

COMMONWEALTH DEPARTMENT OF HEALTH



Australian Radiation Laboratory

Annual Review of Research Projects 1985

Edited by

Donald W Keam

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APRIL 1987

LOWER PLENTY ROAD
YALLAMBIE VICTORIA 3085
TELEPHONE: 433 2211

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FOREWORD

The Australian Radiation Laboratory is a national laboratory whose function is to assist the users of radiation, and those who regulate its use, to ensure that wherever radiation is encountered, it is managed in the safest possible way. In performing this function the Laboratory conducts a varied program of applied research in areas which have implications for occupational or public health. Many projects evolve in a natural way in response to an identified need for information, though often this is achieved by an expansion or extension of existing programs which run as a continuing basis.

This progress report provides a brief outline of current Laboratory research and development projects and their present status. The material has been grouped as far as possible into coherent research fields, which often, though not invariably, reflect corresponding research groups within the Laboratory.

As projects mature they are generally reported in the professional literature and in the Laboratory series of Technical Reports. Fuller details, or reprints of related work may be obtained by writing directly to the individual concerned.

Donald W Keam

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URANIUM, RADON AND ITS DAUGHTERS

ANALYSIS OF DATA FROM THE YEELIRRIE EXPERIMENT

R S O'Brien, K N Wise and S B Solomon

INTRODUCTION

No field trips were made to Yeelirrie during 1985. Since a large body of data had been accumulated during 1984 and the early part of 1985 it was judged more important to analyse this data and determine whether the sensors and data acquisition system were functioning properly and whether the data was useful for predicting the behaviour of radon and radon daughters over the Yeelirrie ore-body.

Examination of the available data showed that the radon daughter sensors have not functioned well at all through 1984 and early 1985. These sensors were developed at ARL but have proved to be unsatisfactory for remote field use because of a tendency to generate high electrical noise levels which prevent data recovery and analysis when they occur. It has not been possible to determine the cause of this problem. Accordingly a new type of commercial radon daughter sensor has been purchased and is being tested in the laboratory with a view to its use as a replacement for the sensors currently in use.

Another problem which has drastically affected data recovery is that the solar cell array which was installed in late 1983 does not generate enough charge during sustained spells of cloudy weather or during the winter months to keep the system operational for more than about 5 to 7 days at a time. This means that data recovery was intermittent throughout 1984. Two ways of overcoming this problem are being pursued at present. A second solar cell array and control unit has been purchased and tested. The tests show that the control unit seems to be much more reliable than the unit currently in use at Yeelirrie (this unit has malfunctioned several times and was supplied with totally inadequate documentation for field repairs) so it is planned to install the second solar cell array and the new controller on the next field trip. A second computer is also being built in the laboratory. The CPU board for this new computer is the standard Z-80 board developed in the laboratory, with low current CMOS chips used wherever possible to minimize current consumption. Tests indicate that this new CPU board uses only about 300 ma of current, whereas the system now in use at Yeelirrie uses about 1.2 amps, so this new computer should also help to reduce the total power consumption.

LABORATORY WORK

A Fortran version of the current control program being used in the computer at Yeelirrie has been written and partially tested on the S-140 at ARL. This program was translated from the original Basic program. Development of this program has greatly helped in the understanding of the program currently in use, which is a hybrid mixture of Basic and machine language programs and sub-programs. If it is deemed desirable at some future date to carry out some high speed sampling runs or to increase the amount of real-time data processing at the measurement site, the current program and operating system will have to be replaced by a system which is capable of operating at a much higher speed. The Fortran program will be a major part of such a fast system.

A draft of a paper on the data acquisition system has been prepared [Ma85]. It has not been resolved what form the paper is to take (i.e. internal report or external publication) so work on this paper has not been completed.

More development and refining of the software necessary to read the data from cassette tapes into the ARL computer has been carried out. All the data recovered between March 1984 and February 1985 has been put through a preliminary analysis to determine which meteorological variables have the greatest influence on the dispersion of radon near the ground. A paper describing this analysis [OB85] is being prepared for publication and should be completed in early 1986.

The software has been developed for a simple box model which will be used to simulate the behaviour of radon over the Yeelirrie ore body. Some work still remains to be done on this model. A more powerful program for solving the large system of coupled simultaneous differential equations in the model has been obtained through the courtesy of Dr N G Barton of the CSIRO Division of Mathematics and Statistics. Testing of this program is still continuing but it is hoped to incorporate it into the model software early in 1986. The results of the early tests of this model will be included in the paper on the preliminary analysis of the data.

The software for a more sophisticated model of the boundary layer over the Yeelirrie ore-body has been developed to the point where the program runs for the one-dimensional case with coarse vertical resolution. This model has the

advantage over the box model that it is capable of including all of the significant meteorological variables, so it can, in principle be used as a tool for diagnostic studies of radon dispersion. However, to obtain maximum benefit from this model, it will be necessary to increase the vertical resolution of the model near the ground, and the software currently being used for solving the equations in the model does not seem to be adequate to handle this particular problem. The program mentioned in conjunction with the box model is also intended for use in this more detailed model as both models require the solution of a large system of differential equations with characteristics which make them difficult to solve with conventional software packages. It may also prove necessary, with this more detailed model, to modify the physics put in to the model so that the rapid variation of temperature and wind speed with height near the ground can be simulated accurately.

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RADON EMANATION MAPPING OF THE YEELIRRIE ORE BODY

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The limits and radon emanation contours of the Yeelirrie uranium ore body (WA) have been surveyed using canisters filled with activated charcoal. In agreement with the erratic ore grade distributions determined up to a depth of 4 metres in the ground, the emanation contours reflect the undulating nature of the upper surfaces of the ore body. Application of the one dimensional diffusion equation, modified to include a variable vertical source term, indicate that observed trends in surface emanation rates at 4 representative locations across the ore body are consistent with those calculated from the model using bore hole logging assays. The model also indicates that the bulk of the radon emanates from the top 2 metres of the overburden. Consequently, information regarding the location and shape of the ore body derived from such measurements should be interpreted with caution.

ACKNOWLEDGEMENTS

We wish to thank K. Hart of the Australian Atomic Energy Commission for performing the finite difference calculations. We also wish to acknowledge V.A. Leach, Dr K.H. Lokan, Dr R.S. O'Brien, B. Petchell and Dr S.B. Solomon of the Australian Radiation Laboratory for assistance with data collection at Yeelirrie.

AEROSOL GENERATION AND MEASUREMENT FOR RADON TEST CHAMBER

S B Solomon

The Australian Radiation Laboratory is the designated Pacific region radon reference laboratory for the OECD/NEA International Intercalibration and Intercomparison Programme for Radon, Thoron and Daughter Products. The forthcoming phase of the programme requires the intercomparison of radon daughter measurements. Unlike radon, which is a noble gas, the short-lived radioactive decay products from radon are formed as metal ions. In order to characterise the test atmosphere for radon daughters it is necessary to specify not only the individual concentrations of each daughter, but also the nature and concentration of aerosol to which these decay products will eventually attach. For this reason a condensation aerosol generator system for monodispersed aerosols has been constructed and an automatic sub-micron particle sizer has been designed and constructed.

Sub-micron Aerosol Generator

The aerosol generator was based on a design used by the Environmental Measurement Laboratory (EML), New York (1), which has been used for preliminary radon daughter measurements. The generator consists of a sample holder (a modified 50 ml pyrex pipette) supported in a 5 cm diameter pyrex tube. An electrically powered, thermostatically controlled heating unit surrounds 30 cm of the 53 cm long tube. The full length of the tube is then surrounded by fibreglass insulation. Filtered air can be supplied to sample holder and to the pyrex tube. The temperature in the sample boat can be monitored continuously using a solid state temperature sensor mounted in the sample boat.

The generator has been used in the ARL chamber to produce monodispersed canauba wax aerosol. This aerosol was produced at a furnace temperature of 165 degree centigrade, driving gas flow of 2 litre per minute and carrier gas flow of 5 litre per minute. The aerosol stream was further diluted by filtered air at 28 litres per minute. For these operating conditions the generator produced an aerosol concentration in 16 m³ radon chamber of approximately 50,000 condensation nuclei (CN) per cm³, as determined from measurements using an Environment One Rich 100 CN counter.

Aerosol Measurement

Instruments for the measurement of size distributions of submicron presently available, use either the electrical mobility or the diffusion rates to separate the different size ranges. No commercially available instrument provides direct information on the distribution of a radioactive aerosol. A TSI Model 3040 wire screen diffusion battery has been combined with a multichannel alpha counting system to produce an instrument capable of direct measurement of the aerosol activity median diameter (AAMD).

The TSI diffusion battery consists of a series of fine wire screens (635 mesh) with 11 sampling ports. Gas drawn from ports further from the inlet passes through progressively more screens, up to a maximum number of 55. Penetration through the battery is determined by the particle size, with the smaller aerosol being removed at a faster rate. The 11 sampling ports were connected to an assembly containing 11 alpha particle detectors, in close proximity to a 0.8 micron pore size filter. The alpha detectors used were silicon photodiode detectors (BPY12) connected to a low noise charge sensitive preamplifier. These photodiodes are small (0.5 cm square) and inexpensive, making them ideal for this application. A single gas pump draws a sample through the filter from a port selected by activating one of 11 solenoid valves. The sequencing of the solenoid valves and the counting of the pulses from the alpha detectors are handled by a single board CMOS microprocessor.

A prototype device was completed late 1985 and the calibration of battery and counters is presently underway. Preliminary calibration using radon daughters attached to 0.1 micron DOP aerosol have produced excellent agreement with the manufacturer's calibration. The battery was also used to measure the wax aerosol described above. These preliminary measurements indicate that the aerosol has a median diameter close to 0.1 micron and a geometric standard deviation of 1.16. This suggests that the wax aerosol is monodispersed and that the generator is operating as per the EML design.

