



Australian Radiation Laboratory

Annual Review of Research Projects 1984

Edited by

Donald W Keam

PART 2

Pages 32 - 65

RADIOPHARMACEUTICALS AND NUCLEAR MEDICINE

CHEMISTRY AND STRUCTURE OF
TECHNETIUM COMPLEXES

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

The practice of nuclear medicine relies heavily on the use of technetium-99m radiopharmaceuticals as functional and imaging agents. Knowledge of the fundamental chemistry of technetium-99m complexes is important to establish structure-distribution relationships and to point the way to the rational design of new organ-specific radiopharmaceuticals. Since the molar concentrations of technetium-99m complexes are very low we have used the long lived technetium-99 which allows complexes to be isolated and to be examined by conventional chemical and spectroscopic methods. Our studies have, in particular, centred on the chemistry and structure of complexes containing the $Tc \equiv N$ core.

The crystal structures of $AsPh_4[TcNCl_4]$ and $AsPh_4[TcNBr_4]$ have been published.^{1,2} The complex anions are square pyramidal with the nitrido ligand in the apical position. Addition of CsCl to a solution of $[TcNCl_4]^-$ in conc. hydrochloric acid results in the formation of the six-coordinate $Cs_2[TcNCl_5]$.³ The chloro ligands of $[TcNCl_4]^-$ are labile, resulting in a convenient route to $Tc \equiv N$ complexes. Thus, reaction of $AsPh_4[TcNCl_4]$ with LiBr in acetone rapidly gives the deep-blue $AsPh_4[TcNBr_4]$. The $[Tc^{VI}NCl_4]^-$ anion is an oxidizing agent and reaction with the reducing ligands $[S_2CNEt_2]^-$, PPh_3 , NCS^- and thiooxine results in the formation of $[TcN(S_2CNEt_2)]$, $[TcNCl_2(PPh_3)_2]$, $[TcN(NCS)_4 \cdot CH_3CN]$ and $[TcN(thiooxine)_2]$ all of which contain the $Tc^V \equiv N$ core. The reaction of KNCS with $[TcNCl_2(PPh_3)_2]$ results in the replacement of only the chloro ligands⁴ and indicates that this complex is a less versatile precursor for $Tc^V \equiv N$ complexes than is $[TcNCl_4]^-$.

The $Tc \equiv N$ bond is very stable to hydrolysis, a fact which supports the formation of ^{99m}TcN -radiopharmaceuticals. The reaction of $[TcNCl_4]^-$ with water gives a brown precipitate which is shown to retain the $Tc \equiv N$ core by its i.r. spectrum and conversion to $[TcNCl_4]^-$ on dissolution in conc. hydrochloric acid.³ Attack at $Tc \equiv N$ has been shown in the reaction of $[TcN(S_2CNEt_2)]$ with S_2Cl_2 or $SOCl_2$ to give $[Tc(NS)Cl_2(S_2CNEt_2)_2]$.⁵

The chemistry of technetium 1,2-benzenedithiolato (bdt) complexes is being investigated. Reaction of bdt with $\text{AsPh}_4[\text{TcOCl}_4]$ gives the expected $\text{AsPh}_4[\text{TcO}(\text{bdt})_2]$ which has been characterized by a crystal structure.⁶ The reaction of bdt with TcO_4^- in acid solution results in the formation of a dimer, $[\text{Tc}_2(\text{bdt})_4]$. The crystal structure of $[\text{Tc}_2(\text{bdt})_4]$ shows the complex to consist of two near-perfect trigonal prisms sharing one face. This structure is of great interest since it appears that it represents a totally new coordination geometry. A paper is in the course of preparation.

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ELECTRON SPIN RESONANCE STUDIES OF TECHNETIUM COMPLEXES

J F Boas

Technetium-99m complexes are widely used as functional and imaging agents in nuclear medicine. However, the structure and fundamental chemistry of technetium complexes is not well known. The use of the long-lived technetium-99 nuclide allows conventional chemical, structural and spectroscopic studies to be performed on these complexes. Electron spin resonance (e.s.r.) is a spectroscopic technique capable of giving detailed information about the electronic structure and bonding of the technetium ion in its three paramagnetic valence states, namely Tc^{2+} (outer electron configuration $4d^5$), Tc^{4+} ($4d^3$) and Tc^{6+} ($4d^1$). Very few e.s.r. studies of technetium complexes have been reported in the literature. Studies of the e.s.r. spectra of a number of technetium complexes are proceeding.

