand Atomic Energy Act was passed on 7 December 1945 to give the State full ownership and control over uranium and other radioactive elements, with the Minister of Mines having power to control the mining and disposal of uranium-bearing rock and its products [23]. In January 1946 Marsden organised a second *New Golden Hind* expedition – this one not secret – to complete the initial survey with a search of the rocks, beaches and gravels in the Southern Sounds from Preservation Inlet up to Thompson Sound. As the only result of the two-year survey, uranium-bearing minerals were found in gold dredge tailings on the West Coast, but their quantity and concentration was deemed too small to permit their economic recovery [24].

A NUCLEAR NEW ZEALAND

After the war, Marsden started to enact his vision for a nuclear New Zealand. If he couldn't be part of the big science taking place in Europe and America he would make it happen at home. In January 1946 Marsden gained Cabinet approval to establish a new team of 10 scientists at the Dominion Physical Laboratory. Their mission was to carry out fundamental and applied atomic research and advise on atomic energy and the application of isotope techniques to problems in agriculture, health and industry. The same Cabinet decision allowed for the secondment of physicists, chemists or engineers to nuclear organisations in the United Kingdom and Canada to ensure New Zealand kept up to date with new developments and techniques. An annual budget of £19,000 was allocated to implement these proposals [25].

In 1946 Watson-Munro and three of the other New Zealanders left Canada for the newly established United Kingdom Atomic Energy Research Establishment in Harwell, while another three of the New Zealand team remained in Canada. In the United Kingdom, Watson-Munro took charge of the construction of a Graphite Low Energy Experiment Pile, or GLEEP, the first nuclear reactor in the United Kingdom, which was completed in August 1947 [26]. Before returning to New Zealand, Watson-Munro, in consultation with Marsden, submitted a report to the New Zealand Government on the construction of a low energy atomic pile in New Zealand. The pile was recommended on two grounds: for the production of radioisotopes for industrial and agricultural research; and to serve as the nucleus of an atomic research project [27]. Marsden also believed the pile would provide a 'long term contribution to Commonwealth defence' [28]. In August 1947, based on Marsden and Watson-Munro's report, New Zealand's newly-established Atomic Energy Research Committee recommended the construction of an Australasian low energy pile in New Zealand [29].

In September 1947 Marsden left his position as secretary of the DSIR to become the DSIR's Scientific Adviser in London. When Marsden arrived in London, he and Watson-Munro met Lord Portal, head of the Atomic Energy (Review of Production) Committee, to talk about the Commonwealth atomic pile. They discussed the advantages of a small atomic pile in New Zealand for research purposes, to be followed up by a large power production pile in Australia, 'capable of producing fissile materials suitable for the manufacture of atomic bombs' [30]. On receiving sympathetic responses to the proposal from both Lord Portal and John Cockcroft, who was now director of the Atomic Energy Research Establishment at Harwell, Marsden was tremendously excited. He admitted he had initially thought the reactor proposal was an 'ambitious dream', but was now convinced it would be 'a statesmanlike step to take at higher levels with enormous repercussions for the good of our country' [31]. In late 1947, in response to a ministerial request, Marsden and Watson-Munro provided an advisory report, which was agreed to by John Cockcroft, on the construction and use of an atomic pile in New Zealand. The report recommended a graphite uranium pile costing £100,000 to construct and up to £35,000 a year to run. The project would use the skills of the New Zealand scientists who had worked on the North American nuclear programmes and would take one-to-two years to build [32]. The Minister of Scientific and Industrial Research, however, was critical of the report, questioning the need for a New Zealand pile on the basis that radioisotopes were available from overseas and New Zealand scientists would be best trained in more sophisticated offshore facilities [33]. Henry Tizard, scientific advisor to the British Ministry of Defence also gave the proposal a lukewarm reception, telling Marsden the defence arguments in favour of the pile were weak [34]. Peter Fraser, the New Zealand Prime Minister, sought the opinion of the British Prime Minister on the value of the project [35]. Clement Atlee replied favourably, saying the project would be of advantage to the Commonwealth and offering the assistance of the United Kingdom Government [36].

Marsden continued to advocate for construction of an atomic pile in New Zealand [37]. But with him being away from New Zealand, and – despite Atlee's offer of assistance – with limited government support for an atomic pile, many of the DSIR's original nuclear sciences team moved into other areas of research. Two of the New Zealand scientists who had worked on ZEEP and GLEEP, Charles Watson-Munro and George Page, eventually moved to the Australian Atomic Energy Commission Research Establishment, where Watson-Munro became director [38]. The DSIR nuclear sciences team Marsden had established continued, though rather than operating a research reactor they were focusing on measuring environmental radioactivity, using radioactive tracers, and experimenting with radiocarbon dating [39].

HEAVY WATER FOR THE BRITISH NUCLEAR PROGRAMME

From London, while continuing to promote the construction of a low energy atomic pile [40]. Marsden also encouraged the New Zealand production of heavy water as a moderator for British atomic piles [41]. In 1949 Marsden reiterated an earlier suggestion to John Cockcroft

[42], that New Zealand's geothermal steam – which was being investigated for electricity generation – could be used to concentrate heavy water through fractional distillation [43]. Cockcroft was receptive to Marsden's suggestion and a DSIR scientist, J.A. (Tony) McWilliams, was transferred to Harwell to study the distillation of ordinary water to heavy water through use of geothermal steam [44]. In March 1952 the New Zealand government received formal advice that the British authorities attached great importance to the development of additional supplies of heavy water and requested a thorough survey of its potential production in New Zealand be undertaken as a matter of urgency [45]. Marsden continued to encourage the project, liaising between Harwell, the DSIR and the Prime Minister's Department. Economic production of heavy water by distillation depended on the design of an efficient production plant and the availability of sufficient steam. Distillation experiments continued at Harwell, while in New Zealand, the DSIR focussed on assessing the availability of geothermal steam and its corrosive properties and conducting heat transfer tests [46]. On a visit to New Zealand in September 1952 John Cockcroft met with Cabinet and the Defence Science (Policy) Committee and made it clear the British wanted heavy water not just to use as a moderator in atomic piles, they were also interested in it from a 'defence research angle' [47].

In May 1953 the New Zealand Cabinet approved in principle the construction of a joint New Zealand/United Kingdom combined heavy water and electricity generating plant [48]. The focus now moved to determining the economics of the project and the nature of the agreement between New Zealand and the United Kingdom. In December 1953, however, the British High Commissioner in Wellington informed Prime Minister Sidney Holland that the Atomic Energy Board in the United Kingdom had decided that it could no longer recommend British participation in the project, citing the possibility that the United States might soon be offering heavy water at 'a keen price' [49]. In March 1954 the heavy water project was briefly revived. At a meeting of the British Chiefs of Staff on 19 March 1954, Sir Norman Brooks, Secretary to the Cabinet, reported plans to improve Britain's capacity to manufacture hydrogen bombs by obtaining thorium from South Africa and heavy water from New Zealand [50]. The next week Marsden was advised that the United Kingdom might reopen discussions on the heavy water project. Loathe to put the reasons for the renewed interest in writing, Marsden cryptically described it to the DSIR secretary in New Zealand as 'a very special urgent important reason' [51]. On 23 April 1954, Viscount Swinton, Secretary of State for Commonwealth Relations, advised Sidney Holland that, on the basis of new cost and supply information, the United Kingdom Government now wanted to proceed with the heavy water project but this time attached great importance to maintaining secrecy [52]. On the same day, Cabinet authorised Holland to tell the British High Commissioner that the New Zealand Government was willing to go forward with the proposed combined heavy water and electricity plant in the Wairakei geothermal area [53]. While Marsden, in London, knew of the secret plans to develop a hydrogen bomb and of its links to the heavy water plant, it is unclear how widely this was known in New Zealand. A report on the revived heavy water plans in a Prime Minister's Department file deduced from official statements and press reports that the project was now focused more on civil development of atomic power and less on defence requirements [54].

By July 1954, moreover, this surmise proved correct. When the British cabinet formally decided to proceed with building a hydrogen bomb, heavy water was abandoned in favour of other materials [55]. But revised cost estimates from American sources meant New Zealand heavy water was again considered attractive for the United Kingdom's nuclear reactor programmes and in February 1955 Geothermal Developments Ltd, whose shareholders were the New Zealand Government and the United Kingdom Atomic Energy Authority (UKAEA), was formed to produce electricity and heavy water at Wairakei. Marsden, who had retired from the public service at the end of July 1954 and returned to New Zealand, was appointed technical adviser to the Board [56]. The Ministry of Works would be responsible for constructing the planned plant, which aimed to be ready for heavy water production by 30 June 1957, and for electricity production a year later [57]. Design work proceeded to the stage where prices for equipment, materials and labour could be accurately estimated but this doubled the cost of the plant, raising the cost of the heavy water it would produce from £44,000 to £90,000 per ton [58] and in January 1956 the UKAEA advised that, faced with the projected price increases, they felt forced to withdraw from the project [59]. Plans were revised to construct a larger power station to absorb the steam, which would no longer be needed for heavy water production [60].

RADIOACTIVE FALLOUT AND NUCLEAR TESTING IN THE PACIFIC

Marsden had a very active retirement – as well as conducting his own research, he was a member, and later chairman, of the Defence Scientific Advisory Committee. He was a member of New Zealand's Atomic Energy Committee, set up in 1958 to advise on New Zealand's activities in atomic affairs, including the organisation and administration of the DSIR's new Institute of Nuclear Sciences [61]. He was part of the New Zealand delegation to the 1958 International Conference on the Peaceful Uses of Atomic Energy [62]. Marsden encouraged the government support of uranium prospecting that began in 1954 and at the second reading of the 1957 Atomic Energy Amendment Act, which dealt with the search for uranium, the Minister of Health took the opportunity to speak on Marsden's role in the birth of nuclear physics [63]. His speech was later discussed in Cabinet, after which Marsden was recommended for a knighthood [64]. Marsden became Sir Ernest Marsden in 1958 [65].

Throughout the 1950s, Marsden continued to recommend the construction of a research reactor in New Zealand while also advocating nuclear power as a cheaper option than a Cook Strait cable, which was also being considered [66]. Not everyone shared his enthusiasm for the nuclear option, however, and in 1956 Marsden told the Dominion newspaper that those who were holding New Zealand back from nuclear power were 'lazy-minded conservative diehards who are afraid of change' who were afraid that nuclear science had become 'a malevolent, uncultured arbiter of our destiny instead of the traditional servant of the industrial revolution' [67]. Marsden's enthusiasm for things nuclear, however, had limits, and following revelations about world-wide radioactive fallout from nuclear bomb tests, he began his own research into the effects of fallout in New Zealand and the Pacific Islands, and in a small way – through his advice to Prime Ministers Sidney Holland and Keith Holyoake – he actually helped to keep New Zealand 'nuclear free'.

By 1955 the United Kingdom needed New Zealand's help for another aspect of their nuclear programme. Australian Prime Minister Robert Menzies had ruled out the testing of hydrogen bombs on or near the Australian mainland so when the United Kingdom began plans to test the hydrogen-bomb, a new test range had to be found. Scientists from the Aldermaston weapons development laboratory estimated the site should be at least 500 miles from inhabited land or shipping lanes. The best options were considered to be 'various remote islands or the icy wilderness of Antarctica' [68]. The Kermadec Islands, a New Zealand territory some 1000 km north-east of New Zealand (and now part of New Zealand's largest marine reserve), was chosen as the most promising site. In May 1955 Sir Anthony Eden, the British Prime Minister, contacted Sidney Holland to request the use of the Kermadec Islands for the bomb tests. Eden described how the weapons could be either exploded on one of the islands from a tower, or fired in a ship anchored near an island, and asked if Holland would agree in principle to the weapons trials so the United Kingdom could investigate the site further. Eden concluded by expressing his earnest 'hope that, in the interests of our common defence effort and the importance of the deterrent for Commonwealth Strategy, you will find it possible to agree' [69].

Fig 2. Source: Auckland Star, 27 April 1956.

Holland was wary of the British request and took note of negative publicity surrounding earlier newspaper reports of British plans to test in Antarctica. He sought the opinion of Ernest Marsden, who advised Holland that while an isolated island in the Pacific was ‘a logical choice’ for the proposed weapons test, the Kermadec Islands were not necessarily the best option. He acknowledged the weather was suitable but noted the presence of occasional ships and aircraft in the area and reminded Holland of the Japanese fishermen who suffered radiation sickness – one died – after their boat was unintentionally stationed 135 kilometres from the United States’s first hydrogen bomb detonation at Bikini Atoll on 1 March 1954. Marsden acknowledged the Government might on the one hand feel a ‘moral obligation’ to cooperate with the British request but on the other hand might ‘feel that the sacrifice and difficulties in the use of the Kermadecs is questionable’.

Without bluntly advising Holland to refuse the request Marsden suggested the Auckland Islands, some 320 kilometres south-south-west of New Zealand, as a preferable alternative to the Kermadecs [70].

On 15 July 1955 Holland warned the British High Commissioner in Wellington that the use of the Kermadecs for nuclear tests would be a ‘political H-bomb’ in New Zealand – not least because they would take place in an election year – and declined the British request [71]. Eden expressed his disappointment at Holland’s refusal, reiterating the importance of the planned trials to the ‘defence of the free world’ and advising that if Britain did not find a suitable alternative he might be compelled to ask Holland to reconsider the matter [72]. Britain looked for a new site and in 1956 eventually settled on Christmas Island and Malden Island (now part of the Republic of Kiribati).