Further calibration of both the aerosol generator and the diffusion battery particle sizer are currently underway. These instruments will also be used in a forthcoming Radon Aerosol Workshop to be held at ARL during March 1986. This will allow the calibrations to be compared with those of other devices for particle size measurement used by overseas laboratories.

RADIATION EFFECTS IN SOLIDS AND GASES

STUDIES OF THERMOLUMINESCENCE MECHANISMS IN SOLIDS

J F Boas and R J Danby

Studies of thermoluminescence (TL) mechanisms in the solid state have continued in two main areas.

(a) Rare-earth doped calcium sulphate.

A study of the thermoluminescence mechanisms and defect centers in CaSO_4 doped with Dy has been initiated, using as a starting point the results obtained previously on CaSO_4 doped with Eu and Gd.¹ The importance of CaSO_4 :Dy lies in the fact that it is the TL material currently used by the Personal Radiation Monitoring Service (PRMS) of A.R.L. and it is the TL material of choice for the automatic PRMS, based on TL dosimetry, which is being introduced at present.

Measurements to date have used electron spin resonance (e.s.r.) in an attempt to determine the number of Dy^{3+} ion sites, their local symmetry and their location in the CaSO_4 lattice. The measurements are not straightforward, due to the extremely anisotropic behaviour of the Dy^{3+} e.s.r. signals and their complex temperature dependence which requires measurements to be made over the range 2K up to 20K. However it seems likely that there are four or five main sites, each with orthorhombic or lower symmetry, analogous to the situation in CaSO_4 :Gd³⁺ and CaSO_4 :Eu³⁺. Whether all of these sites take part in the TL process is still unresolved.

(b) Alkaline-earth oxides.

A characteristic feature of highly colored regions of crystals of CaO grown by arc fusion is that they exhibit an intense long-lived phosphorescence at ~600 nm at room temperature after excitation with light of wave-length less than 500 nm. It is generally accepted that this emission results from the thermally activated release of an electron from a trap, its subsequent capture by an F^+ center (an anion vacancy containing a single electron) and the radiative decay of the excited state of the resultant F center to the ground state. The thermoluminescence glow curves of crystals from a variety of sources all have their most prominent peaks at around 80 and 330 K and it is this latter peak which is responsible for the room-temperature phosphorescence. However, the nature of the metastable traps which give rise to the peaks in the glow curves has not been clearly established.

In the present study, a combination of e.s.r. measurements at two microwave frequencies (4 GHz and 9 GHz) and studies of the thermoluminescence glow curves and optical emission spectra has identified the metastable trap responsible for the glow peak at 180 K in highly coloured and Mg doped (nominally 1%) CaO. The model of the defect is one in which an electron is trapped in a P center (an anion cation vacancy pair aligned along $\langle 100 \rangle$) with an H^- ion present substitutionally in the collinear anion site immediately next to the cation vacancy (see Figure 1). These results have been the subject of a recent publication.²

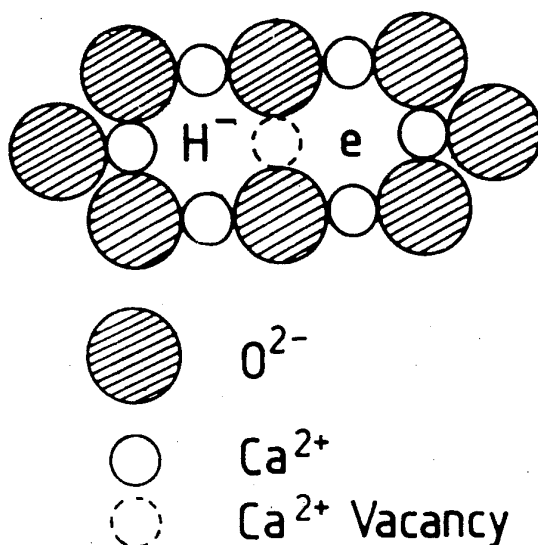


Figure 1

These measurements, taken in conjunction with those of other authors suggest a key role for substitutionally trapped hydrogen ions in the TL processes in these materials.³ Similar suggestions have been made for LiF.⁴ However we have been unable to find evidence for the involvement of hydrogen ions or other e.s.r. detectable centers with the glow peaks at around 80K and 330K.

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DETERMINATION OF THE ABSOLUTE FLUORESCENCE
YIELDS FROM ELECTRON IRRADIATED GASES

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The measurements of the fluorescence yields of exciplex molecules formed by the pulsed-electron beam irradiation of rare gas halogen systems were extended to the XeF^* (351 nm), XeCl^* (308 nm), XeBr^* (282 nm and 324 nm) and XeI^* (251 nm and 319 nm) exciplexes. The $^2\Sigma_{1/2}^+ \rightarrow ^2\Sigma_{1/2}^+$ transition for each exciplex molecule was studied while the $^2\Sigma_{1/2}^+ \rightarrow ^2\Pi_{1/2}$ transition (319 nm) of the XeI^* exciplex was also investigated. The emission spectra of these exciplex molecules are shown in Figure 1.

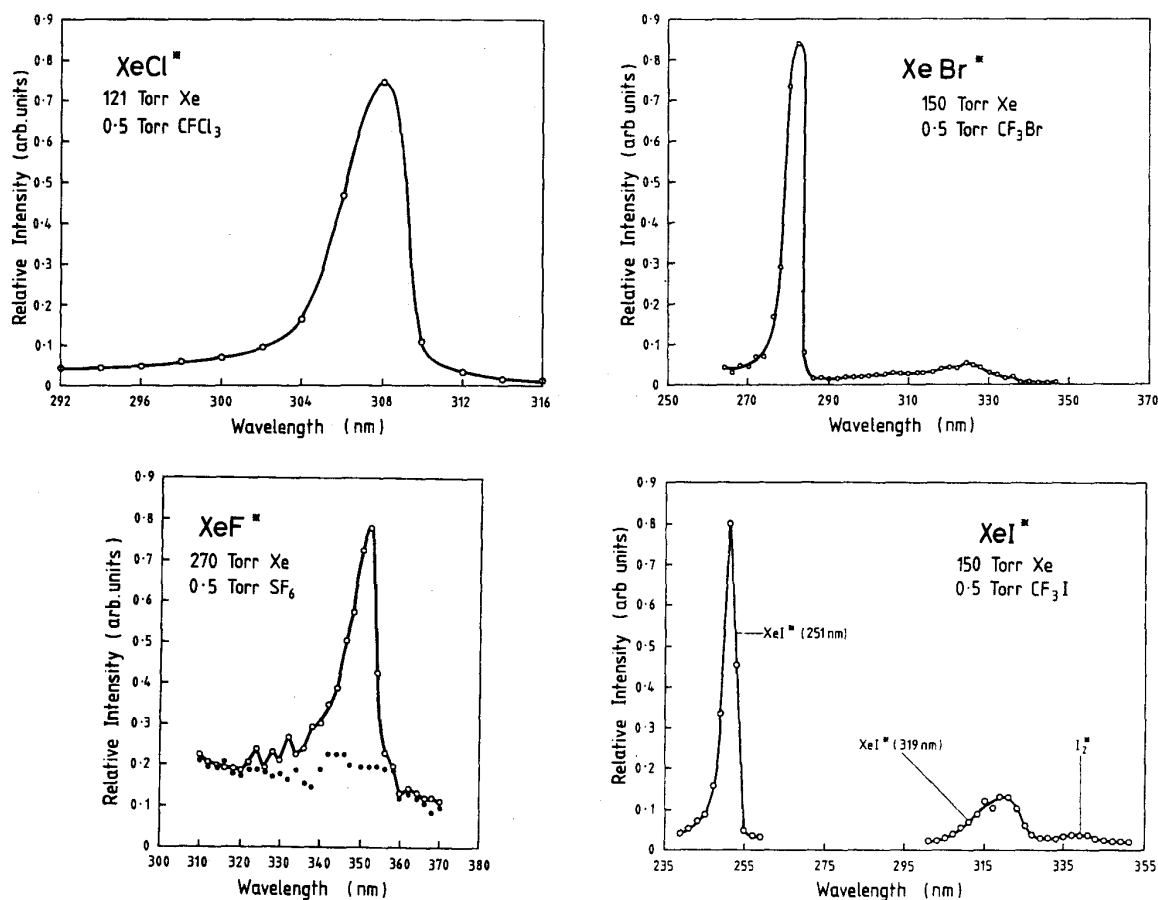


Figure 1: Emission spectra for the XeCl^* , XeBr^* , XeI^* (251 nm), XeI^* (319 nm) and XeF^* exciplex molecules.

The fluorescence yields were measured as a function of rare gas pressure and halogen source gas pressure and the results are shown in Figures 2 and 3.