- (i) An e.s.r. study of the Tc^{2+} ion in five- and six- coordinate complexes involving the nitrosyl ion in an out-of-plane position has shown the behaviour expected from a $4d^5$ ion, where the strong ligand field has resulted in a low spin complex. The interpretation of the spectra of $[(\theta_4As)_2(TcNO(SCN)_5)]$ has shown that the current methods of analysis of the e.s.r. spectra of low spin d^5 complexes may not be adequate.¹ A detailed analysis of some other nitrosyltechnetate (II) complexes is in progress.
- (ii) An e.s.r. study of the ions $[TcNCl_4]^-$ and $[TcNBr_4]^-$ has been made in conjunction with x-ray crystallographic studies. The results show the trends in g and hyperfine values expected from the position of the Tc ion in the periodic table.²
- (iii) ESR measurements at ca. 9.15 GHz and in the range 2-4 GHz have enabled the effects of concentration and solvent composition on the spectra of frozen solutions of trigonal-prismatic tris [2-aminobenzenethiolato(2-)-S,N]technetium(VI) and -rhenium(VI) complexes to be interpreted in terms of the breakdown of molecular aggregates. In the case of $Tc(abt)_3$, this dissociation gives the monomeric species, while $Re(abt)_3$ appears to give a mixture of trimeric and monomeric species. The spectra arising from the

monomeric species are best interpreted by almost isotropic g and A values but with a subtle interplay of anisotropic line width effects. The extent of the delocalization of the unpaired electron in the $2a_2'$ molecular orbital onto the ligands is indicated by the effects on the ESR spectra of intermolecular exchange interactions between $\text{Re}(\text{abt})_3$ molecules, where the Re ions are probably ca. 10 Å apart. This is a rare example of intermolecular exchange interactions without a direct-bonded pathway.³

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* Department of Physics, Monash University.

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 pertechnetate to a lower valency state where it may be coordinated to a number of complexing agents. Most commonly used reducing agents lead to the reduction of Tc to the Tc(IV) or Tc(V) valency states and in many cases the complex formed contains the $\text{Tc}^{\text{V}}\text{O}$ moiety. We have been studying the use of $^{99m}\text{TcNCl}_4^-$ to prepare ^{99m}Tc -complexes containing a TcN group and the effect of the TcN group on biological behaviour. TcNCl_4^- has been characterised by crystallographic and e.s.r. techniques (1) and is able to form complexes by a substitution route. This is a desirable feature for the preparation of ^{99m}Tc -complexes in that it usually results in purer complexes.

A wide range of agents have been used to prepare ^{99m}TcN -complexes for biological study. Results to date show that the ^{99m}TcN moiety forms weak complexes with hard ligands and as a result tends to exchange with serum proteins.(2,3). With soft ligands, however, complexes formed are stable in vivo and generally show different biological behaviour to that of the complex obtained when alternative reducing agents are used.

The use of $^{99m}\text{TcNCl}_4^-$ for the technetium labelling of monoclonal antibodies is also being studied in collaboration with the Research Centre for Cancer and Transplantation, University of Melbourne. Specificity of the labelling procedure is measured by use of in vitro binding assays in which the labelled antibody is incubated with either reactive or non-reactive thymocyte cells. Results showed that high specific activity labelling could be achieved without loss of specificity. Specificity was also verified in vivo by the localisation of a labelled specific monoclonal antibody following injection into mice containing palpable tumors. Labelled non-specific antibody failed to localise in the same tumor. Further work is in progress.

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UPTAKE OF LIGAND FREE TECHNETIUM IN TUMOURS - A
NEW GENERAL MODEL FOR TECHNETIUM TUMOUR SCINTIGRAPHY

P M Pojer, A C Jakovljevic, M Lichtenstein* and (in part) K N Wise.

INTRODUCTION

As a result of our studies with technetium-99m labelled magnetic particles we discovered that technetium labelled boride particles dissolved, allowing the technetium to be excreted in the urine. This biological behaviour was unlike that of colloidal technetium or pertechnetate and it was therefore hypothesised that, in the absence of any ligands, the technetium was transported as a protein complex. Since weak complexes of technetium have been used in tumour scintigraphy for some time, we felt the labelled metal boride would be a good model to check whether ligands are required to transport the isotope to tumours.