While not offering New Zealand territory for the tests, Holland still supported them in principal. New Zealand was happy to assist the United Kingdom with logistical support for the bomb tests and in May 1956, when three Labour MPs asked if Holland would protest at the continuation of nuclear bomb tests in the Pacific. Holland replied that 'the development of this branch of the nuclear sciences must continue' and 'periodic tests are essential to this work' [73]. In a later statement he added 'New Zealand will be helping to ensure that the United Kingdom remains in the forefront in the field of nuclear research' [74].

RETIREMENT PROJECTS ON RADIOACTIVITY

At about the same time that he was advising Holland against allowing the United Kingdom to test hydrogen bombs in the Kermadec Islands, Marsden was beginning his own research into the biological effects of background radiation. In his retirement he worked up to six days a week, from either his attic laboratory at his home, or as a guest worker at the DSIR's Dominion Physical Laboratory or the Royal Cancer Hospital in London [75]. He was passionate about this new line of work, telling a colleague 'I wish I could start my career again and work on these radiobiological problems' [76]. Marsden liked an audience and received a lot of press coverage – he sometimes talked up the effects of radiation from bomb tests and sometimes minimalised them, pointing out radiation levels from fallout were very low in comparison to natural background radiation [77]. He rightly, however, said the effects of radiation from bomb fallout were not fully understood and deserved further study [78]. Much of Marsden's research was interesting and unusual and attracted coverage in the daily press. His most publicised findings came from his research into Niue Island, where a DSIR Soil Bureau study had showed the island's soil had unusually high levels of radioactivity [79]. This prompted Marsden to further research and he found the radioactivity of food grown on the island to be up to 100 times normal [80]. His findings caused quite a stir internationally, with the popular press picking up on Marsden's assertions that Niueans were a master race. Not only were they taller, much happier and less prone to disease than other races, he was reported to have said, selective breeding had led to the population building up a resistance to radiation which would be advantageous in the event of a nuclear war [81]. Despite criticism of his theory, Marsden persisted, stating in 1962, 'My contention that the people of Niue Island would be better off in a nuclear war than the rest of us is a good story and I'm sticking to it!' [82].

Another of Marsden's high profile projects was his investigations into the radioactivity of tobacco. By the 1960s, links between cigarette smoking and lung cancer had been established. Marsden saw the striking increase in British deaths from lung cancer as being possibly linked to increased imports of Southern Rhodesian tobacco, which he had found to have high levels of polonium-related radioactivity [83]. In 1965, at Marsden's request, the DSIR's chemistry division developed a new type of cigarette filter to reduce the amount of polonium inhaled when smoking cigarettes [84].

Despite his seemingly eccentric scientific pursuits, Marsden maintained his international scientific connections and was held in high regard by the physics community. While working on his retirement projects he corresponded with some of the top Commonwealth nuclear scientists – including John Cockcroft and William Penney in the United Kingdom, and Charles Watson-Munro in Australia – using his connections to call in favours for advice or equipment that may otherwise have been difficult to obtain. In return, Marsden was known to send eminent scientists parcels of New Zealand lamb, to arrive just in time for Christmas [85]. In 1961 he was invited to be President of the Rutherford Jubilee International Conference in Manchester, a gathering of 500 of the world's leading physicists to commemorate the fiftieth anniversary of the discovery of the atomic nucleus [86].

A 'NUCLEAR-FREE' NEW ZEALAND?

In 1959, by which time the United Kingdom had completed its nuclear testing programme in Australia and the Pacific, Marsden began speaking out against the testing of nuclear weapons. He highlighted the worldwide increase in radioactive fallout resulting from Russian and American nuclear tests and told the Auckland Star 'the time has come for an absolute standstill on such atomic explosions to give time for a proper assessment of the damage already done to us and to our children even yet unborn' [87]. This wasn't the first time Marsden had publicly opposed nuclear weapons. Following the Second World War he had supported the 1946 Baruch Plan, which called for international inspection of all nuclear-related facilities to ensure they were not working on atomic weapons and stipulated that the United States dispose of its atomic weapons, stop all weapons work and turn over its atomic energy knowledge to the United Nations. In a 1947 speech, Marsden, who advocated atomic energy as being of 'untold benefit to the world' said that it was not, however, safe to develop atomic energy on a world-wide scale until there was a practical and enforceable agreement that it would not be used for atomic bombs [88]. No such agreement was put in place and his stated views on atomic weapons seem to conflict with his concurrent plans for development of a nuclear reactor in New Zealand, which he promoted as being of defence significance to the Commonwealth. They also conflicted with his support, in the early 1950s, of British plans to develop nuclear weapons, and his enthusiasm for New Zealand to assist the British nuclear programme by constructing a nuclear reactor, and providing heavy water and uranium.

After the British nuclear programme was concluded in 1958, Marsden declared that New Zealand was partly to blame for the Commonwealth 'falling miserably behind in nuclear development'. If there was a third nuclear power, Marsden declared, there would be no 'bombing competition' between Russia and America [89]. Marsden continued to criticise New Zealand's lack of investment in defence science, including telling Prime Minister Keith Holyoake that New Zealand had been 'grossly discourteous and negligent of opportunities to help Britain' in this area [90]; a reference to New Zealand's continued failure to construct an atomic pile [91].

But why, at the same time as implicating New Zealand in the United Kingdom's failure to keep up with the arm's race, was Marsden speaking out against nuclear weapons? As journalist Tony Reid described in a newspaper profile of Marsden, his attitudes to nuclear weapons development were, 'ambiguous and sometimes contradictory' [92]. It is possible that despite his initial personal misgivings about the post-war development of nuclear weapons, Marsden's loyalty to Britain, along with the close involvement of many of his friends and former colleagues in the British nuclear programmes, caused him to push these misgivings aside. Marsden was easily seduced by science – as demonstrated by his willingness in early 1945 to leave his position as head of the DSIR to take a junior physicist's role on the North American nuclear programme – and the development of nuclear weapons was at the forefront of scientific and technological development. Once the British nuclear testing programme was concluded, therefore, and with evidence of increased environmental radioactivity resulting from bomb fallout, Marsden had no hesitation in publicly opposing nuclear weapons.

After a number of anti-nuclear statements to the media from 1959 onwards, Marsden began communicating his anti-nuclear weapons sentiments to Prime Minister Keith Holyoake in 1961 [93]. Then in 1963, when the French announced their proposal to move their test site to the South Pacific, Marsden advocated, in a letter to Holyoake, a nuclear-bomb free Southern Hemisphere. He pointed out that fallout from nuclear bomb tests had so far impacted more on the Northern Hemisphere than the Southern, and called on Holyoake to announce that New Zealand would not provide any assistance to countries carrying out bomb tests in the Southern Hemisphere, and suggested he call on other Southern Hemisphere countries to do the same [94]. In May 1963 the New Zealand Government formally protested to the French Government over their preparations for a nuclear test at Gambier Island [95]. Later that year New Zealand being the first country, after the United States, United Kingdom and USSR, to ratify the Partial Test Ban Treaty, demonstrating, in Holyoake's words, New Zealand's 'desire to see an end to nuclear tests that are likely to give rise to contamination of the atmosphere' [96].

While focussing on his research into environmental radioactivity, Marsden continued to speak out against nuclear weapons development and testing. On a visit to South Africa Marsden described the hydrogen bomb as 'the most striking example of the possibilities of misuse of modern scientific knowledge' [97]. In June 1965 he told Salient, the Victoria University student newspaper, 'we must do what we can to stop nuclear warfare. We must do what we can to promote nuclear disarmament' [98]. In 1966, the year France began testing nuclear bombs in the Pacific, a stroke left Marsden confined to a wheelchair, and in December 1970, at the age of 81, he died.

CONCLUSION

In 1985, 15 years after Marsden's death, New Zealand gained international attention for its nuclear-free policy, which was enshrined in legislation two years later. By 1970, however, the year of Marsden's death, New Zealand was already on a path to being nuclear free. In 1968 the New Zealand Government had ratified the Treaty on the Non-Proliferation of Nuclear Weapons, and was now making diplomatic protests over French tests in the Pacific, monitoring fallout in the South Pacific, and working internationally towards disarmament [99]. Ernest Marsden, who had a significant role in establishing and encouraging nuclear science in New Zealand, had a lesser-known role speaking out about against nuclear weapons development and testing. Through his advice to Prime Ministers Holland and Holyoake, and through his regular public lectures and statements to the media, he alerted the country to the extent of radioactive fallout from nuclear bomb tests, and the potential biological effects of environmental radiation, and in so doing helped to encourage the country on a path to what we now call a 'nuclear free' New Zealand.

Fig 3. Sir Ernest Marsden in June 1961, on board the Sydney Star at Bluff, New Zealand, testing the radioactivity of a sample of seawater. Photo: Reference number F-153607-1/2, Alexander Turnbull Library, Wellington, New Zealand.

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British Nuclear Testing in Australia: Performing the Maralinga Experiment through Verbatim Theatre

PAUL BROWN

Abstract: This paper reports and comments on, in a way that is relevant to historians of science, an outcome of the 2002 Adelaide Festival of Arts, which initiated a program of cultural activities associated with Maralinga, the site of the British permanent testing facility from 1956–67. In its original conception, this particular festival focussed on themes of ecological sustainability, truth and reconciliation and cultural diversity.

Keywords: Maralinga, Adelaide Festival of Arts, theatre, nuclear veterans

CONTEXT

Since 2002, reflection on British nuclear testing has intensified in Australia and New Zealand, as the fifty year anniversary of each test program passes, and the implications of the tests are variously acknowledged and evaluated [1]. At the same time, in those countries which hosted tests and in Britain, the quest intensifies for compensation for traditional owners of contaminated country, nuclear veterans and other affected communities. The Royal Commission into British Nuclear Testing, established in 1984, and which reported at length in 1985, anchors the public understanding of how the Australian tests were conducted, and details the serious social and environmental consequences they caused [2].

Nuclear test veterans in Australia and Britain have never felt great comfort from the conclusions of the Royal Commission. The findings do clarify the dangers veterans faced, and the breakdown of protocols which may have caused their illnesses. The inquiry also helped explain the fears veterans still experience due to secrecy and mismanagement on the part of scientists and authorities. However, the Commission recommendations have offered little assistance for veterans in their struggle for recognition and compensation. In the years since the blasts, in both Australia and Britain, only a handful of veterans or their families have achieved victories in compensation cases. This is largely because procedures place burden of proof on veterans to demonstrate first that they attended the tests, and second that they received a radiation dose at the test site that has been responsible for their illnesses [3]. The Royal Commission itself recognized the technical difficulties in veterans making such a case, and the absence of documentation (due to loss or obfuscation) worsens their situation [4].

RESPONSE THROUGH CULTURAL PROJECTS

The purpose of this paper is to report and comment (in a way that is relevant to historians of science [5]) on an outcome of the 2002 Adelaide Festival of Arts, which initiated a program of cultural activities associated with Maralinga, the site of the British permanent testing facility from 1956–67. In its original conception, this particular festival focussed themes of ecological sustainability, truth and reconciliation and cultural diversity [6]. Many of the projects involved an exploration of scientific and technological concerns. An objective was:

‘to re-examine the cross roads of science, technology, ethics and religion. It is imperative, as technological and scientific research changes the way that we inhabit the world around us, that we explore and identify meaningful ways to create space for ceremony and for engaging with current ethical debates’ [7].

Pursuing these objectives, the festival, through its directorate, its Artists Advisory Committee and teams of professional artists, embarked upon ten Maralinga projects, including performance and visual arts, and featuring both the Aboriginal experience and the experience of other Australian communities [8].

In this context, the Australian Nuclear Veterans Association, with funding from the Australia Council for the Arts, began an oral history and 'verbatim theatre' project in 2003 [9]. The approach involved establishing a research team of academics and theatre workers who conducted taped interviews with surviving veterans, widows of veterans and veterans' children. The focus has remained on Maralinga, although the stories of Monte Bello, Christmas Island or other tests sites are of equal importance [10]. Carefully transcribed, the interviews have become the basis of theatre workshops and ultimately a play script, which in coming years will be performed by major theatre companies, schools and community groups. In 2005 the project broadened to include research, interviews and workshops with British veterans and theatre workers, and to date, public readings have taken place in both Britain and Australia, with seasons of the play planned in both countries for 2006 and beyond [11].

The play, with the working title 'Half a Life', creates a dramatic structure for the performance of stories owned by Australian and British veterans and their families. Interview fragments or 'grabs' are edited together to create monologue or dialogue for actors [12]. The project trades on current interest in forms of documentary theatre made popular in both Britain and Australia, where analysts have remarked on the potential for constructing 'truth' through documentary theatre for a society no longer trusting of government reports, newspaper stories or other forms of 'official' history [13]. In theatrical circles, 'Half a Life' is also cutting edge because it brings together environmental and cultural activity, while contributing to the collection of 'verbatim' plays devised in Britain and Australia over the last decade.