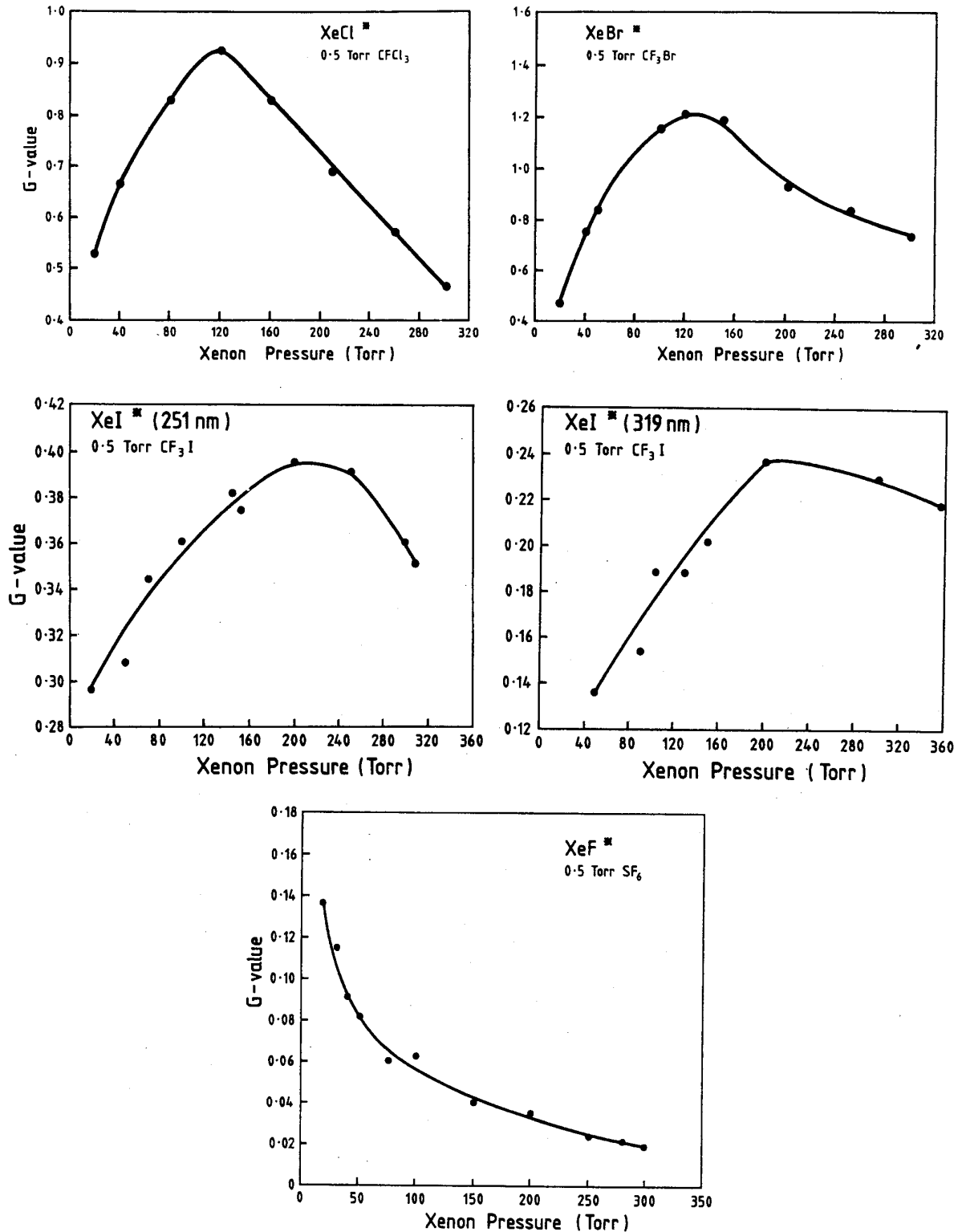


Figure 2: Variation in the fluorescence yields as a function of rare gas pressure for a constant halogen source gas pressure of 0.5 Torr.

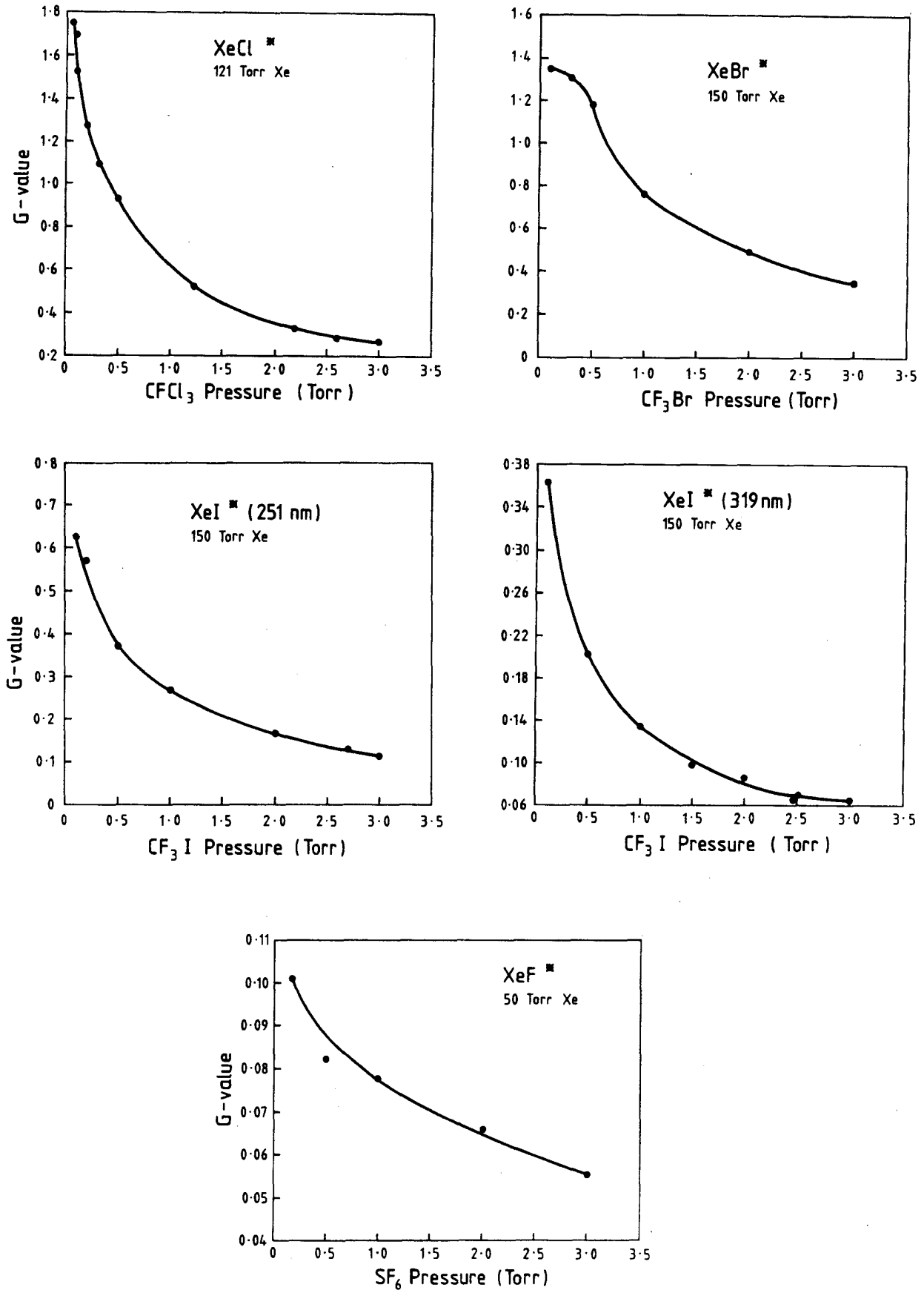
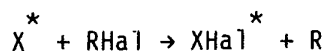


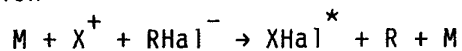
Figure 3: Variation in the fluorescence yields as a function of halogen source gas for a constant rare gas pressure.

From time dependent emission studies it was found that, as in the case of KrF^* exciplex molecule (1,2), the electronic excited state was formed by two independent processes, namely

(i) energy transfer



and (ii) ion recombination



where X^* is the excited rare gas atom, RHal is the halogen source gas molecule, XHal^* is the exciplex molecule, X^+ is the rare gas ion, RHal^- is the halogen ion and M is a third body.

In the case of the XeF^* exciplex molecule it was observed that the contribution to the overall yield from the energy transfer formation process was no more than 5% for the gas pressures studied here. Of the remaining gas systems studied only the yield of XeBr^* could be resolved into its two formation processes; these results are shown in Table 1.

Table 1: Percentage contributions of the ion recombination and energy transfer processes to the formation of XeBr^* as a function of CF_3Br pressure for a constant xenon pressure of 20 Torr.

CF_3Br Pressure (Torr)	Ion Recombination (%)	Energy Transfer (%)
0.04	> 90	< 10
0.07	83	17
0.10	75	25
0.11	77	23
0.16	70	30
0.20	69	31
0.21	63	37

This research project is nearing completion and a detailed account of the work will be published in the near future.

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X-RAYS AND CLINICAL DOSIMETRY

THE RADIO-OPACITY OF SURGICAL AND RADIOLOGICAL
DEVICES USED IN VIVO:
A TEST METHOD FOR MARKERS IN SURGICAL GAUZE

O J Wilson and B F Young

ABSTRACT

Most radio-opaque markers used in surgical gauze contain barium sulphate, and a minimum percentage content of this is required to ensure an acceptable level of radio-opacity. When this minimum percentage of barium sulphate is specified by Standards authorities, a suitable test method must be available to determine compliance. A new radiographic test method is presented which can be used to determine the barium sulphate content or equivalence to within two per cent of compliance requirements. The method consists of immersing the marker in a solution of barium sulphate which is then radiographed. Compliance can be evaluated by inspection of the radiograph. The method was found to be virtually independent of X-ray energy, film/screen combination and thickness or shape of the test object. The method is also an appropriate test for any other material or object, such as vascular catheters used in radiology, for which a radio-opacity equivalent to that for a particular barium sulphate content is required.

(This is the abstract of a paper which has been submitted to Physics in Medicine and Biology).

MEASUREMENT STANDARDS IN RADIATION DOSIMETRY

ABSORBED DOSE MICROCALORIMETER

R B Huntley

The ARL absorbed dose microcalorimeter is now complete. The device has been found to operate satisfactorily, and is being evaluated.