RESULTS

Intravenous injection of technetium-99m labelled nickel boride into mice bearing a T-cell lymphoma in the thigh, did, in fact, show preferential accumulation of the label in the tumour (Jakovljevic, 1984) as shown in table 1.

Table 1. Biodistribution of labelled nickel
boride in tumoured mice**

	Hours after IV administration		
	7.5	52	72
Tumour/blood	0.70 ± 0.30	1.38 ± 0.12	1.91 ± 0.35
Tumour/muscle	2.77 ± 1.53	2.78 ± 1.34	4.39 ± 3.52
Tumour/skin	1.22 ± 0.55	1.02 ± 0.39	1.08 ± 0.16

** Mean of 5 mice ± SD

A further test of this hypothesis which involved a comparison (Pojer, 1985) of the accumulation of technetium pyrophosphate (as control) and the same radiopharmaceutical in the presence of iron dextran (which should lead to enhanced dissociation of the radiopharmaceutical) showed a dramatic increase in uptake in the tumour, as shown in table 2.

* Royal Melbourne Hospital.

Table 2. The effect of iron dextran on tumour uptake of technetium-99m administered IV as pyrophosphate

	Controls*	Iron pretreated mice**
Tumour/blood	2.34 ± 0.92	3.64 ± 1.12
Tumour/muscle	2.99 ± 1.13	4.66 ± 2.60
Tumour/skin	1.13 ± 0.43	1.12 ± 0.43

* Mean of 8 mice ± SD

** Mean of 6 mice ± SD

The implication is that weakly chelated technetium apparently owes its tumour visualizing properties to the ease with which the complex dissociates and not to any inherent property associated with the ligand.

Although clinical evaluations of this theory were envisaged, this project has now been discontinued.

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DEUTERATIONS WITH DEUTERATED RANEY NICKEL

P M Pojer and (in part) A C Jakovljevic

INTRODUCTION

Studies of magnetic particles which could be labelled with technetium-99m (Pojer, 1982a; Pojer, 1982b; Jakovljevic, 1983; Lichtenstein, 1984; Pojer, 1984a) led us to investigate the surface reducing properties of Raney nickel. The applied use of surface reductions of technetium-99m has also been the subject of a provisional patent (Lichtenstein, 1983). Raney nickel could reduce pertechnetate and this property was ascribed to surface hydrogen atoms.

RESULTS

The Raney nickel surface hydrogen atoms could be exchanged with deuterium oxide to a preparation which now, presumably, contained surface deuterium atoms. This preparation was used to effect the following deuterium labelling experiments:

- (1) Exchange of "activated" aliphatic hydrogens (eg benzylic hydrogens, those adjacent to carbonyl groups, etc) to deuteriums.
- (2) Exchange aromatic ring hydrogens to deuterium.
- (3) Convert natural α -"hydrogenated" amino acids to α -"deuterated" amino acids.
- (4) Reduce aromatic carbonyl compounds to benzylic compounds labelled with deuterium at the benzylic positions.
- (5) Reduce alkenes and alkynes to deuterated saturated molecules
- (6) Reduce aromatic rings to fully deuterated cyclohexanes.
The addition across double and triple bonds was found, as expected, to occur in a cis manner. Hydrogen/deuterium exchange in amino acids proceeded with racemisation.

This work has been the subject of a publication (Pojer, 1984b) and a patent (Pojer, 1984c) and has now been discontinued.

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THE DEVELOPMENT OF THE WHOLE-BODY MONITOR AS AN EFFECTIVE
INSTRUMENT TO ESTIMATE IN-VIVO BODY BURDENS

L H Kotler

A semi-empirical expression has been developed (1) to estimate the efficiency at any point below a 150 mm x 75mm NaI(Tl) detector. The expression is valid for a set of discrete photon energies in the region 121 keV to 2599 keV. It has not been feasible to generalise some of the energy dependent parameters of the semi-empirical expression. Therefore in order to calculate the efficiency at an arbitrary energy it has proved necessary to calculate the efficiency at all discrete energies (at the point of interest) and then interpolate appropriately. The energies of interest have been extended to include the 59.6 keV photon of Americium-241 as this nuclide may be present in subjects who have been in Maralinga.