IMPLICATIONS OF ROYAL COMMISSION FINDINGS

Although since 1985 there have been many analyses and public campaigns associated with the atomic tests, the Royal Commission into British Nuclear Testing, presided over by Justice McClelland, remains the most extensive social, political and scientific 'negotiation' to have taken place. The inquiry heard testimony from Australian and British nuclear veterans, and taking also the advice of scientific experts, produced a number of findings relevant to veterans' health. For example, the Royal Commission found that so-called 'safe-firing' protocols were underpinned by the pre-1958 'paradigm' which assumed there were 'safe levels' of radiation dose, prescribed via the concept of a 'permissible weekly dose' (Conclusion 50) [14]. The Commission concluded that, within this paradigm, policies on radiation exposure were 'reasonable and compatible with international recommendations applicable at the time' (Conclusion 51).

However, the Commission found there were serious and minor departures from *compliance* with internationally recognised procedures (Conclusion 52), and that overall many of the tests violated 'safe firing' protocols. The Commission also concluded that the Atomic Weapons Tests Safety Committee (AWTSC) headed by Ernest Titterton [15] had been unwilling and unable to intervene (Conclusion 47). Further, the Commission argued that safety measures taken in the 1950s would be considered inadequate by today's standards, noting that since 1965 radiation protection measures have been based on the assumption that 'any exposure may involve some risk' (Conclusion 53).

Such findings set the scene for an exploration of the health issues now affecting veterans, who were variously deployed in a wide range of tasks associated with the preparation and aftermath of bomb tests. For those men working in forward areas immediately before and after tests, and for personnel observing the explosions, protocols were relatively well delineated [16]. However, the Commission findings imply that relaxation of rules, discipline and protocols in the weeks and months *between* tests created an uncontrolled experiment into the effects on servicemen working on contaminated land, exposed frequently to dust, with a vast array of equipment, some of which would have been radioactive.

In a finding that continues to frustrate veterans, the Royal Commission concluded that illness, disease or abnormality cannot be unequivocally associated with radiation exposure, except possibly in a case of exposure well above the dose limit (Conclusion 62). The Commissioner went further, stating that 'Their exposure to radiation as participants in the trial program has increased the risk of cancer among nuclear veterans' but that this increased risk cannot be quantified (Conclusions 74, 75); further, there is now little prospect of carrying out any worthwhile epidemiological study of those involved in the tests (Conclusion 201). At the same time, the Commission pointed to serious inadequacies in official reports on human health impacts and other outcomes of the tests. For example, the Commission found that the report by the Australian Ionising Radiation Advisory Council was not an adequate scientific account of the testing program; nor could the Donovan Report [17] be regarded as an adequate epidemiological study of the health of atomic test personnel (Conclusions 195–200).

Since the Commission's report in 1985, there have been attempts to systematically study the health of veterans, there have been new revelations as government documents are made public, and evidence has been brought forward in a number of compensation claims by veterans [18]. Equally systematic has been the defensiveness and counter-argument by government departments in both Britain and Australia. In terms of negotiated public understanding of the tests, the causal link between service at Maralinga and veterans' health problems remains as controversial as it was at the time of the Royal Commission. Because of this, we could say simply that the Maralinga experiments are incomplete: If one purpose of the tests was to assess the behaviour and resilience of men under atomic fire, then the results of that experiment are not yet confirmed.

Indicating other uncertainties, the Royal Commission also found that 'Operation of the need to know principle and the minimal amount of information given to participants has been a factor contributing to participants' concerns and fears regarding what might have resulted from their experience at Maralinga' (Conclusion 132). There has been no systematic assessment of the long term psychological impact of the tests, even though anecdotally it is widely known that many veterans have sought psychiatric counselling [19].

These circumstances – an incomplete scientific testing program and abiding fear and uncertainty amongst veterans – indicate the need for new knowledge, if possible to be constructed through integrated social processes. This is the context for the 'Half a Life' theatre project.

EXAMPLES OF FINDINGS FROM THE ORAL HISTORY AND THEATRE PROJECT

The 'Half a Life' oral history and theatre project parallels and complements work by veterans in both Australia and Britain to understand more completely the impacts of their service at Maralinga and other test sites. Consistent with the Royal Commission findings, 'Half a Life' indicates veterans themselves had little understanding of the overall plan for the tests, and of the exact nature of the scientific experiments involved. Yet veterans and their families have the wherewithal to extend or make new knowledge about their ill health; this is knowledge relevant to overall understanding of the tests. It is knowledge which, if communicated through public processes and through veterans' networks, can address the 'fear of the unknown' that haunts many veterans and their families. Once complete, the play script for 'Half a Life' will report some of this new knowledge about the British nuclear tests at Maralinga. What follows here is a brief and selective summary of findings, drawn from interview transcripts and from the processes of play-making which have involved theatre workers, researchers and veterans.

HIDDEN EXPERIENCE

Secrecy has played an important part in the lives of veterans and their families. Men who have remained silent about their experience at Maralinga have done so because of continuing allegiance to the secrecy agreements they signed at the time of the tests. But for some this has meant their families remained ill informed until serious illness or psychiatric counseling cause details to emerge. Secrecy, when coupled with government inaction, and with the methodological difficulties indicated by the Royal Commission, has delayed for up to fifty years individual attempts to gain compensation; this greatly exacerbates the problem of proving a causal link between illness and radiation exposure. The 'Half a Life' project is one way that previously hidden experience can be consolidated and revealed. In some cases, the interview process itself becomes the means by which knowledge is extended and communicated within the families, as shown in this exchange between Ric Johnstone, President of the Australian Nuclear Veterans Association, and a veteran's widow. The interviewer asks what the widow knew of her husband's job at Maralinga. Ric answers:

Ric (RJ/bb): 'Total response, that's what it's called, yeah. All sorts of things, they have buildings out there, two story buildings, which they built [for testing in the blasts]. They had brick buildings, concrete buildings, prefabricated buildings. They had ah, all sorts of vechicles, trucks, tanks ... aircraft put around at different places. And ah, one thing that most people don't know is, that they had lots of animals too. They had goats and pigs and, and rabbits in cages, they had ah, carrier pigeons. And we had an animal mortuary, where we used to take the animal carcasses back to. That's the sort of thing Reg would have been doing, go out with a truck to bring ah, carcasses back or something, and take them to the mortuary ... Some of em were actually just boxed and sent back to the UK. And then, the next day, they're burned and the ashes are tested for Strontium 90 or Radium 223 or whatever the element might be they're looking for. It was a big deal.'

Bev (BB/rj): 'No he didn't talk much about it.'

Ric (RJ/bb): 'Only to me and, and Lex and the others, when we all got together [in the 1970s] we sort of started talking about it' [20].

HEALTH IMPACTS

Several of the interviews for 'Half a Life' convey details of cancer and other illnesses affecting veterans and their families. For example, the following account is laced through with the humour often found in veterans' testimony, even when describing horrific circumstances.

Ric (RJ/sc25): 'I came back from Maralinga, and got married as you know, and then we came back over to New South Wales ... But I'd been getting these bouts of nausea n' diarrhea n' stuff, and ah, the doctors' at Richmond decided I had radiation poisoning ... So they put me in hospital and put me in a ward on my own, with a verandah outside ... and ah, every now and again, they'd wheel somebody past on the banana cart ... and on this occasion, they wheeled a guy past who was sort-of sitting up ... but, sorta laying down, but in a sorta situp sort-of position, and he looked in and saw me, and I saw him, and waved because I recognized his face, 'cos he was also at Maralinga ... The next, time the doctor came into my room, I said, 'That bloke next door's a mate-o-mine', ah, and I was up, I was able to get up and walk around, so I said, 'I'll go in and say g'day to him, and see him', n' he said 'no ya can't do that, ya can't', and I said, 'well what's he in there for, what's he being treated for?', and ah, the doctor said 'That's all, private information, we can't tell you about our patients'. But the next day the male nurse came in ... and I said, 'What's up with my mate next door there?', n' he said 'Oh he's got a broken leg' ... I said 'Oh really, a broken leg, how did he do that?' He said 'I dunno, fell off a truck or something' ... 'Oh righto' I said, 'Well can I get up and go and see him?' He said 'Oh no, you're not allowed in there' ... and I said 'Oh-alright'. I never, never saw him again and never, what I should-of-done was gone in anyhow, but I didn't ... And a couple of days later, I said 'How's me mate goin' next door?' and they said 'Oh, he died' ... I said 'Died of a broken leg!?' And they said (laughter) 'There were complications.' ... So I think he was there for the same reason I was. But this ah, and this orderly told me later, that he had some sort of blood condition too, which is why I was there, and eventually when they let me out, they said I was lucky because they had blood, leukemia going on. My red cells were eating the white cells or something, was how it was described to me, or the whites were eating the reds, I think, yeah I think the whites were eating the reds ... but I suspect the guy next door ... his bone marrow didn't pick up again ... But my bone marrow had come good, and was starting to regenerate fresh, blood cells, so I survived' [21].

The veterans' testimony also includes descriptions of health impacts suffered by their 'genetically impaired offspring'. The project findings emphasize that even where direct causal links cannot be proved, it is the *fear* that illness may be associated with radiation exposure at Maralinga which plays out prominently in the later part of veterans lives, especially each man's fear that he has imparted genetic defects to his family. A British veteran conveys this alongside his humorous recounting of his accidental exposure to radiation:

Rev John (REVJ6): 'I must be the only Church Minister with a radioactive bum. We were up there one day in the forward area, and it was boiling hot and I'm a 19 year old, at the time. Entirely innocent, this is just a great lark and a holiday. And ah, it was boiling hot and, and the Sergeant said, 'Lets have a break'. So what I did, and two or three others, is that I actually crawled inside the rim of one of our great big lorries, lorries. And so you put your bum here, and your rest, feet rest there and you put your shoulders on a bit of the curve of the inside of the rim of this great lorry. Well of course the lorry had been driving around the forward area and so all the dust is, is hot. And what happens, that transfers, not only through your overalls, this so-called protective layer, but into your bum. And lo and behold for 4 or 5 of us ... and when it came to our bums, ding, ding, ding, ding, they were all clanging cymbals and great, loud noises. And we had to scrub and scrub and scrub, with just ordinary running, running water out of a shower, until the Geiger counter went down sufficient and we were counted to be safe. So this was why I laugh and say, 'The Reverend John Walden, only Minister in the world with a radioactive bum.' I'm quite unique.'

Rev John (REVJ62): 'The other side of the story is, that, last August, I had my first grandchild, from my youngest son. He didn't know it but I was most careful in asking questions about this birth, was she normal, you know, has she got two heads, or fifteen arms or whatever, was she breathing properly, were all the tests done on her ... And she was a perfectly normal baby. He doesn't know why I was asking that, but I was greatly concerned in case there was going to be something wrong with this baby. And until I die I might well have a huge conscience that some form of deformity was passed through my genes' [22].

LIFE BETWEEN THE BLASTS

One of the most important types of testimony emerging from the 'Half a Life' project is the detailed description of camp life between the blasts. Previous public records (films, news stories and even the Royal Commission) have given emphasis to the experience of the men during and immediately after the blasts. Such testimony is certainly important, as the men recall and eloquently recount the sights and sounds of the blasts. But in 'Half a Life', interviews have also explored the daily lives of the men in the long periods of preparation and then clean up associated with the tests. Men were typically assigned for up to nine months, even though bomb tests were clustered within just a few weeks. This meant long periods with minimal work, with the opportunity for exposure to radioactive materials through a wide range of recreational and other 'unofficial' activities. Several examples are contained in this scene titled 'Hot Zones', as follows.

Danny (DM49/51): 'There were weeks, sometimes months, between the bomb tests. You just wandered where the hell you wanted. We were told it was safe.'

Dawn (DC48): 'People think that there was a big fence around everything ...

Danny: 'I can't even remember if, there must have been military police in the camp though, there must have been military police in the camp, I can't actually remember seeing any. It was very, very relaxed security.'

Malcolm (MS13): 'There was equipment left everywhere.'

John (JM11): 'We worked on vehicles, which had been driving around here, there and everywhere, and we worked on them and underneath them, and obviously all the dust and dirt and so on, er, even to the minor thing like changing a wheel, er, y' you were liable to dislodge dirt and dust from under the vehicle.'

Bob (BS29,79): 'Most of the normal dust, they'd never bother with decontamination ...'

Malcolm: 'And the first thing you did after you'd serviced the vehicle was get a shower, and get the ooze off you know.'

Bob (BS50): 'We used to race the ferrets, the ferrets had supposedly been, or dingos rather, scout cars had supposedly been decontaminated. We had a racetrack down in the bush.'

Dawn (DC48): 'For each, each blast, there was something to be built, so you were, you were passing where this one had been built for a previous blast, to build, eh, build the other one. So you were passing where it's been.'

Rick S (RS7,8): 'So we were working in radioa ... in contaminated area.'

Avon (AH25): 'And we were actually working there for a few weeks before we found out there was even a bomb let off there ... But the scientists would often come, used to often come dressed immaculately but with a pair of white rubber boots on, an' no-one took much notice of that, at first, but then it became evident they were takin' precautions not to get their boots contaminated. So they wore them while they were at these sites where they were aware that it was contaminated, but we weren't ... an it made some of us think' [23].

COMMENTARY

The 'Half a Life' playscript is built from material such as the fragments and scenes above [24]. The findings raise some issues of concern to analysts of knowledge formation, science and technology systems. The remainder of this paper provides brief comments on selected well-known themes.

UNRULY TECHNOLOGY

Official accounts of scientific experiments or of the introduction of new technology typically give focus to the intentions of the experiments and to the results as measured against those intentions. The physical dimensions and direct impact of the blasts, the short term effects on structures, equipment, and men in the field – all these were efficiently recorded at Maralinga. Likewise there was an 'orderly' character to field studies of the spread of atmospheric pollution, even though these were not without their controversy [25]. However, the British nuclear testing program has also been an open-ended experiment, with outcomes never anticipated, and ways of measuring those outcomes never foreshadowed.