Heater control circuits have been built and are providing the desired degree of temperature control. Typical results are shown in table 1 below.

TABLE 1. TEMPERATURE CONTROL

Item controlled	Tolerance in mK	Control achieved in mK	
		Short term (1h)	Long term (24h)
Thermistor bridge	100	5	50
Null detector	100	10	60
Connector panel	100	5	30
Vacuum vessel	10	10	30
Mantle	1	0.05	0.15
Jacket 2	0.1	0.007	0.06

The temperature variations observed in jacket 1 and the absorber are 100 to 300 times greater than those in jacket 2, but are still small compared with the temperature rise of about 25 mK due to radiation heating in a 1000 s exposure.

Several possible explanations exist for the larger variations in temperature of the inner jackets; these will be investigated in due course.

Time constants of heat transfer between the various parts of the microcalorimeter have been evaluated. When the temperature of all components was stable, the vacuum vessel temperature was suddenly increased by 100 mK. With the mantle temperature control circuit disabled, its temperature change was recorded as a function of time, using a computer controlled measurement system. The computer program also fits an exponential curve to the data. Heat loss to the inner jackets was included in this measurement intentionally, as this occurs in practice when there is a change in the temperature of a controlled element. The heat loss to the inner jackets represents only a minor perturbation, as the inner parts have much smaller heat capacities than the outer jackets.

Similar procedures were followed to find the time constants for heat transfer from the mantle to the combination of jacket 2, jacket 1 and the absorber, from jacket 2 to jacket 1 and the absorber, and finally from jacket 1 to the absorber. In each case, heat loss to the outer components was prevented by simultaneously heating the outer parts at the same rate for the same time.

A typical computer plot is shown in figure 1, and results are summarised in table 2 below.

TABLE 2. TIME CONSTANTS OF HEAT TRANSFER

Parts heated	Parts floating	Part measured	Time constant sec
Vacuum vessel	M, J2, J1, A	Mantle	5000
V, M	J2, J1, A	Jacket 2	2000
V, M, J2	J1, A	Jacket 1	1500
V, M, J2, J1	A	Absorber	230

There is an uncertainty of about 50% in the results of these measurements, the reason for which is not clear at present. This does not detract significantly from the usefulness of the results, which are intended to provide an order of magnitude check on the thermal isolation achieved between the various parts of the microcalorimeter.

The ultimate sensitivity will be determined next; preliminary indications are for a very good result. Correction factors will then be found, leading to the establishment of an absolute absorbed dose standard. Measurements will be made with various radiation sources, starting with cobalt-60, then caesium-137, 300 kV x-rays, then LINAC x-rays and electrons when available. This will provide a calibration facility for dosimeters in terms of absorbed dose in all those radiation beams in which the microcalorimeter gives satisfactory results. Attention will be given to simplifying the temperature control and monitoring systems, reducing the number of measuring instruments through the use of a dedicated microcomputer. This will provide independence from the main ARL computer and will render the whole system much more portable; it is intended to move the microcalorimeter from one exposure room to another, and possibly to other establishments.

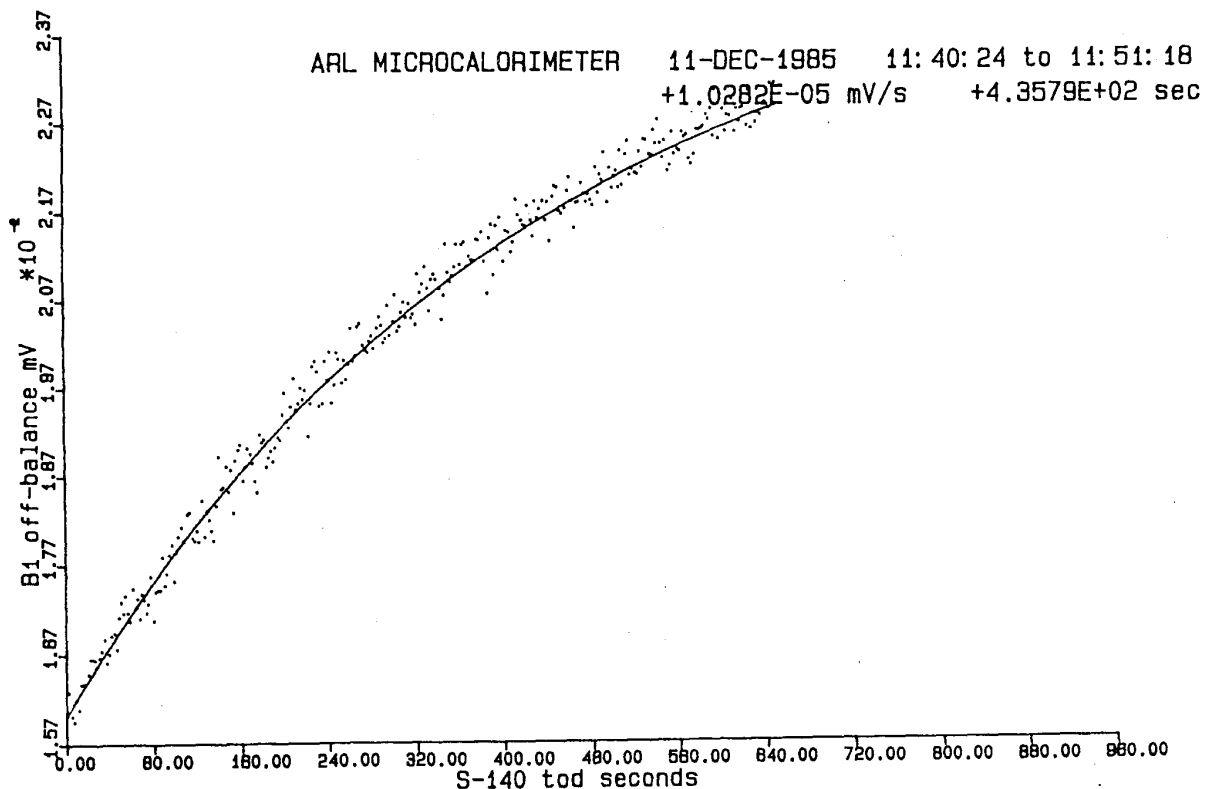


Figure 1: Typical computer plot.

PHOTONEUTRON PRODUCTION IN TISSUE IRRADIATED WITH HIGH ENERGY BREMSSTRAHLUNG

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In this report brief details are given of a measurement of the yield of photoneutrons from a tissue equivalent target irradiated with high energy bremsstrahlung. The measurement is part of an investigation into the contribution to patient dose and irradiation room scatter of various photonuclear processes during gamma ray radiotherapy (A1982, A1982a, A1985).

Targets consisting of a sealed perspex cylinder containing tissue equivalent liquid were irradiated with bremsstrahlung of end point energy from 6 to 28 MeV from the University of Melbourne betatron. The liquid is a composition $C_5H_{40}O_{18}N$ as suggested by Rossi and Failla and known as tissue approximation (ICRU77); it was made up of a mixture of water (58.2% by weight), glycerol (34.3%) and urea (7.5%) and has a density of 1.105 g/cm^3 . The perspex containers have an inside diameter of 38 mm and are sealed with 1.6 mm perspex sheet. Two targets were made up of length 50 mm and 144 mm respectively.

The incident beam energy was monitored using a thin-walled transmission ionization chamber which had been previously calibrated against a standard NBS P2 chamber. The neutron detector consists of sixteen BF3 detectors embedded in a paraffin block and surrounded by a cadmium sheet to shield the detector from externally produced neutrons. Background yields were also measured using identical empty perspex cylinders.

The raw data were corrected for various detector efficiency factors, deadtime losses and beam monitor calibration factors and the measured background was subtracted. A separate test confirmed that the number of contaminant neutrons in the gamma beam scattered by the tissue equivalent target was negligible. The final measured yields are shown in figure 1. The error bars (± 1 standard deviation) include both counting errors and estimated systematic errors due to uncertainties in calibration and efficiency factors.

The photoneutron yields from tissue can also be estimated using the known neutron production cross sections for the various constituent atoms. In a previous report it was shown that the usual assumption that for a target consisting of oxygen, nitrogen, carbon and hydrogen only the atoms ^{16}O , ^{14}N and ^{12}C need be considered was not valid (A1985). Because of their low photoneutron threshold the rarer isotopes of constituent elements such as ^2H , ^{13}C , ^{15}N , ^{17}O and ^{18}O must also be included to accurately estimate yields for bremsstrahlung energies below about 22 MeV. The results of such an estimation for tissue approximation including all the isotopes is shown as the lines in figure 1. The method used for the calculation is as described previously (A1985a). Cross sections from the literature were carefully selected to represent accurate, modern values; details will be given in the final publication of this work. As these cross sections were measured using similar methods to that used by us to measure the yields directly we expect that similar systematic errors of the order of 10% will apply to the estimated yields.