The lung phantom which has been used to the present (2) has now been replaced by a geometric model in which the measurement efficiency of the lung is determined from the average efficiency of a series of random points within it. An advantage of this method is that it allows the dimensions of the "lung" and "chest" to be varied both to suit the individual subject in a more complete manner than previously (2), and to match the standardised dimensions recommended by the I.C.R.P. (3). Furthermore, the sensitivity of the estimate of "lung" efficiency to "lung" dimensions may be directly determined. The mathematical model of the lung is more 'realistic' as it allows the posterior surface of the lung to have dimensions which differ from that of the anterior surface. The model of the lung is depicted in 2 perspectives in Figure 1. The attenuation coefficients for the "lung" material have been empirically determined from measurements on utility bags (2). The material which has been used to simulate the tissue above the lung is perspex (2).

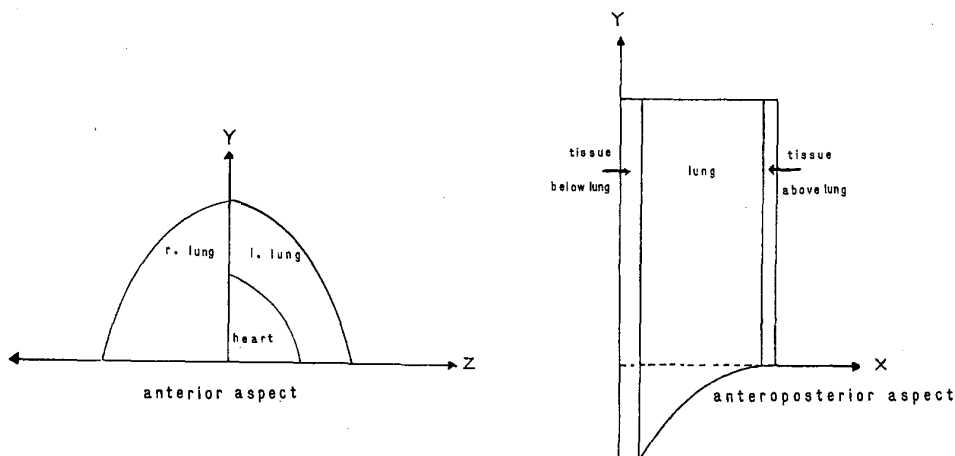


FIGURE 1. Geometrical model of human lung.

A geometric model has also been determined for the liver. The model, depicted in Figure 2, is half an elliptical paraboloid with the anterior surface of the 'liver' being the flat part of the semi-paraboloid. As it can be described analytically its volume can be matched to that of the I.C.R.P. 'standard man' (3). This model is useful in studying ingestion of americium-241, since the isotope may be present in both the lungs and liver.

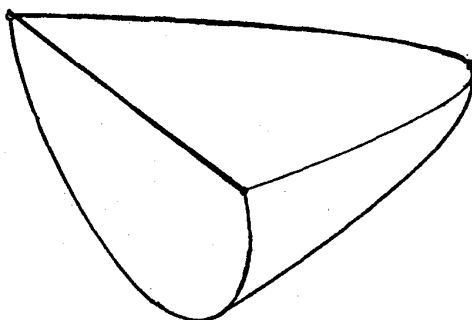


FIGURE 2. Geometric model of human liver.

Work is continuing on the analysis of repeated measurements on two subjects using the least-squares fitting procedure (1). Another standard spectrum has been added to the three described previously (1). This spectrum represents the fallout product caesium-137, which has remained in the body. In order to further improve the fit between data and model it has been found necessary to correct for variations in the zero of the pulse-height scale which have occurred since the standard spectra were generated. There is no direct means of determining this correction at the time of measurement. However it may be estimated by repeatedly performing the least squares fitting procedure with a systematic variation of this parameter. The number of channels by which the zero is shifted to minimise the residual sum of squares is taken as the correct value of the shift. An example of the variation of the residual sum of squares with zero shift is depicted in Figure 3.