Bryan Wynne has used the term 'unruly technology' to emphasize the unintended consequences of experiments with science and technology, and to highlight the threat to technical systems that arise from uncontrolled and uncontrollable circumstances [26]. That Maralinga experiments were 'unruly' is made clear by 'Half a Life' participants, in the stories above, and, as a further example, in this testimony from an officer's daughter who was eight when her father served at Maralinga:

Dagmar (DR7): 'Ah yes, ah yes each time he came back [to base near Adelaide], he would be, the ... they um, they suggested that mum put a bunk in the ah the ah bunk bed, in the corner of the kitchen for him and then they put a yellow tape about 3 feet around the whole area and we'd hand him his meals on a tray ... um, and we'd all ... the whole family would all be interviewed by ASIO and the British Officers, yeah and.. just did what they told us um ... they took off rather quickly after they arr took their radioactivity measurements. (DR8) Yes ... and we weren't allowed to approach him, um and we were meant to stay outside the barrier of the tape ... um so he was ah ... probably really as far away as, as ever ... And we weren't allowed to go and play ... so one day he called the dog and the dog ran over to him and um ... ah ... Dad grabbed me when I went for the dog. He grabbed me and just held me' [27].

In this story fragment, the imperatives of family relations intervene in the orderly conduct of science. Making use of Bryan Wynne's terms, these imperatives provide a 'contextualisation' which challenges the universality normally believed (by scientists, by the public) to be the possible and desirable outcome of scientific research. The 'technical system' of a properly conducted atom bomb test is unable to allow for a dog, an eight year old daughter or an emotional man, which break down the integrity of the testing regime in an uncontrolled way. On the other hand, this doesn't mean an understanding of such 'unruly' outcomes is unattainable.

PUBLIC UNDERSTANDING OF SCIENCE, KNOWLEDGE AND TRUST

Briefly surveying the debates about so called 'Public Understanding of Science' over the last fifteen years (and Wynne's analysis sits in this context), we can notice that the idea that science should be undertaken in public has taken deep root [28]. So too has the need to bring alongside science other forms of knowledge, such as 'lay' and 'indigenous' knowledge, and with this to privilege equally *contextualised* knowledge alongside the *universal* knowledge claims of science [29]. In practice, to do this requires sophisticated processes of public participation in knowledge production, and we can look to examples such as science shops and consensus conferences, standing committees of stakeholder experts, and other forms of participatory democracy that attend decision making processes. These have been reasonably well studied across many fields [30]. Taking this further, analysts of controversy and public participation processes have noted the importance of *trust* in all its forms. In his seminal discussion of 'suspended doubt', Gavan McDonell has described the processes by which participants in decision making processes put aside their disagreements and their (sometimes) seemingly incommensurable values and assumptions, in search of the knowledge that is needed to make sense of everyday life. In such processes, which should be allowed to play out over time, provisional trust becomes a pre-condition for knowledge formation [31].

A project such as 'Half a Life' indicates the possibilities for engendering suspended doubt, developing trust, and from this, producing contextualised knowledge. As an example of a Community Cultural Development (CCD) project, 'Half a Life' uses processes which are just as intentional, just as institutionalised, just as governed by set protocols as is the official production of scientific knowledge. CCD is characterised by participatory activities in which community members of various backgrounds and beliefs work with (commonly but not always) professional arts workers, to make creative works that deal with issues and concerns important to the community. Meanwhile these activities enhance that community's capacity to make decisions, take actions and undertake further developmental work. Typical procedures include steering groups, partnerships between organisations, workshops, training sessions, rehearsals, exhibitions, performances, with feedback and cross-checking mechanisms such as trial readings, discussions groups, web-based interaction, surveys, and media documentation [32].

In all such activities, information and ideas circulate in an environment of suspended doubt, often ostensibly for the purpose of making a common creative work. This is how contextualised knowledge is produced. Such ways of making knowledge through arts and cultural projects, and the importance of this for decision making, are increasingly well understood. For example, in the British experience, long range studies have evaluated the feedback loop between cultural activity and government policy across many sectors, with the arts influencing policy through discoveries made in participatory projects [33]. Meanwhile, the interpretations made in this paper are underpinned by a broader study hosted by the Australia Council for the Arts. This research has confirmed the connections between CCD and policy and programs across sectors such as health, environment and rural development [34].

DECISION MAKING WITH CONTEXTUALISED KNOWLEDGE

For the nuclear veterans' associations in both Australia and Britain, 'Half a Life' is a participatory way of telling their story, creating advocacy, improving networking and awareness, and bringing to public attention a new body of oral history material reporting long term social outcomes of the atomic tests. By its process, the 'Half a Life' project is a 'meeting' between the veterans community and a younger generation of researchers, theatre workers and veterans' descendents, all wanting to understand and keep alive the story of nuclear testing, then able through performance to communicate this story to the public and to veterans themselves [35].

The 'Half a Life' project supports 'transformative' cultural activities [36] by which the veterans' situation is recognized and legitimated, fostering a sense of justice and healing, with prospects that both the process and the public outcomes (such as readings, performances, media coverage, and documentation) will have impacts within decision making realms. To be specific, the knowledge generated through the 'Half a Life' process, can assist in the following ways.

1. The project will increase sharing of stories, advice and resources between British and Australian communities of nuclear veterans. Through this, 'bonding social capital' will increase as the project links people inside the community of nuclear veterans in each country. The opportunity to tell their story, first hand, to other interested community members will be validating and rewarding for participants, and this alone can help deal with the residual fears that veterans experience.

2. 'Bridging social capital' will be enhanced by the capacity to communicate the story to new arenas. It will take the message from nuclear veterans into other communities and groups (especially other non-nuclear veteran groups and also young people, academic, and political groups). This will potentially assist with decision making, for example in deliberations about veterans entitlements in the follow up to Australian government's recent Review [37].

A NOTE ON LIMITATIONS OF CONTEXTUALISED KNOWLEDGE

We have to be careful not to suggest communities might generate all the knowledge needed using their traditional methods or community processes such as CCD, and there are subtleties at Maralinga that are important to understand. In a famous incident, Maralinga Tjarutja leader Archie Barton upbraided a government official for saying that the long term problem of recording and monitoring contamination could be left in the hands of traditional people who could understand it through their 'dreaming'. Barton's rejection of this suggestion is based on the need communities have for western science to be *part* of their decision making. Maralinga Tjarutja know that western science does have some uses! Monitoring nuclear radiation is one of them [38].

The same logic applies to the knowledge generated through the nuclear veterans oral history and theatre project. As a community, veterans will make use of the ideas and information generated and circulating in the 'Half a Life' project. But in their approaches to government for compensation, veterans remain hopeful that new techniques could become available for scientifically demonstrating that particular forms of illness *must* have resulted from radiation exposure. Veterans associations in both Britain and Australia continue to work closely with scientists as a way of influencing government policy and achieving recognition and compensation [39].

CONCLUSION

British Nuclear Testing in Australia and New Zealand follows the well mapped contours of colonial science. Bomb experiments were devised at the 'centre' by British scientists requiring remote country which they could devastate in search of results relevant to Britain's Cold War political imperatives. Meanwhile, at the 'periphery', the Australian public and indeed the Australian scientific community remained marginalised, with decisions made on their behalf by British politicians and scientific teams, aided by a most compliant Prime Minister Robert Menzies [40].

Perhaps the historical study of Australian and New Zealand science has also typically followed these contours, with focus on the relationship between 'peripheral' scientists and the perceived 'centre' of knowledge production. The 'Half a Life' project is a different way of constructing a history of a scientific experiment, with focus on a 'peoples history', in this case the experience of nuclear veterans and their families. Beyond this 'meta-science' function, the project also produces knowledge about the impacts of nuclear testing, in a way that helps complete the experiment itself. The 1985 Royal Commission report, a trail of unsuccessful compensation cases, and recent government initiatives such as the Clarke Report into Veterans Entitlements, all point to a deficit in official knowledge about the outcomes of the tests, and to the insurmountable difficulties in making health impact assessments using 'normal' science. The processes of community cultural development constitute a participatory and transformational form of knowledge production, with findings relevant to policy and decision making. In this case the contextualised knowledge made between researchers, theatre workers and veterans helps our understanding of the nuclear testing experience, and of the long term social and health outcomes for men exposed to the dangers of the atomic tests.

REFERENCES AND NOTES

[1] The key British tests were Emu 1953, Monte Bello Island 1956, Christmas Island 1957–58, Malden Island 1957, Maralinga 1956–1957. Details are widely available, for example in the report of the Royal Commission into British Nuclear Tests in Australia, 1985, or on the website of the British Nuclear Test Veterans Association.

[2] The Royal Commission, led by Justice McLelland, recommended, in summary, extension of compensation provisions to cover civilians as well as military personnel, the establishment of a register of civilian and military participants, a new clean-up of the Maralinga site with costs borne by Britain, control of access to the site, and compensation for traditional owners, the Maralinga Tjarutja.

[3] The British and Australian approaches contrast with that of the US government. Under Ronald Reagan, the US Congress voted a form of blanket compensation for veterans of US nuclear tests. In this approach, 22 types of cancer are accepted, on a presumptive basis, as related to the service of atomic test participants. Being there for a test and having the prescribed disease is sufficient for compensation and health care to be provided. This detail is from the Australian Government's 2003 Report of the Review of Veterans' Entitlements (The 'Clarke Report'), accessible at `http://www.veteransreview.gov.au/report`.

[4] Obfuscation and loss of documents by government authorities are commonly reported by veterans, for example see submissions to the Clarke Report (see note 3), which notes that in Australia, of the five compensation cases heard by courts, the Commonwealth won all but one of them.

[5] This paper was first presented at the conference of the Australasian Association for the History, Philosophy and Social Studies of Science, Dunedin, December 2005.

[6] The politics and outcomes of the work by 2002 Adelaide Festival director Peter Sellars and his creative team are controversial. Sellers was effectively sacked shortly before the festival, with his community-based program overturned in part by the Festival's conservative hierarchy.

[7] Peter Sellers, 2002 Adelaide Festival Program overview.

[8] The author was a member of the 2002 Adelaide Festival artists advisory committee.

[9] The author is the facilitator and script editor for the 'Half a Life' project, making this paper an 'insider' perspective.

[10] As I have noted elsewhere 'Ultimately, the choice to focus on Maralinga relates to the need for time and space 'unity' in a dramatic structure. This perhaps indicates one of the limitations of theatre, rather than any sense that Maralinga has greater importance his-

torically than other test sites. However, it can be said that the Maralinga experience is representative of the testimony of other test veterans; and that of all the sites, Maralinga saw the greatest numbers of service personnel across its decade of operations'. See Paul Brown, Maralinga: Theatre from a Place of War, in Gay McAuley (ed.), *Ground Work: Performance and the Politics of Place*, Peter Lang, Berne (2006).

[11] The four public readings, each at a different stage of script development, have been at Sydney's Belvoir Street Theatre on 8 December 2003 and 7 June 2004, at the University of Leeds on 18 November 2005 and at Leeds Civic Hall on 20 November 2005.

[12] A more detailed description of the process for the 'Half a Life' project will be published with the playscript. See P.F. Brown, *Half a Life*, Currency Press, Sydney, in preparation.

[13] The possibility that verbatim theatre is 'truth' is highly contentious. The author has previously discussed verbatim theatre in the context of an earlier oral history and verbatim project concerning the 1989 Newcastle earthquake, suggesting that it is 'a fabrication, just like any other drama spun from a writer's head. Perhaps it will seem like 'the' truth. But it remains only one truth and the construct of a particular process: in this case a terrible event, provoking an idea for a play, interested people to steer the project, then research, taped interviews, transcription, culling, editing, cut and paste, structuring, re-cut and re-paste, and (turning a new corner) exploration by cast, director and crew, new arrangement of the text, production (all the usual elements) and finally the storytelling that takes place in performance ... Each exploration by cast and crew – like an archaeological dig – is bound to make new discoveries.' This extract is from P.F. Brown, *Aftershocks*, Currency Press, Sydney (1993), page vi. For a seminal analysis of verbatim theatre, see Derek Paget, Verbatim theatre: oral history and documentary techniques. *New Theatre Quarterly*, **3**, No. 12 (1987).

[14] The numbered conclusions are from the 1985 Report of the Royal Commission into British Nuclear Tests in Australia, Vol. III, Conclusions and Recommendations, Parliamentary Paper No. 484/1985.

[15] It would not be overstating it to say that the Royal Commission laid a great deal of blame at the feet of Titterton, as the most senior Australian scientist, and clearly a man willing to place safety concerns below the logistical needs of atomic testing.

[16] For example, a special force of 'Indoctrinees' was trained for deployment at close range to the blasts. They were issued with full protective clothing. It was also customary that all personnel on the range would be invited (along with selected members of the public such as politicians, and media), to witness the tests. Protocols included facing away from the blast with hands tightly shielding the eyes.

[17] This report is by Donovan et al., *Health of Atomic Personnel*, Commonwealth Department of Health (1983).