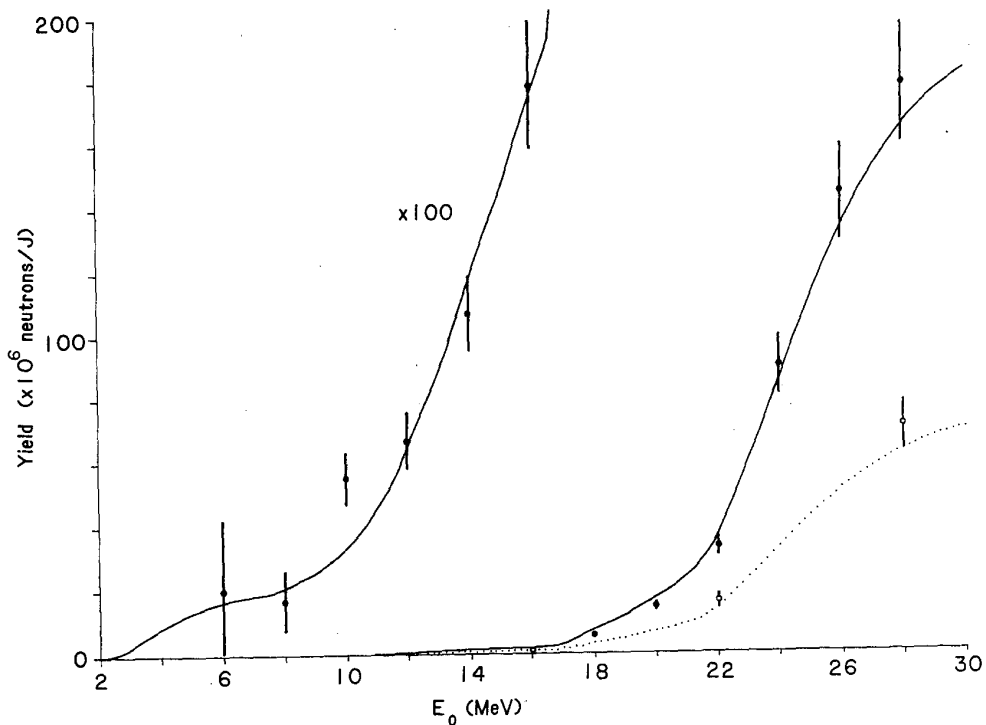


Figure 1: Measured photoneutron yield in units of neutrons/J from tissue approximation targets as a function of bremsstrahlung end point energy E_0 (data points). The solid line and the dotted line show the estimated yields for a 144 mm target and for a 50 mm target respectively.

The measured and calculated yields generally agree over the energy range. At the highest energies the yield measurements appear to be systematically higher than the calculated values but are within the bounds of experimental errors. Real disagreement only occurs for energies of 18 MeV and 20 MeV but this was shown to be probably due to a systematic difference between ^{16}O cross section estimates near threshold measured at different laboratories.

The overall agreement of the estimated and measured yields both confirms the experimental results and allows the calculational method to be used confidently to estimate the photoneutron yields from tissue for other circumstances as required.

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RADIOPHARMACEUTICALS AND NUCLEAR MEDICINE

CHEMISTRY AND STRUCTURE OF TECHNETIUM COMPLEXES

J Baldas, J Bonnyman, S Colmanet and G A Williams

Technetium-99m complexes are widely used as functional and imaging agents in nuclear medicine. The rational design of new organ-specific radiopharmaceuticals relies largely on knowledge of structure-distribution relationships and the mechanisms of *in vivo* localization. With this view in mind we have continued our studies of technetium chemistry by the use of the long-lived technetium-99 nuclide.

Crystal structure of $[\text{TcN}(\text{thiooxine})_2]$ (thiooxine = 8-thioquinolinolato) has been published.¹ The coordination environment of technetium is distorted square-pyramidal with the nitrido nitrogen atom in the apical position and the local donor atoms of the 8-thioquinoline ligands diametrically opposed.

Reaction of the TcNCl_4^- with thiourea (tu) gives a complex with the composition $\text{TcN}(\text{tu})_4\text{Cl}_2$. Conductivity studies have indicated that this complex is a 1:1 electrolyte and hence should be formulated as $[\text{TcN}(\text{tu})_4\text{Cl}]\text{Cl}$. The $[\text{TcN}(\text{tu})_4\text{Cl}]\text{Cl}$ complex is water-soluble and provides a convenient starting material for the preparation of $\text{Tc}^{\text{V}}\equiv\text{N}$ complexes in aqueous solution by substitution reactions. Thus, reaction of $\text{Na}[\text{S}_2\text{CNET}_2]$ and thiooxine HCl with $[\text{TcN}(\text{tu})_4\text{Cl}]\text{Cl}$ in water gives $[\text{TcN}(\text{S}_2\text{CNET}_2)_2]$ and $[\text{TcN}(\text{thiooxine})_2]$ respectively in high yield. The reaction of $[\text{TcN}(\text{tu})_4\text{Cl}]\text{Cl}$ with PPH_3 in ethanol gives $[\text{TcNCl}_2(\text{PPH}_3)_2]$ in near-quantitative yield.

The reaction of $\text{AsPh}_4[\text{TcNBr}_4]$ with 1,2-benzenedithiol (bdt) in acetone results, surprisingly, in the loss of the nitrido nitrogen atom and the formation of $\text{AsPh}_4[\text{Tc}(\text{bdt})_3]$. The crystal structure of $\text{AsPh}_4[\text{Tc}(\text{bdt})_3]$ has been determined and shows that the $[\text{Tc}(\text{bdt})_3]^-$ anion is trigonal-prismatic.

The $(\text{AsPh}_4)_2[\text{Tc}(\text{ox})_3]$ (ox = oxalato) complex has been prepared by the reaction of $(\text{NH}_4)_2[\text{TcBr}_6]$ with oxalic acid. The crystal structure determination showed that, as expected, the $[\text{Tc}(\text{ox})_3]^{2-}$ anion is octahedral.

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BIOLOGICAL BEHAVIOUR OF ^{99m}Tc -COMPLEXES BASED ON THE TcN GROUP

J Baldas and J Bonnyman

Preparation of technetium-99m radiopharmaceuticals usually requires the reduction of technetium as pertechnetate to a lower valency state where it may be coordinated to a number of complexing agents. We have been studying the use of $^{99m}\text{TcNCl}_4^-$ to prepare ^{99m}TcN -complexes containing a technetium-nitrido (TcN) group and the effect of the TcN group on biological behaviour.

Results to date (1, 2) show that the TcN moiety forms weak complexes with hard ligands and that the group tends to exchange with serum proteins. Complexes with soft ligands, however, are stable and generally show different biological behaviour to that observed when the same ligand is coordinated to technetium using the more conventional reduction system. It should also be noted that the most stable complexes appear to be formed by soft ligands that can act as reducing agents. This observation is consistent with our experience in the preparation of complexes containing the TcN group using technetium-99 where most characterised TcN complexes contain Tc in the Tc^{V} valency state.

A range of monoclonal antibodies has been labelled at high specific activity using $^{99m}\text{TcNCl}_4^-$ without loss of specificity. Specificity was measured in "in vitro" binding assays using reactive thymocyte cells. A clinical trial using antibodies labelled by this technique is currently in progress. This work is being performed in collaboration with the Research Centre for Cancer and Transplantation, University of Melbourne.

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ERADICATION OF T-LYMPHOCYTES FROM DONOR
BONE MARROW FOR ACUTE NON-LYMPHOBLASTIC LEUKEMIA

P M Pojer

INTRODUCTION

The major problem in matched bone marrow transplants for acute non-lymphoblastic leukemia is the graft versus host disease (GVHD) which results from the action of T-lymphocytes present in the donor marrow. Eradication of the T-cells would greatly enhance the efficacy and application of bone marrow transplantations.

It was envisaged that these cells might be largely eradicated by incubation of the marrow with anti-T cell monoclonal antibodies and removing the resulting complex by magnetic means.

RESULTS

(a) It was found that magnetic boride particles (for bibliography, see previous Research Reports) would not only be labelled with technetium -99m but could also be efficiently (>90%) coated with the required antibody (Allen, 1986). The resultant preparation is one which:

- (1) Is easily visualised using conventional gamma camera technology.
- (2) Specifically binds with the T-lymphocytes.
- (3) Can be magnetically sorted from the stem cells in the marrow.
- (4) By use of boron-10, any remaining T-cells not magnetically removed but still in the vicinity of a boride particle can be specifically destroyed by thermal neutrons. [These are captured by ^{10}B atoms and the resultant alpha emission (high LET products) will lead to cell death].

A multi-disciplinary team involving chemists from the Australian Radiation Laboratory, physicists from the Australian Atomic Energy Commission, immunologists from Melbourne University, and medical researchers from

St Vincent's Hospital (Sydney) and Flinders Medical Centre (Adelaide) was established for this project. The contributions from the Australian Radiation Laboratory have subsequently been discontinued.

(b) In a related project, model experiments aimed at the treatment of gliomas using magnetic boride particles and boron neutron capture therapy, have been conducted in collaboration with the Department of Neurosurgery at Royal Melbourne Hospital. We succeeded in concentrating labelled magnetic boride particles in the brain of a rat. This project has now also been discontinued.

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NON-IONISING ELECTROMAGNETIC RADIATIONS

LASER RADIOMETRY - ELECTRICALLY CALIBRATED PYROELECTRIC RADIOMETER

W A Cornelius and R V Sargent

A reliable broadband measurement standard is required by industry and regulatory authorities for the measurement of continuous laser sources so that laser hazards may be accurately quantified. An electrically calibrated pyroelectric radiometer (ECPR) is being developed to meet this need.

The design details and operating mode of the ECPR are described in an earlier report¹. The intended performance specifications for the completed radiometer are as follows:

1. The ECPR must measure the radiant power of collimated continuous wave (c.w.) laser beams.
2. The spectral range of the ECPR should cover ultraviolet to far infrared.
3. Measurement uncertainty should not exceed 1% for radiant power within the range 0.1 microwatt to 5 milliwatt and the instrument should evaluate and display the probable error in the measurement (this is necessary because the laser output may fluctuate during the measurement cycle and noise in the measurement process depends on ambient conditions).
4. The response time to achieve 1% accuracy should not exceed several seconds following any change in radiant power.
5. The measurement accuracy achieved should be largely independent of maintenance procedures and operator skills.
6. Any changes that may affect the accuracy of measurement (e.g. component drift, noise or circuit failure) should be immediately notified to the operator via an internal diagnostic monitoring schedule.