[18] In the 1990s, British researcher Sue Rabbitt Roff assembled data on veterans' health, making use of information from nuclear veterans, and newly released government documents. See S. Rabbitt Roff, Mortality and morbidity of members of the British Nuclear Test Veterans Association and the New Zealand Nuclear Test Veterans Association and their families. *Medicine, Conflict and Survival*, **15**, Supplement 1 (1999). Rabbitt Roff's findings were strongly attacked by the British Government. In Australia, the Commonwealth Government Review of Veterans' Entitlements (the 'Clarke Report', see Note 3) highlighted the need for a new cancer and mortality study, and has established a scientific advisory body to oversee this. One objective is to reconstruct the doses veterans would have received – an approach that has been met with skepticism by veterans themselves.

[19] The veterans associations in both Britain and Australia argue this.

[20] Ric Johnstone and Beverley Beaver interviewed by Paul Brown. Bracketed annotations, e.g., (RJ,bb), indicate fragments or 'grabs' within the original transcript.

[21] Ric Johnstone interviewed by Paul Brown, with veteran's widow Sandy Caporn also present, October 2003.

[22] British veteran, Reverend John Walden interviewed by Lucy Skilbeck and Paul Brown, April 2005.

[23] This extract is from the performance script used for a reading of the play at Leeds Civic Hall on 20 November 2005. It is constructed from interviews with several veterans (Danny McNulty, Rick Soweby, Bob Smith, Malcolm Smedley, Avon Hudson, John MacIntosh), and one of the widows (Dawn Chasty).

[24] For the play script see P.F. Brown, *Half a Life*, Currency Press, Sydney, in preparation. Also see a longer version of this summary in P.F. Brown, Maralinga: theatre from a place of war, in G. McAuley (ed.), *Ground Work: Performance and the Politics of Place*, Peter Lang, Berne (2006).

[25] The story of Hedley Marston and the testing of animals around Australia is replete with controversy. See, among other sources, R. Cross, *Fallout: Hedley Marston and the British Bomb Tests in Australia*, Wakefield Press, Adelaide (2001).

[26] Brian Wynne is a well known sociologist of science. Among several relevant publications, see B. Wynne, Unruly technology: practical rules, impractical discourses and public understanding, *Social Studies of Science*, **18**, 147–67 (1988).

[27] Dagmar Richards interviewed by Paul Brown, Sydney, 2003.

[28] Brian Wynne reviewed this argument, for example, at a Melbourne University conference on Public Understanding of Science, in 2003.

[29] See A. Irwin, *Citizen Science: a Study of People, Expertise and Sustainable Development*, Routledge, London (1995).

[30] See various discussions in the journal *Public Understanding of Science*.

[31] This greatly simplifies McDonell's study, which is in G. McDonell, Scientific and everyday knowledge: trust and the politics of environmental initiatives, *Social Studies of Science*, **27**, 834–835 (1997). Elsewhere I have given more detail of the relevance of McDonell's ideas in the realm of community cultural development and specifically the Maralinga project. See P.L. Brown, Maralinga: theatre from a place of war, in G. McAuley (ed.), *Ground Work: Performance and the Politics of Place*, Peter Lang, Berne (2006).

[32] There is a wide range of literature on Community Cultural Development in Australia. Definitions, policies and case studies are readily available from the Australia Council for the Arts.

[33] See the range of reports produced by the Comedia organisation, for example F. Matarasso, *Use or Ornament? The Social Impact of Participation in the Arts*, Comedia, Stroud (1997).

[34] D. Mills and P. Brown, *Art and Wellbeing*, Australia Council for the Arts, Sydney (2004). The Australia Council is the federal government's arts funding and policy body.

[35] Unpublished Report in 2004 by the Australian Nuclear Veterans Association to the Australia Council on the first stage of the project.

[36] The 'instrumental' uses of the arts are well understood, for example in the way the arts can be used for educational purposes. 'Transformative' arts projects are those with deeper impacts on policy and decision making and can imply the need for change in institutions and other social structures.

[37] Findings of the review are in the 'Clarke Report': see Note 3.

[38] This incident is discussed by Jim Green in his web article *Maralinga: a host of indiscretions, short cuts and cover-ups*. The government official was Geoff Williams who in discussing the problems of long term recordkeeping suggested to a government committee that traditional 'Dreamtime stories' would provide a methodology. He said, 'hopefully, the Aborigines themselves – they have a very good way of keeping records. I think they have records going back beyond our sort of memory, do they not? They have their own way of recording things.' Archie Barton branded his comments 'an insult to the culture ... it's an issue that's been created by white man. How the hell do you get that in

a Dreamtime Story?'

[39] In the case of Joyce Northey, one of a handful of British veteran's widows to gain compensation, the key evidence included a photograph that demonstrated her husband was present in the test zone, and technical evidence that the cancer he died from was highly likely to be the result of radiation exposure. For a concise summary of links between veterans' campaigns and scientific research, see *About Us* on the website of the British Nuclear Test Veterans Association.

[40] The Royal Commission concluded that evidence did not exist to contradict the view that, in agreeing to provide Australian territory for atomic tests, Prime Minister Menzies acted alone, without consulting even the Australian cabinet. See also Anna Binnie's previous paper in this issue.

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Prospects for Enrichment: New Zealand Responses to the Peaceful Atom in the 1950s

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Abstract: The origin of the anti-nuclear movement in New Zealand is discussed. An assessment is made of the impact of the New Zealand Campaign for Nuclear Disarmament on New Zealand politics and foreign policy.

Keywords: Anti-nuclear movement, New Zealand, New Zealand Campaign for Nuclear Disarmament, politics, foreign policy, 'Atoms for Peace'.

INTRODUCTION

This paper forms part of a wider study of the history of anti-nuclear New Zealand before it became famous, its roots if you will, on which the transformations in that nation's identity and foreign policy of the 1970s and 1980s would grow. The heart of that project is the story of a peace group I first researched as a student two decades ago, the New Zealand Campaign for Nuclear Disarmament (NZCND). This country's first exclusively anti-nuclear national organisation, it tried to convert New Zealanders to the disarmament cause in the early 1960s, and was a local manifestation of the second stage of a three-stage global movement. In it, moreover, the influence of scientists was just as significant as it in other Western societies [2], and kept leaping out at me (in the same way that the role of other groups like Christians and mothers did) in the primary sources my study is based on – NZCND records, and reports on New Zealand society and politics sent home by the diplomats of all three Western nuclear powers based there.

In order to appreciate the full significance of NZCND's contribution to the development of New Zealand politics, identity and foreign policy, one must first examine those factors – some obvious, some not – which mitigated against the appeal of the anti-nuclear cause before and when this group appeared. That is where this paper seeks to make a contribution. Its aim is to discuss the influence in this country of President Eisenhower's attempt to calm the rising worldwide 'nuclear fears' of the mid-1950s through his 'Atoms for Peace' initiative. It does not argue that the ensuing excitement over 'the peaceful atom' was the only or even the main factor preventing New Zealand embracing the anti-nuclear cause until the 1970s and 1980s; anti-communism, anti-Japanese sentiment, faith in and friendship towards the two original Western nuclear powers, and a host of factors specific to the arms race itself were more important. Nevertheless, Eisenhower's initiative, in tandem with a coincidental burst of hope that this country might have uranium deposits of its own to exploit, did revive official and popular interest in the peaceful uses of atomic energy, just as it did elsewhere in the world, thereby diverting New Zealanders' attention away from more disturbing nuclear developments. Along the way, it helped New Zealanders come to see the United States as the 'true atomic workshop of the world', and encouraged them to be wowed and not just concerned by its technological might [3].

SCREENS AND WALLS

By the end of 1953, nine years after Hiroshima and Nagasaki, there was still much about nuclear energy that even citizens of democracies did not know, especially in regard to its bellicose applications. From their wartime origins in the Manhattan Project, when the US government cordoned off vast tracts of land in Tennessee and Washington State to build factories that appeared to produce nothing, the vast majority of nuclear weapons-related activities were not for public consumption, in any country. In fact, the opposite was true; so stringently protected did the whole process of preparing for nuclear war become, that even in the democracies, defence labs and test-sites became states-within-states, replete with their own airplanes and nigh-sovereign secrets, and surrounded by guards with orders to shoot-to-kill unauthorised intruders [4]. Within these enclaves, moreover, officers and officials asserted their control to such a degree over scientists that in the US at least the information about the different parts of the bomb-building process was often divided between labs, and withheld from anyone whose political loyalties came to be deemed suspect. This was in sharp contrast to the pre-1939 days when scientists shared their research freely across borders and now neither atomic scientists nor their ideas could travel easily across the new Iron Curtain [5]. In such a context, therefore, information about nuclear tests was especially guarded, if it was divulged at all. Besides the lack of warning Britain gave about its atomic debut described elsewhere in this edition, the Soviets never did announce their atomic breakthrough, and neither President Truman nor the Atomic Energy Commission would say how many tests America conducted in the Pacific in 1951. They did not encourage coverage of its first H-bomb test or convey its 'leap in destructiveness' [6]. Indeed, even some defining facts about the new weapon's dangers – the adverse consequences of explosions, for instance, or the handling of radioactive material in bomb construction – were not merely censored, as occurred after Hiroshima and Nagasaki. With total disregard for the health of its citizens adjoining such sites, they could even be hidden by government lying, as occurred when Washington told hundreds of private companies processing radioactive elements there were no 'special dangers' for their workers, when America's Atomic Energy Commission (AEC) said the danger from its nuclear tests was 'no worse than having a tooth X-rayed', when its Commissioner said America was working on a clean bomb' while enhancing the radioactivity of its existing weapons, and when the residents of St. George, Utah, were given assurances though tests in Nevada 'apparently always plaster[ed]' them with fallout [7].

Important as these physical or propaganda walls to hide their preparations for nuclear combat were, they were not the only means Western nuclear powers employed to head off public concern about what they were up to. A further tactic – indeed, a giant distraction – was to play up the peaceful potential of the atom, thereby tapping into the utopian hopes and genuine scientific excitement that immediately manifested themselves, once the new energy source's power was first revealed in war.

NEW ZEALAND'S FIRST DOMESTIC NUCLEAR STEPS

To understand how this tactic played out in New Zealand though, we first need to consider New Zealanders' prior and autonomous aspirations for the peaceful atom. In telling this story, I will not address the role of Ernest Marsden in shaping those aspirations in any depth, as it features prominently in a companion paper in this issue. Nevertheless, it is impossible to leave Marsden out altogether. Once he was alerted to uranium's military potential in 1943, he not only set the wheels in motion by which this county's scientists became involved in the Manhattan Project, but immediately instructed the government Geological Survey team in December 1943 to see if this element was present in this country in any exploitable amounts. On his return from abroad in June 1944, he set up an atomic energy section within the same section of the DSIR that pioneered this nation's breakthroughs with radar. Within a week of Hiroshima, he was able to announce that small concentrations of uranium were present in a mineral found predominantly on the South Island's West Coast. As he conceded, its recovery was probably not 'economically practicable', at least not with 'old-fashioned methods' [8]. The *New Zealand Herald* later deduced from President Truman's announcement of the Bomb, that the appealing 'possibilities of harnessing atomic energy for peaceable uses', which some had raised, 'can very well be put aside for the time being', for scientists were 'definite that years of work will be needed before the new forces can be brought under control' [9].

When it came to peaceful possibilities of the new energy source, nevertheless, some New Zealanders (like Britons or Americans) could not let facts stand in the way of dreams. Among those who preferred to be inspired by those overseas authorities who instead emphasised 'the great possibilities if energy on the scale represented in the bomb is made available to drive machinery and provide sources of power' were the *Christchurch Press* and the *New Zealand Herald*, who between them passed onto their readers the speculation of the *Manchester Guardian* that 'atomic power may provide energy for exploring the solar system and the universe', pronounced that 'atomic energy might supplement the power from coal, oil and falling water', and noted that New Zealand's Prime Minister in these years, Peter Fraser, 'had taken part in discussions with the British on the possibility of using atomic power' [10]. More importantly though, Marsden, Fraser's deputy Walter Nash, and the *Herald's* editor Leslie Munro, later New Zealand's Ambassador to the United Nations when Atoms for Peace was announced, were interested too. As Munro noted, 'but for a second world war, the labours of physicists . . . might . . . ultimately have borne only peaceful fruit'; for Marsden, the 'discovery of atomic energy' held out hopes as high 'as opening up the vast mineral resources that lie beneath the gigantic icecap of Antarctica' – including uranium [11].

Convinced by its wartime results and peacetime potential, therefore, the Fraser government announced just four days after Nagasaki that it 'would do all in its power to aid the development of atomic power and its application to the best purposes of mankind' [12]. In December 1945, moreover, it backed up this boast by passing an Atomic Energy Bill, which, like its foreign equivalents, gave the Crown a monopoly over the development within its domain of this energy and materials it relied on, and control of research on it. With the DSIR Minister noting that 'no subject was of greater importance to humanity than atomic energy' and hoping that 'within a year or two of receiving sufficient uranium [the DSIR] will be harnessing atomic energy in New Zealand', the Acting Minister of Mines asserted in moving the Bill's second reading that 'this energy is so wrapped up with the development of a country that it cannot be allowed to pass into the control of private interests', and that the West Coast black-sands held 'a fairly high percentage' of the 'radioactive ores we want so badly'. In January 1946, accordingly, the Labour government began discussing the possibility of a nuclear research programme, and in late 1948 Fraser discussed matters to do with an 'atomic pile' with Britain's Defence Minister in late 1948. As Nash announced to the 1948 Labour Conference, 'rather than have a cessation of atomic energy research, the Government was anxious to have it go to the limit. Its only concern was with the use of atomic energy and he hoped that it would never be used for military purposes' [13].