7. The ECPR should maintain calibration indefinitely (a decade at least).
8. Calibration should be traceable to Australian Standards.
9. The ECPR should be reasonably portable and suited to a wide range of ambient operating conditions (e.g. temperature, acoustic noise, etc.).
10. The ECPR design should be suited for routine manufacture and calibration by Australian industry.

A working prototype ECPR has been developed. A microcomputer is used to monitor and control all ECPR functions. The control software has been structured so that it can be readily adapted to different microcomputer architecture and also to assist the rapid replacement and recalibration of ECPR circuit modules that may be required in the event of component failure. The operating logic and software used to control the ECPR appears to be faultless (approximately 98% of the software routines have been tested to date). Dynamic range tests have revealed a non-linear ECPR response which was found to be due to the presence of excessive offset currents and amplifier distortion in the bipolar null balance power supply circuit. Consequently, this circuit module will have to be redesigned. All other circuit modules appear to function satisfactorily. Despite this problem, it is anticipated that all of the above performance specifications will be met.

Remaining work to improve the prototype ECPR performance involves elimination of the offset currents in the null balance power supply circuit and the interfacing of a chopper speed control circuit to the microcomputer controller (the latter is desirable in the final ECPR design though not essential to prototype ECPR operation and testing). Further performance and software tests will begin when the modified prototype is operational. Specialized software for the initial calibration of ECPR circuit components will also be developed to improve the speed and precision of the initial ECPR calibration process required at manufacture. Systematic correction factors associated with electrical/optical heating inequivalence in the pyroelectric detector are determined by the methods described in a published paper² and through measurement of the reflectivity of the optical absorber layer.

Intercomparison with National Measurement Laboratory standards and final circuit design (i.e. streamlining mechanical layout of circuitry and rationalisation of power supplies and connector leads) to improve portability and reliability will follow. An Australian manufacturer will finally be sought to produce and market the ECPR.

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ULTRAVIOLET RADIOMETRY

H P Gies, C R Roy and G Elliott

The dosimetry of ultraviolet radiation (UVR) is complicated by factors which make accurate quantification difficult, such as the fact that most UVR is measured in the presence of much larger amounts of visible radiation using detectors which are usually more sensitive to this visible radiation than to UVR. The rapid change in biological effectiveness with wavelength in the UV region makes knowledge of the spectral power distribution of UVR extremely important. The present aim in UV radiometry is to further develop the measurement and calibration capability in the UV, as well as determining the spectral power distributions of various UVR sources and to assess their potential human health hazards.

Experimental Details

The different spectroradiometric and radiometric measurement systems were described in the 1984 report. The accurate measurement of the spectral distribution of UVR sources in the laboratory is carried out on the Spex 1404 double grating monochromator system. This system has a maximum resolution of 0.005 nm. The monochromator has been moved into a new laboratory with a large optical bench, and the choice of input optics has been increased with the acquisition of a number of different light guides and integrating spheres. The light detection system has also been improved with the addition of a Keithley model 617 autoranging picoammeter. The system is controlled by a microcomputer, with a link to the main laboratory computer for data transfer.

Field measurements of spectral distribution of UVR sources are made with the Optronics 740 A spectroradiometer system. This system is currently being upgraded, with the Osborne PC, the microprocessor controller and the wavelength drive unit all being replaced by an Ericsson PC, thus making the instrument more portable and the data acquisition and handling more efficient.

Radiometric measurements of UVR sources are made with the International Light 700 A and 1700 A radiometers. Interchangeable heads and filters allow radiometric measurements in the UV-A, UV-B and UV-C regions. A programme is under way to evaluate a number of different UVR sources with these radiometers and to compute sensitivity factors for each of these sources which will make the radiometers direct reading.

The above measurement systems are calibrated using standard lamps traceable to NBS and NML, which allow calibrations over the wavelength range 250-1000 nm (tungsten halogen standard lamps) and 200-400 nm (deuterium lamps). An intercomparison of these lamps is carried out periodically.

Investigations

The following investigations are in progress or have recently been completed.

(a) VDTs

Measurements of the electromagnetic radiation emissions from VDTs have continued. More than eighty different colour and monochrome sets have been examined. The complete results have been published (1-3).

(b) Solaria

Measurements of the UVR sources in use in solaria were completed and the full data and results have been published in a technical report (4). A paper examining the hazards of exposure to these sources of UVR has also been published (5).

(c) UVR Sources

A number of different sources of UVR in use in industry and commerce such as blacklights, signature verification units and germicidal lamps have been measured. This work is continuing.

(d) Protection Against UVR Exposure

Measurements of the protective effects of clothing and other materials against UVR have been made. Additional and more detailed measurements will be made at a later date as part of a program to examine the exposure and protection of outdoor workers to solar UVR and compliance with the IRPA guidelines (6). A preliminary paper on this work has been accepted for publication (7).

(e) Polysulphone Dosimetry

Thin films of polysulphone are useful as UVR dosimeters and have been used in studies of personal UVR doses received in various outdoor activities, as well as for studies of the anatomical distribution of UVR. Preliminary measurements of the effect of varying solar zenith angle and air mass on the response of the film have been made, using an Oriel 300 Watt solar simulator in the laboratory, and the results of the study will be presented at the 1986 ARPS conference (8).

(f) Ocular Protection

A study of ocular exposure to solar UVR doses has been initiated. Previous studies of ocular doses of UVR (9,10) used polysulphone film as dosimeters. The spectroradiometer will be used to measure ocular exposure using rotating hollow fibreglass headforms. The transmittance properties of protective eyewear (such as sunglasses, ski goggles and safety glasses) in the UV region have been measured and the ocular doses received in their use have been calculated. A paper is to be presented at the ARPS conference and the results submitted for publication.

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SPECTRORADIOMETRIC MEASUREMENT OF SOLAR ULTRAVIOLET RADIATION

C R Roy, H P Gies and G Elliott

The need to determine accurately the spectral power distribution of solar ultraviolet radiation (UVR) at the earth's surface was discussed in the 1983 and 1984 reports. The adoption of an Australian occupational standard for exposure to UVR has further increased the need for accurate solar UV spectral data, especially in regard to the UVR exposure of outdoor workers.

Experimental Details

The solar laboratory installed in the north-west corner of the ARL grounds is operational and a schematic of the measurement system is shown in Figure 1. Considerable testing of the input optics of the detection system has resulted in the present configuration which consists of a 100 mm integrating sphere coupled to the monochromator entrance slit by a 1 m liquid light guide. The integrating sphere is raised into position through a hatch in the laboratory roof, and spectral measurements are made at solar noon when cloud-free conditions prevail. Spectral scans are controlled by a microprocessor and data is initially stored on disc for eventual transfer to the laboratory computer.

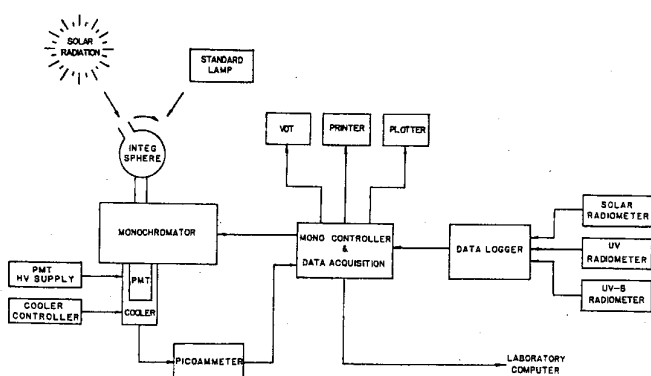


Figure 1: A schematic of the experimental arrangement used in the measurement of solar UVR.

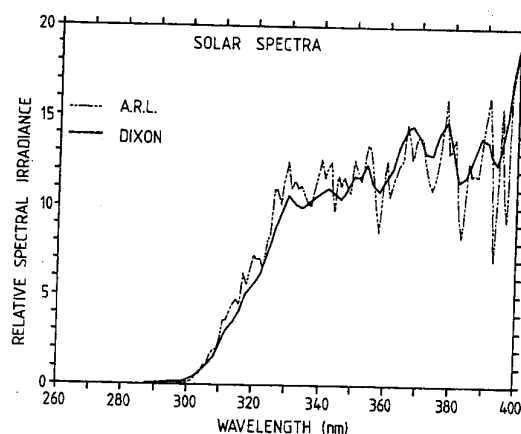


Figure 2: A comparison of the spectral distribution of solar UVR measured by Dixon (1978) with that measured at ARL.

Comparison of spectral distributions of solar radiation measured at ARL in April and that of Dixon (1) are shown in Figure 2. The spectral irradiance values are normalized at 400 nm, and the higher resolution of the Spex 1680B monochromator in comparison with the previous measurements is obvious.

Solar UVR is monitored continuously with an Epley UV radiometer (model TUVR). This has an interference filter which limits the spectral response to the 295 to 385 nm wavelength interval. The UV-B region of the spectrum is measured continuously by an International Light IL 700A UV-B (280-315 nm) radiometer. Total sun and sky radiation are measured with an Epley precision spectral pyranometer. This has a spectral response covering the 0.285 to 2.8 micron region. All three radiometers are interfaced to a datalogger (Figure 1), which has a backup power supply, should the mains supply fail for any reason. Data is stored on tape as 10 minute averages, and transferred to the main computer weekly. Typical results for all three radiometers are shown for an April day in Figure 3.

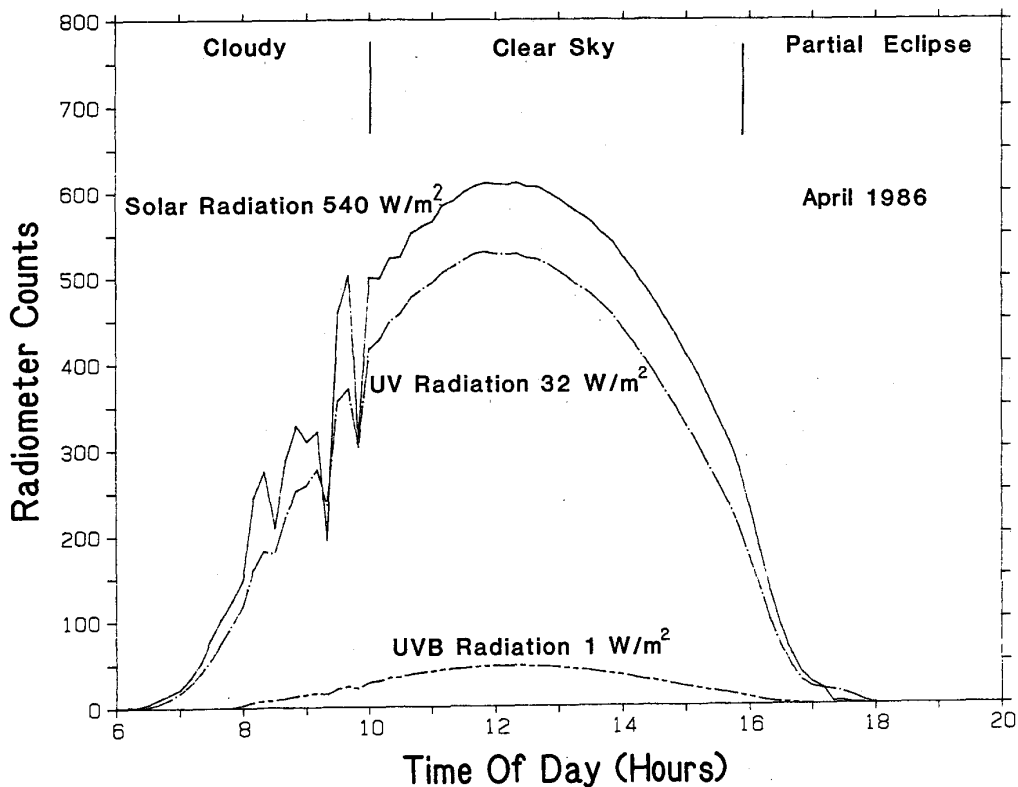


Figure 3: The variation of solar radiation with time of day, showing curves for total solar radiation, UV radiation and UV-B radiation.

The effect of clouds, which were present in the morning, on the irradiance levels can be clearly seen in the figure. The variation in UV-B irradiance with time of day is shown in Figure 4, the highest values occurring at solar noon, and between 60 and 70 percent of the total daily UV-B occurs in the 3-4 hour period around solar noon. The UV-B, as for solar radiation is a maximum in summer and a minimum in winter. Some solar UVR data has been published (2).

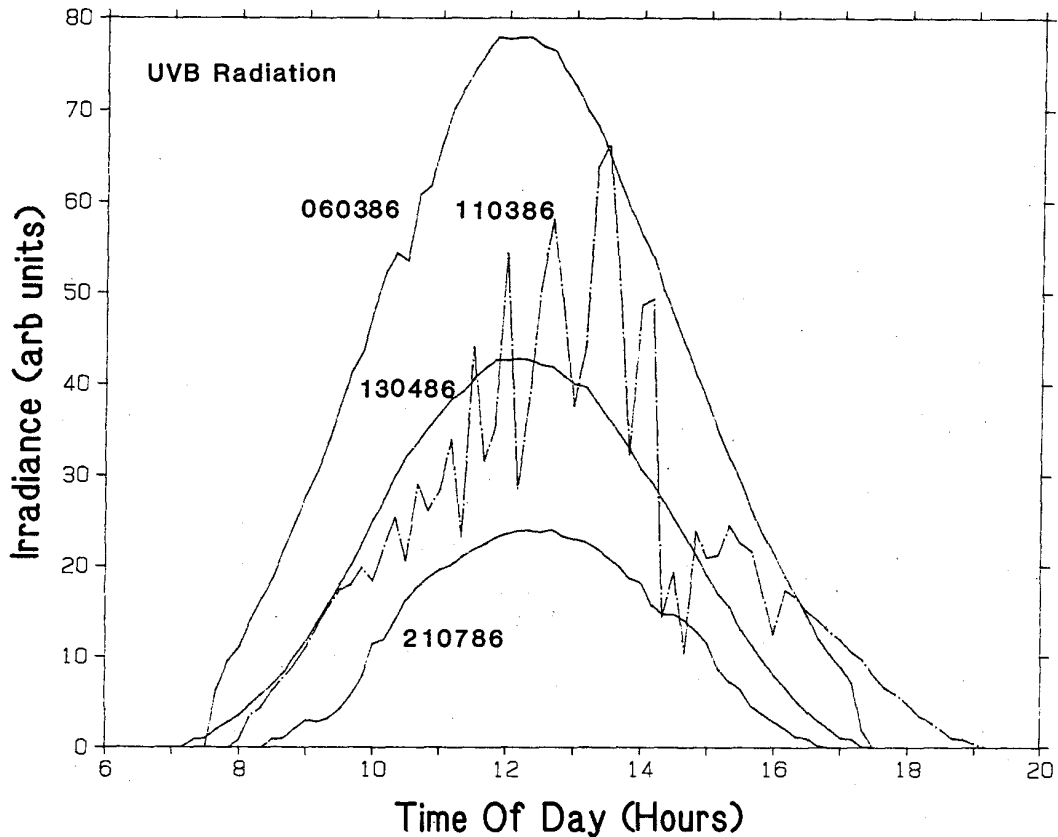


Figure 4: The variation of UV-B radiation with time of day for a number of days measured at different times of the year.

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THE PHOTOBIOSYNTHESES OF VITAMIN D3 IN THALASSAEMIC CHILDREN

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The rationale for this project was given in the ARL 1983 Annual Report. The analysis of vitamin D3 involves a competitive protein binding assay using sheep plasma and it has now been verified under a variety of conditions including varying plasma concentrations, temperature and degree of shaking of the assay tubes. Typical binding curves for two different plasma concentrations are shown in Figure 1.

Problems are still present in the assay of actual samples. The highest priority is being given to improving the recovery of vitamin D3 from the cleanup procedure which is carried out prior to the actual assay. This procedure involves almost twenty different steps with losses at each step resulting in a final recovery of only 20%. These losses are being quantified and minimised with the ultimate aim of doubling the recovery of vitamin D3. Clinical trials cannot commence until this problem is resolved.

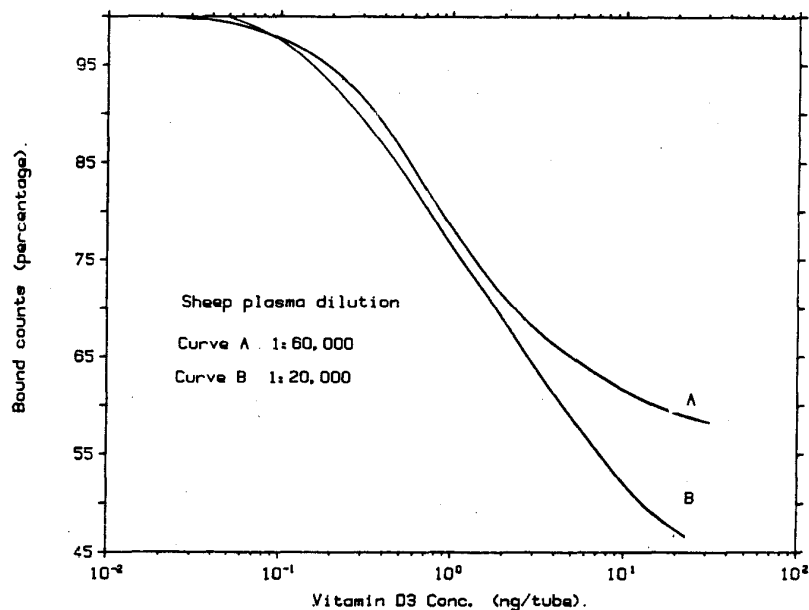


Figure 1: Vitamin binding curve obtained for the competitive binding assay using sheep plasma.

ENVIRONMENTAL RADIOCHEMISTRY AND RADIATION MONITORING

RESIDUAL RADIOACTIVE CONTAMINATION AT MARALINGA AND EMU

K H Lokan (editor)

An account¹ is provided of residual contamination at Maralinga and Emu, in South Australia, where the United Kingdom Atomic Weapons Research Establishment conducted nuclear weapons development trials between 1953 and 1963.

Detailed information is presented about contamination levels at sites on the range where radioactive materials were dispersed. Some of these were associated with trials involving natural uranium or short-lived isotopes which are no longer present. Such sites are of little radiological significance. There are, however, four sites where plutonium-239 was dispersed in substantial quantities from minor trials and information is presented about its distribution. Much of this material has been diluted by mixing with local soil, but there is a significant quantity of material present in the form of contaminated fragments, particularly at Taranaki. A considerable quantity of uranium-235 is also present at Taranaki, but this is of minor radiological significance.

An assessment is made of the radiological significance of the dispersed plutonium, and it is concluded that the material represents a potential long term hazard while it remains in its present form.

Residual radioactivity associated with all but one of the seven major trial sites involving nuclear explosions continues to decay in a predictable way and will, in the worst case, fall below levels considered safe for continuous occupancy within about fifty years. One site, Tadge, contains significant concentrations of plutonium over a small area and is considered to be an additional plutonium-contaminated locality.