ADVANCES AND CONSTRAINTS

Even so, Fraser had felt a need to warn MPs in his speech supporting the 1945 Bill that 'there might be a race for atomic energy' and that 'prospectors from other countries had been wandering about New Zealand, and had found quantities of uranium without notifying the government'. This can not pass without comment. Fraser's intervention had been prompted by a complaint from an Opposition MP, W.J. Polson, that the Bill's penalties for offenders against its provisions were 'tremendously fierce and savage' [14], which in turn suggests that the new technology's full import was not obvious to everyone. In fact, even Fraser's initial interest in it may have been partly motivated by unrelated issues, as the British politician who first asked him for Manhattan Project scientists was the same person he was negotiating with to renew a vital bulk export contract [15]. Equally, some very real barriers to New Zealand's early nuclear development must be outlined. In the search for uranium, for example, the aforementioned unauthorised survey of New Zealand possibilities (by an American Embassy-linked Union Carbide mining engineer in violation of an Anglo-American deal for Britain to search in its Commonwealth) had proved fruitless, while in 1948 the DSIR itself concluded after Marsden's South Island searches that the percentage of uranium oxide in the region's rocks was too low to make uranium extraction economic and ended its hunt for the sought-after ore. In a setback to the development of local nuclear research, Fraser's government had not taken up a suggestion made to Marsden by Sir John Cockcroft, the director of British reactor projects, that an experimental reactor be constructed with British help in 'this part of the world', even though the Americans were prepared in recognition of their services to allow a limited transfer of atomic know-how to New Zealand and the DSIR scientists whom Marsden had sent to the Manhattan Project had played vital roles in helping Britain build its first experimental reactors in Canada and then at the UK's own subsequent research facility in Harwell. Once Marsden forsook the DSIR for a spell as the government's scientific adviser in London, there was no influential nationally-based champion of a New Zealand research reactor [16].

As Rebecca Priestley's paper in this volume has demonstrated, however, this was not the end of a nuclear New Zealand. The DSIR's annual report had still been 'reasonably hopeful' as late as 1947 that a viable uranium deposit could be found on the West Coast, and five years on an article appeared in a popular British monthly (which the US Secretary of State had his Wellington Embassy investigate) claiming that 'the greatest uranium fields in the world' had been 'found in New Zealand and that production will begin soon' [17]. As for nuclear research, the flamboyant Gordon Watson-Munro, one of New Zealand's Manhattan Project scientists, had given an inaugural lecture as the new Professor of Physics at Victoria University College on the peacetime uses of atomic energy that focussed on thermonuclear possibilities (before he was enticed to Australia). The research team was set up and the DSIR had announced 'the erection of an atomic pile' for the use of scientists and medical researchers. In terms of applying nuclear knowledge, radionuclides were used in animal research tracer studies in 1946, for clinical purposes in Christchurch hospital in 1948 and in industrial radiography from the early 1950s, while two scientists, G. Page and Gordon Fergusson, who continued to work in the Dominion Physical Laboratory in Lower Hutt, and a dynamic counterpart, Athol Rafter in the Dominion Laboratory in Wellington, were undertaking and disseminating valuable applied research on such uses of isotopes in medicine, industry, agriculture and geochemistry. In fact, putting to good use both his graduate training in the US and the assistance he secured from the US developer of radiocarbon dating techniques, Rafter would ultimately develop applications for isotopes of such 'international interest and significance' that he would be invited by the original pioneer of those techniques, W.F. Libby, to participate in 'Project Sunshine', a late 1950s U.S. Atomic Energy Commission programme monitoring the dramatically rising levels of atmospheric radioactivity unleashed by the era's many thermonuclear bomb tests [18].

However, As Ross Galbraith and other have argued, the full flowering of nuclear research in New Zeland remained impeded throughout much of the 1950s by the fact that the new laboratory Rafter proposed in 1952 for such research would not be built for another decade, and by the cost of creating a national nuclear institute, the way in which the siting of it became a political football (as universities pressed the need for pure over applied research, and their competing cases to build any new facilities on their own campuses), the failure to arrange a framework for 'exchanges of information on defence science between the United States and New Zealand', officials' view as late as 1958 that atomic power production was not yet economically viable, and that New Zealand could not 'afford to gamble with the supply of power by considering the building of atomic power stations in the immediate future' [19]. Furthermore, the popular image of scientists in New Zealand was somewhat ambiguous, which did not help scientists' efforts to pitch for research resources [20]. Even so, by the end of that decade, and no matter how 'sluggishly', a Division of Nuclear Sciences had been established within the DSIR, a £8,917 grant had been given to the International Atomic Energy Agency to keep New Zealand 'up to date in the field of atomic energy', and the country was ready to work with the Americans to take nuclear research to a new level. In fact, it had already received its first Atoms for Peace gift from them, a technical library on the uses of atomic energy that Sid Holland lauded before Parliament in mid-1955, and signed a bilateral agreement in June 1956 for 'Cooperation . . . concerning civil uses of atomic energy' [21].

THE RATIONALE BEHIND ATOMS FOR PEACE

How though had the possibility of Atoms for Peace gifts come about in the first place? To answer that question, we need to discuss that programme and the President who announced it. Long seen as amiable and popular but more interested in golf than his job, Eisenhower has come to be reassessed as a subtle, engaged, and publicity-savvy Commander-in-Chief, who took a vital interest not just in his country's national security, but in how nuclear weapons affected that security, and what American voters thought of those weapons [22]. As scholars are now arguing, Eisenhower and his advisers believed not in reducing the West's reliance on nuclear weapons but in increasing it. To him, such weapons signalled Cold War resolve, were cheaper than keeping men in uniform, the 'best guarantee against the eruption of a global conflagration' and a 'source of strength in dealing with the Soviet Union; rather than being eliminated, they should become the 'central plank of US national security policy'. As a military man, the President believed they would be used in a future war, and also that, just as arms did not cause war, disarmament could not prevent it. Only elimination of the causes of war (in his eyes, a revolutionary change in the Communist system) could do that. While Eisenhower was in the White House, though most New Zealanders, Americans and other Westerners and their governments thought otherwise on account of his deliberate sops to their fears, American disarmament proposals would at best be confidence-building measures, at worst mirages [23].

For a brief moment early in his first term, Eisenhower did consider telling his people what the full consequences of a nuclear war would be, so as to prepare them for one should it break out [24]. After concluding this might unleash hysteria, the rest of his eight years in the White House were marked by a series of steps to portray American nuclear policy both at home and abroad in more favourable, peace-seeking terms. Years after this ex-Supreme Commander of Allied forces in World War II (and NATO forces thereafter) said of Hiroshima 'it wasn't necessary to hit them with that awful thing', years before his oft-quoted lament on leaving office at the growth of his country's military-industrial complex, and even as his nation continued to prepare for nuclear war, the popular President reassured his public that 'these armaments do not reflect the way we want to live; they merely reflect the way, under present conditions, we have to live' [25]. Contrary to his own budget-balancing instincts and belief that 'Americans recoil by nature from the idea of "propaganda" ', Eisenhower approved a 50 percent increase in the funding of the United States Information Agency to help it study foreign attitudes to the Bomb and counter the previously unchallenged Soviet peace campaign overseas, and sanctioned an AEC campaign at home which told Americans that nuclear dangers were not as great as often made out [26]. More dramatically, he launched two appeals at the United Nations that seemed to convey a deep personal wish for disarmament, the 'Atoms for Peace' proposal of December 1953, and its 'Open Skies' successor in May 1955.

The most successful of all Eisenhower's efforts to 'overcome' his country's already prevalent reputation in New Zealand and other countriess 'as a nuclear bully' and to 'convince the people in the world that we are working for peace and not trying to blow them to kingdom come with our atom and thermonuclear bombs', Atoms for Peace was premised on a simple idea. This was that the two rival superpowers and Britain hand some of the radioactive materials they used to make nuclear weapons over to a new, UN-supervised International Atomic Energy Agency, which would make those materials available to other countries in the world for research and other peaceful purposes [27]. Prior to this offer, progress on most non-military utilisations of nuclear energy had stalled around the world, as post-Hiroshima dreams of atomic utopias had came up against the technical barriers in the way of producing nuclear power cheaply and against many governments' monopolisation of the technology involved and the total priority nuclear weapon states gave to research that developed bombs over that which led to power production or other uses [28]. Before 1953, admittedly, the medical applications of radioactive isotopes already noted in the New Zealand context above had been recognised. Groups like Britain's Atomic Scientists' Association, the AEC and two major US corporations had tried to keep public interest in the potential of nuclear power alive through exhibits like the 1947–48 'Atomic Train', which 146,000 people saw and 53,000 people read about, despite government hostility in England, and which UNESCO sent to Scandinavia and the Middle East. The 1948 'Man and the Atom' exhibit in New York's Central Park toured other American cities [29]. It took Atoms for Peace, nevertheless, to restore global excitement about the peaceful possibilities of the new energy source, for only it linked such possibilities to the need to make what Ike described to Churchill as 'even the tiniest of starts' in opening a hitherto-shut 'door of world-wide discussion' on humanity's nuclear future [30].

THE INITIATIVE'S AMERICAN AND OVERSEAS IMPACT

In the US, in keeping with Eisenhower's broad approach to national security, which embraced the nation's economic health and historic principles as much as its diplomacy and military defence, Atoms for Peace had deep repercussions, as the President connected it to his push to make nuclear power production commercially viable by unleashing 'the genius and enterprise of American business'. Soon afterward, in 1955, albeit through the will of a naval officer rather than that genius, the United States launched the world's first nuclear-powered submarine, the *Nautilus*, and became home to the world's first fully commercial electricity-producing reactors. In engineering terms, the AEC was emboldened to champion its 'Project Plowshare', which claimed harbours and canals could be built using controlled nuclear explosions. In the cultural field the peaceful potential of atomic energy was lauded anew by Walt Disney in *Our Friend the Atom*, the 1957 cartoon that showed in schools and on television 'how a menacing giant was turned into a faithful servant', and in the 1967 *How and Why Wonder Book of Atomic Energy*, which acknowledged that the atomic age had begun in deadly fashion but sought all the same to take the young 'science-minded reader along the exciting road of discovery about the atom that led to the first use of atomic energy in a controlled way' [31].

Beyond America's borders, the consequences were no less significant. Because it saw the clear propaganda potential of this 'Atomic Marshall Plan', and how through it 'atomic energy, which has become the foremost symbol of man's inventive capacities, could also become the symbol of a strong but peaceful and purposeful America', the USIA went into overdrive to popularise Atoms for Peace, placing celebratory articles and multi-media exhibits on it throughout the non-communist world. In response to their efforts, the targets of the propaganda did line up to access the American offer and sign individual bilateral Atoms for Peace agreements with Washington that helped America 'consolidate friendly relationships with countries sympathetic to US economic and foreign policy interests' [32].

COINCIDENTAL CATALYSTS IN NEW ZEALAND

One of them was New Zealand. We must also acknowledge that two other prompts appeared independently of Eisenhower's initiative in the mid-1950s to reinvigorate attention to the uses of radioactive elements. The first was only fully known by a select few officials, the expensive studies New Zealand undertook in response to a British request to examine the feasibility of using the North Island's geothermal energy belt to produce heavy water for Britain's new H-bomb programme as well as electricity for local use. But the other was much more public. This was the news that the West Coast's uranium deposits might be rich enough after all to justify the huge cost of mining them, and give a mineral-poor country a potential new energy source and form of foreign exchange.

In one of the better-known vignettes of New Zealand's early nuclear history, two elderly prospectors had ventured their luck in the Buller Gorge in 1955 and come upon a seam of uranium ore with enough of the right isotope to spark not just 'a rush to buy Geiger counters', 'considerable amateur prospecting' and 'a rash of other discoveries', but renewed official interest in the region's radioactive potential as well [33]. In one expression of this interest, which lasted the rest of the decade, the Director of the Geological Survey reiterated that the prospectors' discovery was not commercially viable, but only in the context of a report that said it gave 'a valuable lead as to places where prospecting might have a favourable outcome'. In a second manifestation of it, and 'in response to the widespread interest in uranium prospecting', he re-issued a 1954 report on 'Prospecting for Radioactive Minerals in New Zealand' (the two prospectors had used it), which said it was 'worth the attempt to find out whether radioactive minerals occur in quantity in New Zealand', and told the US Embassy that 'a good commercial proposition is considered probable' [34].

For its part, and prompted by its backbenchers, who lauded the 'near-'miraculous' 'rise in importance of these radioactive minerals in the last decade', the way 'large deposits could be vital to a country's future', and how 'we need not fear for the future of the Commonwealth in the matter of the possession of nuclear weapons by other countries' should 'extensive deposits' be found there and in Canada and Australia, the response of the country's then-National government went well beyond seizing the public relations opportunity of having its Prime Minister Sid Holland photographed holding a Geiger counter. It tried to stimulate more prospecting for radioactive ores in 1956 and 1957 by introducing an Atomic Energy Amendment Act to make the rewards for finds more lucrative and by building a new road in the region to help a Nelson company prospect. Similarly, Labour politicians showed an interest in the uranium fields as well. On the one hand, some of that party's MPs complained that the surveying of potential ore sites 'had been made on a piecemeal and haphazard basis', that the new incentives for prospecting were still insufficient, and that the government 'had not done enough to encourage the finding of uranium'. On the other, the local Labour member said the area's proximity to a railway and settled community meant that 'never yet ... has a prospecting area been located in such favourable conditions'. When it became the government again in 1957, indeed, Labour based a geologist in the region 'to search for radioactive materials', and amended the law again so as to better negotiate the use of any deposits that were found with the UK Atomic Energy Authority (which sent visitors to the field back in 1957 who now told Wellington and London that 'the outlook for uranium discovery was very good') [35].

NEW ZEALANDERS AND ATOMS FOR PEACE

As important as these real and potential mineral discoveries were, and as important as New Zealanders' ongoing pride and interest in the 'strides' British sources were telling them Britain was making 'in developing power from atomic sources' was too [36], President Eisenhower's 'epoch-making' speech had a impact upon New Zealand's early attitudes towards nuclear power. Within a year of his speech a group of American congressmen had come to see geothermal sites and to extol the peaceful uses of nuclear energy. At the UN, now-Ambassador Munro welcomed the 'generous spirit' behind the President's 'eloquent plea' and the accompanying call from Secretary Dulles to make 'this new force a tool of humanitarianism and statesmanship, and not merely a fearsome addition to the arsenal of war'. Not only was there now new hope that scientists 'from even the smallest countries, which may have little to offer by way of raw materials or industrial energy, may make vital contributions' as Rutherford had once done, the ambassador suggested that if 'real cooperation and understanding can be built up in a joint international enterprise devoted to the development of peaceful uses of atomic energy, need we doubt the possibility of diverting all fissile material from destructive to beneficent ends?' [37]. The American Embassy observed that Ike's appeal and the 1955 Atoms for Peace conference in Geneva that followed it each received 'unusually full coverage by the New Zealand Press Association', and that editors were 'enthusiastic' about his 'sincere', 'bold-sighted' and 'constructive' proposal [38]. More notably, an interest in building power-generating reactors i sprang forth overnight after that Geneva conference, when the US offered to sell research reactors at half-price to willing partners.

Typically, Marsden was the first to react, urging the training in universities of nuclear physicists and engineers 'in view of [the] possible establishment of atomic power stations in [the] North Island within 10 years'. On more than one occasion, the head of the DSIR said nuclear power could be a solution to the North Island's anticipated need (even when geothermal energy was factored into the equation) for more power by the mid-1960s, while in Parliament the Labour Opposition asked National ministers to respond to calls from its officials and an Auckland physics professor, Percy Burbidge, to look into Britain's purported advances in the provision of nuclear energy for power and plan nuclear reactors. Throughout 1955 and 1956, Labour MPs seemed oblivious to their rejection when they were in government in the 1940s of Marsden's suggestion that a research reactor be built, and keen (like the editors of the *Here & Now* journal further to their left) to rush New Zealand into a nuclear-powered future. In fact, they accused their National opponents of being too tied to hydro-electric and coal-station interests and afraid to act in the matter without British sanction or Australian precedents [39]. As for those rivals occupying the Treasury benches, even they were not as hostile to nuclear power as they sometimes made out. The Minister in Charge of the State Hydro-Electric Department said that New Zealand had a 'vastly different' set of energy sources available to it than Britain. The Minister of Mines and one of the party's new MPs argued that New Zealand would not be in the age of atomic energy in ten years' time and that 'it was possible to overestimate the immediate benefits to be derive from atomic energy'. Prime Minister Holland never made one government department ultimately responsible for considering the adoption of nuclear power and no plans for a nuclear power station entered the country's formal plan for its energy future until 1964 [40]. Nevertheless, the National government should not have been accused of failing to consider the nation's atomic prospects. After all, it did send Marsden and the State Hydro-Electric Department's Chief Engineer to overseas conferences on nuclear power, and on the latter's return establish a Committee to make recommendations to it on 'the implications for New Zealand on the development of the peaceful uses of atomic energy'. Importantly, like the Labour government that succeeded it, it was willing to explore Atoms for Peace deals with the US to assist the preliminary task of boosting the nation's atomic research capacity [41].

AGREEMENTS AND CONSEQUENCES

Like a parallel deal Washington signed with Canberra the same month, the June 1956 deal between New Zealand's National government and the United States was 'more far-reaching than any except those concluded with Britain and Canada'. In addition, whereas many countries simply rushed to buy the half-price US-built research reactors Washington was offering in association with such arrangements, New Zealand's use of this agreement was more considered. As a consequence of the deal, New Zealand received enriched uranium from the Americans that could have been used for a research reactor. In 1958 the new Labour government led by Nash hosted a sales delegation from the US Atomic Energy Commission, which told the press 'the offer of assistance in obtaining a reactor' was 'still good' and of the 'various types of assistance' that were 'fair game' for New Zealand to choose from. In 1960, similarly, it succumbed to the urgings of the American Embassy and was about to apply for a subsidised one (instead of buying a British model) before its application had to be withdrawn (to Foreign Affairs' pique) when an embarrassed State Department said US Senators had come to consider developed countries like New Zealand quite capable of paying the whole cost [42]. Even so, there was always a range of opinion, scientific as well as political, and even within the DSIR, that argued New Zealand had no need for a small research reactor that would only reproduce a little of what had already been done overseas when its links to the mother country ensured it would receive the fruits of British research. Tto those critics, a series of smaller pieces of equipment that would enhance the pure and applied research already being done that would lead to original results would be far more useful [43]. In the end, it was their views that won the day. When the US gave New Zealand a grant in March 1960 it was 'for procuring equipment and materials for nuclear research and training', and when £110,000 of Atoms for Peace gifts did arrive in 1961 and 1962, they did so as mass spectrometers, a pulse analyser, a differential thermal analysis apparatus and other smaller items that boosted the industrial, environmental and isotope-related work of the Institute of Nuclear Sciences that was finally created in Lower Hutt, and as other equipment for university radiochemistry and physics labs [44].

From the American point of view the money was well spent. In fulfilment of the original propaganda aims of the Atoms for Peace programme, the US Ambassador was told, on his visit to the University of Auckland in 1961 to see the gifts the USAEC had given that institution and the laboratory created for them (and named after an American nuclear physicist), of its Vice-Chancellor's 'very deep appreciation', and noted himself that 'the professors, students, and members of the executive Council were happy, enthusiastic, and generally grateful'. Beyond the recipients' predictable pleasure at receiving good equipment, the broader political advantages of the deal were clear. Aside from the 'essential boost' it gave to the New Zealand entities working to develop nuclear research – Canterbury University received a sub-critical reactor too – and the opportunity it afforded the Ambassador to put his country's nuclear intentions in the best possible light and have his remarks reported in the press, New Zealanders' reception of these gifts showed they could be wowed when their superpower ally showed them its technological might. Indeed, a recognition even grew among them that America and not their beloved Britain was the global centre of intellectual progress and true 'atomic workshop of the world' [45].

As one sign of that recognition, the rising Labour MP Michael Moohan was very impressed with his visit to the Oak Ridge plant during his all-expenses paid 1956 trip to the US. As another, the executive secretary of New Zealand's Atomic Energy Committee appreciated the information its US equivalent gave it on nuclear-related training courses available in the USA. Even so, the most suggestive indication of the broad appeal of the peaceful atom appears to have come in 1960, when Aucklanders and Wellingtonians flocked to their ports in their thousands in welcome when the *USS Halibut* underlined the ANZUS defence relationship by making the first visit by a nuclear submarine to this country's ports [46]. To them, the *Halibut* was no 'death ship', as its successors would be tagged by late 1970s and early 1980s protesters. On the contrary, it was a symbol of progress and its capacity to travel the oceans was a vivid and attractive manifestation of the possibilities, not the fears, that New Zealanders again hoped the atom could foster.

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Thesis Abstract: An Early Carboniferous Fossil Assemblage from Fish Hill, Mansfield Basin, Australia

JILLIAN M. GARVEY

Abstract of a Thesis submitted for the Degree of Doctor of Philosophy,
La Trobe University, Victoria, 2005

This thesis investigates the vertebrate taphonomy, micro- and macrofossil fauna, trace fossils, and the depositional environment of an Early Carboniferous (Tournaisian, approximately 350 mya) fossil fish locality, 'Fish Hill', in the Hearns Mudstone Member of the Snowy Plains Formation (previously known as the Devil's Plain Formation), Mansfield Basin, Australia. While vertebrate material has been known from the region since the late 1800s, the origin and distribution of this material was not clear. To evaluate the taphonomic history and search for new fossil material, three field seasons between 2000 and 2003 were conducted. During that time the original quarries from the 1880s were systematically re-opened and taphonomically surveyed. In addition, new quarries were excavated to provide access to the entire stratigraphic sequence, allowing the depositional environment to be deduced. This extended the work done during the late 1800s as it studied each horizon on Fish Hill separately, rather than considering it to be a single locality. Twenty-one vertebrate fossil assemblages (VFAs) were recorded, each representing a different depositional event. Three taphonomic pathways were found to have been responsible for these VFAs, with autochthonous, parautochthonous and allochthonous assemblages identified.

Geological investigations of the locality extended work commenced by Sweet during the 1880s, finding that the beds were deposited by a large meandering river system. Three facies within this system were identified: the main river channel, the sand-sheet or crevasse splay, and floodplain environments. Fossiliferous material was recovered from all environments. The absence of tetrapods from this palaeocommunity is interesting. Comparison of the Fish Hill locality to those with or without tetrapods found no environmental or ecological reasons for their absence. The original argument that the Mansfield Basin was too cold for tetrapods during the Early Carboniferous, the idea that they may have evolved more towards terrestriality than previously thought, or that their absence is a result of taphonomic or sampling basis, all seem possible.

Based on the data presented here, the Fish Hill assemblage is interpreted to represent a pocket of endemic fish that share close affinities with Late Devonian faunas from Gondwana. This community may then have become extinct, as there is no fossil evidence of a similar community in southeast Australia after the Early Tournaisian. The relative difficulty in determining the phylogenetic position of the individual taxa from Fish Hill has been impaired by the establishment, on the basis of incomplete material, of several new genera endemic to the Mansfield Basin. Not until more fossil material is collected can this problem be resolved.

This thesis also provides a new interpretation of the pectoral fin and vertebral column of the rhizodontid *Barameda decipiens*. This increases knowledge of the morphology of the fin in the Rhizodontida. New information from an X-ray and improved casts indicates that the fin is typical of other Carboniferous rhizodontids, branching out into a broad paddle shaped fin. This re-interpretation also provides new information on the vertebral column of *Barameda*. Descriptions of three partially articulated vertebrate fossils identified during this research are discussed. These specimens provide further information on the endemic taxa *Gyracanthides murrayi*, *Delatitia breviceps* and *Barameda decipiens*. Also discussed is a new fossil locality

in the Snowy Plains Formation which predominately consists of *G. murrayi* spines.

During fieldwork all ichnofossils were recorded and calcareous material collected to sample for vertebrate microfossils. This resulted in trace fossils and chondrichthyians from Fish Hill being formally described for the first time. This information greatly extends the faunal information of the Snowy Plains Formation.

The information presented in this thesis indicates how important it is to consider all aspects: invertebrate, vertebrate macro- and microfossils, and ichnotaxa, when studying and reconstructing Late Palaeozoic environments. The Fish Hill fauna is significant, as it is the earliest known freshwater (non-marine) fauna from the Carboniferous. It is also the only Carboniferous material from southeast Australia.

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Thesis Abstract: Impacts of Environmental Weed Invasion on Arthropod Biodiversity and Associated Community Structure and Processes

CLAIRE J. STEPHENS

Abstract of a Thesis submitted for the Degree of Doctor of Philosophy,
University of Adelaide, Adelaide, South Australia, 2005

Invasive exotic species frequently change natural patterns of biodiversity. This study investigated the effects of one of Australia's most serious environmental weeds, bridal creeper (Asparagus asparagoides), in remnant eucalypt woodland in South Australia. Research considered the impact of bridal creeper on different taxa and trophic groups (plants, arthropods and parasitic Hymenoptera), high-level (orders and families) and low-level (species) taxonomic assemblages, and ecological processes (parasitism and pollination). The impact of bridal creeper on the native plant community was overwhelmingly detrimental, undoubtedly due to direct interactions with the weed such as shading and root competition. It was predicted therefore, that the replacement of a species-rich and open ground-cover by a closed homogenous one would have flow-on effects to other biota in the habitat.

Despite the significantly adverse impact on the native plant community, a very abundant and diverse arthropod and wasp community occurred in bridal creeper invaded habitat. There was some evidence, however, that the weed was not providing seasonally equivalent habitat to that of native vegetation for several herbivorous and nectar-feeding groups. Invaded areas were also being used for the reproduction and development of a diverse range of parasitic wasps and their hosts. However, the homogenous habitat produced by bridal creeper compared with native vegetation was reflected in the composition of the wasp assemblages in invaded areas. Wasp functional group analysis based on host niche associations revealed the mobility and multi-habitat use of parasitic wasps and, presumably, their hosts. The collection from foliage of parasitoids of litter-associated arthropods and, in the absence of herbivores, the presence of parasitoids of plant-associated insects on bridal creeper, showed that many species used different habitat for juvenile development compared with that used by adults. The indirect effect of higher levels of leaf litter associated with bridal creeper invasion also resulted in greater numbers of litter-associated arthropods and their parasitoids and, in particular, the extreme abundance of one soil and litter parasitoid species which dominated the wasp assemblage that emerged from invaded habitat. Finally, the highly specific interaction between an orchid and its pollinator was not impacted upon by the presence of bridal creeper, and may have even been enhanced due the increase in the numbers of its soil/litter-associated pollinator in weed-invaded areas. Consequently, the ground-cover plant community that was so completely altered by bridal creeper was not as important as other components of the woodland habitat, such as the soil, leaf litter and canopy microhabitats, for the reproduction and development of the majority of arthropod taxa recorded.