Measurements of beryllium concentrations in soil are presented.

Chapter headings and authors are as follows:

1. Plutonium Contamination at Maralinga. M B Cooper, P A Burns, G A Williams, K H Lokan and J C Duggleby.
2. Residual Radioactive Contamination of the Maralinga and Emu Major Trial Sites. J C Duggleby, M B Cooper and P A Smith.
3. Residual Radioactive Contamination at Other Minor Trial Sites. G A Williams, I S Leith and K H Lokan.
4. Beryllium Contamination at Maralinga and Emu. G A Williams.
5. Some Remarks on Risk. P A Burns, M B Cooper and K H Lokan.

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ENVIRONMENTAL RADIATION AT THE MONTE BELLO ISLANDS
AND OTHER REMNANTS FROM THE NUCLEAR WEAPONS TESTS
CONDUCTED IN 1952 AND 1956

John R Moroney

(Abstract of Submission to the Royal Commission into
British Nuclear Tests in Australia, July 1985)

The results from the survey of environmental radiation on Alpha and Trimouille Is. in August 1984 are presented. The environs of G1, Red Beacon and G2 had recently been studied (Cooper et al 1983) and the survey concentrated, therefore, on the radiation fields of lower intensity beyond them. The environmental radiation fields, as defined by the recent measurements, are consistent with expectation based on the review of survey results from 1962 to 1978 (Moroney and Cooper 1982). There is no indication that a seriously contaminated area had been overlooked in the earlier work.

External exposure to environmental radiation is not a hazard to health for the casual visitor to any area at the Monte Bello Islands. This includes the two main areas of residual radioactive contamination, namely northern Alpha I. from Mosaic G2 and central Trimouille I. from Hurricane.

The opportunity was taken to resolve the uncertainty regarding the location of HMS Plym - the platform for Hurricane - and to gather other information on remnants of the nuclear tests.

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PUBLIC HEALTH IMPACT OF FALLOUT FROM
BRITISH NUCLEAR WEAPONS TESTS IN AUSTRALIA, 1952-1957

K N Wise and J R Moroney

During the period 1952-1957, Britain conducted 12 full-scale nuclear weapons tests in Australia in five series, viz. Hurricane(1952), Totem(1953), Mosaic(1956), Buffalo(1956) and Antler(1957). Radioactive fallout from the tests reached many parts of Australia. As part of research undertaken for the Royal Commission into British Nuclear Tests in Australia, we reviewed the several pathways by which radionuclides in fallout could have irradiated the population. A methodology was developed for estimating the radiation doses from the available data and the possible effect that the radiation exposure had on public health was assessed (1).

The information available for each test includes the explosive yield and the approximate trajectories taken by the debris clouds across Australia. Fallout radioactivity was measured for numerous population centres after each test in the last three series. However, there was no systematic monitoring of fallout for the first two test series; and there were no measurements for increased radioactivity in food products subsequent to any of the 12 nuclear tests. It was required, therefore, to provide the missing data by calculation.

Estimation of the radiation doses was approached in two parts: (a) the contributions from the Mosaic, Buffalo and Antler series which were monitored, and (b) the contributions from the Hurricane and Totem series for which there are few fallout data.

In part (a), the activities of the radionuclides making up the measured fallout were established by calculation. Standard models were then used to derive the radiation doses for the population centres - from external radiation, from ingestion of radionuclides in food and from inhalation of radionuclides in air. A simple treatment was adopted to estimate radiation doses from drinking contaminated water.

For part (b), the data assembled in (a) provided the basis for developing statistical models for predicting radiation doses from weapon yields and trajectories of the radioactive clouds. The models were then applied to give the radiation doses to population centres following the tests in Hurricane and Totem, using their yields and cloud trajectories.

Overall, contamination of the food chains was the dominant pathway, as some 67% of the radiation dose to the population came from that source. The most important single contaminant was iodine-131, which, in milk, accounted for some 45% of the total radiation dose. External radiation from radionuclides on the ground contributed about 17% of the population dose; and consumption of contaminated water made up 14%. Inhalation of airborne debris accounted for the remaining 3%.

The radiation doses from fallout in the 12 nuclear tests were delivered to the Australian population over four years. During that period, the population received, on average, a radiation dose from natural sources of some 4000 microsievert. The radiation dose from fallout in the nuclear tests, averaged over the population, was calculated to total 70 microsievert.

The calculated radiation dose to the population can be interpreted in terms of detriment to health by application of risk factors for exposure to radiation. For simplicity, risk factors of 0.01 per sievert, with linear dose-effect relationship, were applied for both cancer mortality and serious hereditary damage in the first two generations. The calculation then gave seven cancer deaths and seven serious hereditary consequences in the Australian population as a result of contamination of the environment with fallout radionuclides from the 12 nuclear tests.

The principal calculations, some results of which are summarised above, were made without radionuclide fractionation in the fallout debris. A full set of calculations with fractionation effects likely to occur in country-wide fallout was not made at the time of the report to the Royal Commission. However, representative calculations made for purposes of comparison, suggested that fractionation effects gave an overall reduction in the radiation dose to the population and removal of the dominance of iodine-131 as the most important single contaminant. Full calculations with fractionation effects are being undertaken.

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HEDLEY R. MARSTON, F.R.S. AND THE ATOMIC WEAPONS TESTS SAFETY
COMMITTEE - THE CONTROVERSY OVER FALLOUT FROM BRITISH NUCLEAR
TESTS IN AUSTRALIA IN 1956

A CHRONOLOGICAL OVERVIEW OF THE CONTROVERSY

H Hamersley and J Moroney

(Abstract of the Submission to the Royal Commission into
British Nuclear Tests in Australia, July 1985)

During the nuclear weapons tests of Operation Buffalo, carried out by the United Kingdom at Maralinga in September-October 1956, a programme of biological studies was undertaken which included investigations of the movement of fission products into food chains. The programme was sponsored jointly by the U.K. Medical Research Council and the U.K. Agricultural Research Council. Several Australian laboratories collaborated with the British on this programme, including the C.S.I.R.O. Division of Biochemistry and General Nutrition located in Adelaide. As well as contributing to the studies at Maralinga, this C.S.I.R.O. Division also undertook an extensive survey of iodine and iodine-131 in the thyroids of grazing animals depastured in areas to the north and north-east of Maralinga in the long-range fallout zone. The survey had the dual purpose of contributing to the "biological programme" and of augmenting the monitoring of fallout being performed by the Australian Atomic Weapons Tests Safety Committee (A.W.T.S.C.). The survey was in the personal charge of the Chief of the Division, Hedley R. Marston, FRS.

Marston began his survey in April 1956, several months in advance of Buffalo, so that he could assess seasonal variation in the iodine content of the glands. He was thus receiving thyroids from his sampling sites and making determinations of iodine in them when Operation Mosaic was carried out at the Monte Bello Islands in May-June 1956. Soon Iodine-131 from the tests was detected in thyroids, and at levels, Marston believed, of such magnitude as

not to accord with various official statements giving re-assuring assessments of the hazards to health of the Australian population presented by the tests. The official assessments were based on the scientific advice of the A.W.T.S.C. Marston believed the assessments were overly re-assuring.

Marston's views were later forcefully expressed in his report to the A.W.T.S.C. (which also discussed the sequel to Buffalo), and this report precipitated an open controversy with the A.W.T.S.C. When Marston moved, towards the middle of 1957, to publish his survey data and his discussion of their significance, others were inexorably drawn into the controversy. In his report to the A.W.T.S.C. he had argued that there had been heavy contamination of areas of Australia with fallout from the tests, and had speculated on what this implied for radiostrontium levels in the food supply to the population. Extensive passages of the report were devoted to discussion of radiostrontium and the hazards it could pose to health. The treatment of radiostrontium and the possible implications for the population in the paper on the survey Marston eventually published in the Australian Journal of Biological Sciences in August 1958. The controversy now embraced not only the disputed scientific questions, but also other issues; they included

- Marston's freedom to publish his results in full, including some data, taken in Adelaide, which were deemed by UKAWRE to require security classification
- the significance of the classified data to the whole set of results; and whether, when taken in full, the data showed unequivocally that the Australian population was at risk from the tests
- the question of whether Marston's critics tried to conceal this situation

and also

- the question of whether Marston's paper, complete with the speculation on radiostrontium, should have been accepted for publication in the Australian Journal of Biological Sciences
- the question of whether the Australian Journal of Biological Sciences should have refused to publish a critique of Marston's paper submitted by the A.W.T.S.C.

- the question of whether the C.S.I.R.O. Editorial Board and the Board of Standards for the Australian Journal of Biological Sciences were even-handed in their treatment of Marston and the A.W.T.S.C. authors

Whether deductions regarding radiostrontium could validly be made from Marston's data on Iodine-131 emerged as the central scientific issue in the dispute.

It is of some interest to note that the possible impact on the health of the population due to contamination of milk supplies by Iodine-131 was overlooked by all parties in the scientific and safety controversy.

To date only fragmentary accounts of the course and development of the controversy have been available. In this study we attempt to provide a fuller account, using documentary sources in which the views and actions of the principals in the controversy are amply recorded. We have decided not to use interviews with any of the surviving principals in preparing our account.

In its present form our treatment lacks something which we plan to supply in the future, namely a discussion of the scientific context in which the controversy developed, in particular the state of scientific knowledge about the environmental pathways through which human populations were potentially at risk from iodine and strontium in nuclear weapons fallout.

One of us (J.M.) was himself a participant in some of the later events reported in this chronological narrative section of the study. This section has largely come from the hand of H.H.