The contrasting results for plant and arthropod diversity found in this study indicate that a plant community may always be negatively impacted by a successful weed due to direct interactions among plant species, such as competition, that in turn reduce growth and fecundity. However, the impact of weed invasion on native fauna can be more complex. Direct (e.g., provision of resources such as habitat) and indirect (e.g., via increased leaf litter) interactions with the weed, species mobility, and multiple habitat use can influence the structure and composition of faunal communities. These findings are important not only for considering the effects of weed invasion on native biota, but also other disruptions where habitat structure and complexity, rather than simply plant diversity per se, are modified via changes in the plant community. This research has also highlighted the value of considering multi-species assemblages whose members comprise wide ranging taxonomic, trophic and ecological classifications to investigate the impacts of habitat change.

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Thesis Abstract: Pacing Strategy and High-intensity Cycling Performance

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Abstract of a Thesis submitted for the Degree of Doctor of Philosophy,
University of Melbourne, Victoria, Australia 2006

Background and Aims

The importance of pacing strategy (i.e. tactics) during short-term (2 – 6 min) exercise is well recognised. Pacing research is, however, scarce and largely inconclusive due to non-significant results, small sample sizes, poor experimental control and / or inappropriate statistical analyses. The current thesis evaluated the variability of repeat performances using different pacing conditions, and whether different pacing conditions significantly affect performance and markers of aerobic and anaerobic energy supply during high-intensity exercise.

Experimental Model

Endurance-trained cyclists performed cycle-ergometer time-trials using different pacing conditions during the first quarter of exercise. The power output during the first quarter of the fast-, even- and slow-start time-trials was fixed such that each subject would complete the first quarter of total work (104.6 ± 13.5 kJ) in 60 s, 75 s and 90 s respectively. The sprint-start protocol simulated a 15-second maximal starting effort, followed by even-pacing for the remainder of the first minute. After the first quarter of work, subjects were instructed to complete the remaining three-quarters of total work in the shortest possible time.

Results

The coefficient of variation (CV), for the 18 subjects who completed three fast-, even-, and slow-start time-trials was 2.4%, 2.6% and 2.0% respectively. There was no main effect for trial number on time-trial performance across these three pacing conditions. The CV for a second cohort of eight subjects performing two fast- and sprint-start time-trials was 1.4% and 1.5% respectively. Finishing time in the second trial (4:50 ± 0:08 min:s), averaged across fast- and sprint-start time-trials was 3.6 ± 3.9 s faster ($P < 0.05$) than recorded in trial one (4:54 ± 0:06 min:s).

Fast-start time-trial finishing time (4:53 ± 0:11 min:s) was 10.7 ± 12.6 s and 15.6 ± 11.4 s faster ($P < 0.05$) than in the even- (5:04 ± 0:11 min:s) and slow-start (5:09 ± 0:11 min:s) time-trials for the twenty-six cyclists tested. Physiological measurements taken in twelve of these cyclists revealed that mean oxygen uptake (VO_2) for the fast-start time-trial (4.3 ± 0.5 L·min^{-1}) was 184 ± 180 mL·min^{-1} and 197 ± 299 mL·min^{-1} higher ($P < 0.05$) than when these cyclists used the even- (4.1 ± 0.5 L·min^{-1}) and slow-start (4.1 ± 0.5 L·min^{-1}) conditions. Markers of anaerobic energy supply (accumulated oxygen deficit (AOD), blood lactate and pH) were not significantly different between pacing conditions. The percentage increase in mean performance and mean VO_2 using the fast-start condition was not significantly correlated.

Sprint-start finishing time (4:48 ± 0:08 min:s) was 2.7 ± 1.7 s faster ($P < 0.05$) than in the fast-start time-trials (4:51 ± 0:08 min:s) for the eight cyclists tested. The difference in finishing time occurred despite no difference (by design) in first quarter split-time between the pacing conditions. No differences in mean VO_2 or AOD were identified between the pacing conditions. First quarter VO_2 during the sprint-start trial (3.4 ± 0.4 L·min^{-1}) was 255 ± 211 mL·min^{-1} higher ($P < 0.05$) than during the fast-start trial (3.1 ± 0.4 L·min^{-1}). Following removal of an outlier, the percentage increase in first quarter VO_2 was significantly correlated ($r = 0.83$, $P < 0.05$) with the relative difference in finishing time.

Conclusion

The major findings of this thesis demonstrate that a brief sprint-start followed by even-pacing is a superior strategy to fast-, even-, and slow-start pacing for $\sim$ 5-minute cycling performance. The overall supremacy of the sprint-start condition may be mediated by an accelerated aerobic energy supply early in exercise which could contribute to a higher power output throughout exercise. In the field, a brief maximal starting effort could also minimise the time spent accelerating up to racing speed, enabling the athlete to spend a greater proportion of the race at their optimal speed, leading to a faster finishing time. Finally, to detect the small but, important changes in performance due to pacing, researchers may need to test multiple trials per pacing condition.

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Annual Report of Council

For the year ended 31st March 2006

PATRONS

The Council expresses its gratitude for their support to our joint patrons, the Governor General, His Excellency, Major General Michael Jefffrey and to Her Excellency Professor Marie Bashir, Governor of the State of NSW.

MEETINGS

Ten Council meetings were held monthly at the Society's Offices at 121 Darlington Rd, Darlington Campus, Sydney University, in addition to subcommittees. A full day future planning meeting was held at St Pauls College. Thanks to John Hardie and Jim Franklin.

Our monthly lectures, at the Darlington Centre, were well attended and many members of the audiences joined the speaker for dinner afterwards, an innovation which has proved popular with both the speakers and the members and guests who came to dinner. A full lecture program for the year was printed and distributed early in the year. The speakers list was:

February, Dr Ann Moyle
Scientific Correspondence of W.B. Clarke

April, Karina Kelly
100 years after Einstein's Extraordinary Year

May, Dr Charlie Lineweaver
Biocosmology: a New Science

June, Prof. Dan Potts
Bactrian Camels in Antiquity

July, Prof. Lesley Rogers
Why did the Vertebrate Brain become Lateralized

August, Dr Alan Wilton
Tails of Dingoes: their Past and their Future

September, Prof. Pat Vickers-Rich
TB: a New Vaccine and the Influence of Genetics

November, Dr Sheila van Holst Pellekaan
DNA studies in Human Evolution

ROYAL SOCIETIES OF AUSTRALIA MEETING

The second such meeting, the first was in Sydney, was held in Melbourne hosted by the Royal Society of Victoria. Matters of mutual interest were discussed and some progress made towards the formation of an umbrella group to support the aims of all the state societies at a national level. A reception was given by the State Governor of Victoria, His Excellency John Landy, at Government House. The next such meeting will be held in Hobart in 2006.

LIBRARY & HERITAGE GRANT

A part of our library, which has languished in boxes for years, has been unpacked, sorted and shelved at our new Darlington Rd premises where they are available to members and approved visitors. Hard and skilful work by a small group led by Robyn Stutchbury has gained us a Federal Heritage Grant. John Hardie accepted the grant on our behalf at a ceremony in Canberra and attended a conservation workshop there. Grant funds enabled us to employ consultant historians Peter Tyler and David Branagan to investigate the significance of our collection of books, medals, drawings and other items. The initial results are very impressive and indicate we have a unique collection of scientific and cultural history going back to colonial times.

Acquisition of journals by gift and exchange has continued during the year. Exchange material from overseas sources has been forwarded to the Dixson Library, University of New England in Armidale where it is available locally or on inter-library loan. Council thanks the staff of the Dixson Library for their continuing maintenance of the foreign journal portion of the Society's Collection.

ANNUAL DINNER

The Annual Dinner was held at the Forum Restaurant University of Sydney on Friday 10th March 2006 and was well attended. The after dinner address was given by Dr Tim Entwisle, Executive Director of the Royal Botanic Gardens

AWARDS

Edgeworth David Medal 2005:
Dr Christopher Barner-Kowollik, UNSW
Clarke Medal 2005 (Geology):
Professor Mark Westoby, Macquarie University
Walter Burfett Prize:
A/Professor Brett Neilan, UNSW
Eureka Prize for Interdisciplinary Research for 2005:
The Royal Society's Prize [initiated by NSW and with contributions from the other state RSs, principally Victoria] went to Dr Brendan Burns and A/Prof. Brett Neilan of UNSW and Prof. Malcolm Walter of Macquarie University.

The Walter Burfett prize fund has been augmented by a generous donation from Anne Thoeming, his daughter. Council decided, with her approval, to change the award to a medal instead of a cash prize. The medal has been designed and made, using photographs of Walter Burfett provided by Ann Thoeming. The first such medal has been awarded to A/Professor Brett Neilan of UNSW, winner of the 2004 Walter Burfitt Prize.

PUBLICATIONS

Journal

Volume 138 of our Journal Parts 1 & 2 were published in August 2005. It contained the Presidential Address 'A Hundred Years after Einstein's Extraordinary Year' by Karina Kelly, 'Ideal Energy Source by Mark Oliphant's Beam Fusion' by Heinrich Hora and 'The Rev. W.B. Clarke and his Scientific Correspondents' by Ann Moyal, a number of thesis abstracts, the usual Report of Council for 2004 and the audited financial statements for the year. Parts 3 & 4 were published in December 2005. During the year we have received requests for permission to reprint material and for photocopies of our journal articles going back to the 19th century,

Council wishes to thank the referees for their time in refereeing our papers and our editor Pete Williams and particularly our Webmaster Mike Lake for preparing and typesetting the master pages for printing and for maintaining our web site, `http://nsw.royalsoc.org.au`. We must also record the generous contribution of Richard Evans who has scanned numerous volumes of the Journal and Proceedings of the Society for our web site.

Bulletin

The Bulletin and Proceedings of The Royal Society of NSW has been published monthly during the year. A new fast printer has enabled us to undertake Bulletin printing in our office instead of contracting it out. We are indebted to the authors of short articles and information submitted to the Bulletin and members who assisted in preparation and distribution.

SOUTHERN HIGHLANDS BRANCH

The Southern Highland Branch held ten meetings with an average attendance of 65 members.. The Branch has sent out 60 monthly Newsletters to members and about 150 notices of meetings each month to other interested people.

The Branch Committee for 2004/2005 was:
Chairman: Mr H.R. Perry BSc
Vice-Chairman: Mr C.F. Wilmot
Hon. Secretary/Treasurer:
Ms Christine Staubner
Member: Miss Marjory Roberts

The Chairman of the Southern Highlands Branch, Roy Perry thanks the management of Fitzroy Inn for their wonderful after-meeting dinners, the many fine guest speakers who visited us, the Council of the Society for its support and the local Branch Committee for their hard work.

The Royal Society of New South Wales
Council's Financial Report for 2005

The Royal Society of New South Wales Financial Statements for the year ended 31 December 2005 are published in the Bulletin & Proceedings.

NOTICE TO AUTHORS

General

Manuscripts should be addressed to The Honorary Secretary, Royal Society of New South Wales, Building H47 University of Sydney NSW 2006.

Manuscripts will be reviewed by the Hon. Editor, in consultation with the Editorial Board, to decide whether the paper will be considered for publication in the Journal. Manuscripts are subjected to peer review by an independant referee. In the event of initial rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by the Editorial Board on behalf of Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Three, single sided, typed copies of the manuscript (double spacing) should be submitted on A4 paper.

Spelling should conform with "The Concise Oxford Dictionary" or "The Macquarie Dictionary". The Systéme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigaphic names must conform with the International Stratigraphic Guide and new names must first be cleared with the Central Register of Australian Stratigraphic Names, Australian Geological Survey Organisation, Canberra, ACT 2601, Australia. The codes of Botanical and Zoological Nomenclature must also be adhered to as neccessary.

The Abstract should be brief and informative.

Tables and Illustrations should be in the form and size intended for insertion in the master manuscript - 150 mm x 200 mm. If this is not readily possible then an indication of the required reduction (such as 'reduce to 1/2 size') must be clearly stated. Tables and illustrations should be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper.

Maps, diagrams and graphs should generally not be larger than a single page. However, larger figures may be split and printed across two opposite pages. The scale of maps or diagrams must be given in bar form.

References are to be cited in the text by giving the author's name and year of publication. References in the Reference List should be listed alphabetically by author and then chronologically by date. Titles of journals should be cited in full – not abbreviated.

Details of submission guidelines can be found in the on-line Style Guide for Authors at http://nsw.royalsoc.org.au/

Master Manuscript for Printing

The journal is printed from master pages prepared by the LaTeX 2_ε typesetting program. When a paper has been accepted for publication, the author(s) will be required to submit the paper in a suitable electronic format. Details can be found in the on-line Style Guide. Galley proofs will be provided to authors for final checking prior to publication.

Reprints

An author who is a member of the Society will receive a number of reprints of their paper free. Authors who are not a members of the Society may purchase reprints.

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