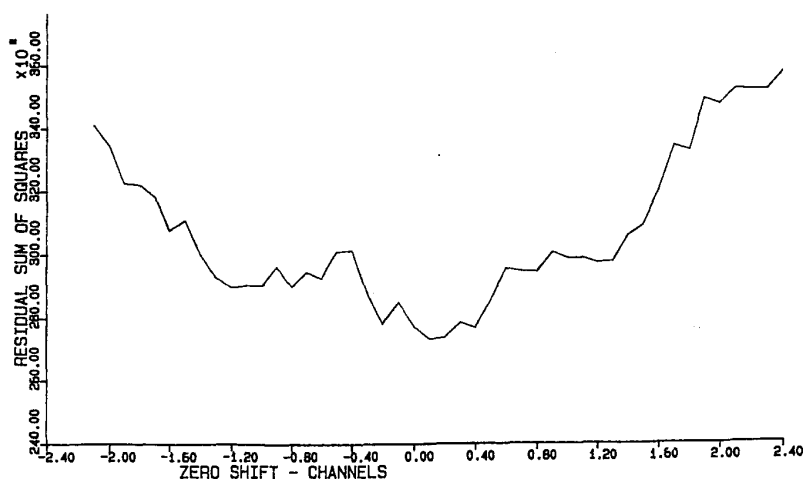


FIGURE 3. Variation of residual sum of squares with zero shift.

Preliminary calculations indicate that the least squares fitting procedure should improve the minimum detectable level by a factor of at least two. For example, for natural uranium it is usually in the range 15 - 20 mg if the calculation is based on a comparison with a previous measurement on a subject. The least squares procedure will generate a minimum detectable level of at least 6 - 10 mg under the same conditions. These latter values are conservative since at this stage it appears that the 'F' statistic may not be a suitable criterion to determine the 'significance' of an additional standard spectrum (1).

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NON-IONISING ELECTROMAGNETIC RADIATIONS

LASER RADIOMETRY - ELECTRICALLY CALIBRATED PYROELECTRIC RADIOMETER

W A Cornelius and R V Sargent

A previous report describes the function, design and operating principles of an electrically calibrated pyroelectric radiometer (ECPR) currently under development (1). The ECPR is primarily intended for use as a measurement standard of radiant power from continuous wave (c.w.) laser beams (although it could be used to calibrate radiometers intended for the measurement of other sources of c.w. radiation ranging from ultraviolet to far infrared wavelengths).

A microcomputer is used to monitor and control the ECPR circuitry so that the desired accuracy and reliability can be achieved. Operating software has been developed and tested in PASCAL language (Z80 based Borland TURBO PASCAL). Assembly routines have been included in the PASCAL code to achieve optimum processing speed. The software has been designed so that it may be readily adapted to different microprocessor systems and also to aid in ECPR circuit replacements where critical system parameters may change (e.g. replacement detector, heater power supply, reference oscillator etc.).

All software dealing with data manipulation, statistical noise analysis and ECPR operating regime has been successfully tested in a program designed to simulate data from the ECPR.

As a consequence of further test results obtained with a partially completed ECPR prototype, modifications were made to a number of the ECPR circuits in order to eliminate noise and instability. In particular, the differential amplifier circuit employed for phase locked voltage and current measurements was redesigned. The power supplies and internal reference oscillator circuits have also been modified to improve system performance.

The electrical heater layer incorporated into the pyroelectric detector design was found to have excessively low resistance values. A different coating pattern was devised to overcome this problem.

Further testing will follow assembly of the complete ECPR circuitry.

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PHOTORADIATION IN THE THERAPY OF TUMOURS

V Delpizzo, W A Cornelius, P M Pojer

The background to this project has been described in detail in a previous report (Delpizzo et al 1985). The experimental work carried out in 1984 was aimed at the direct detection of singlet oxygen production.

The experimental layout is illustrated in figure 1. As a detector we used either of two Judson germanium photodiodes: Mod J 16-18 having a diameter of 1 mm and a responsivity of 0.7 A/W and Mod J 16-8 having a 5 mm diameter and a similar responsivity. The area of the second detector matched more closely that of the aperture at the bottom of the light collecting cone, but its time response is considerably slower than that of the 1 mm diode. The detectors were operated at room temperature.

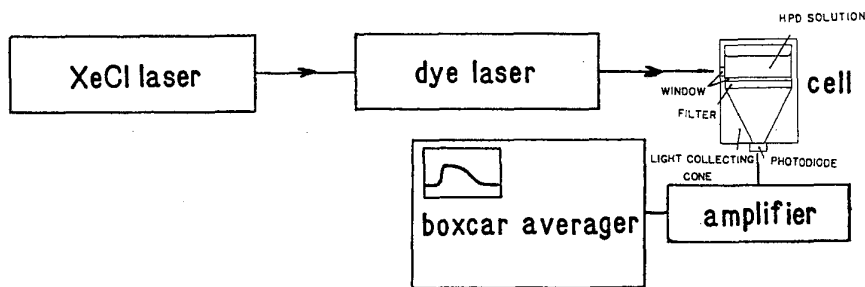


FIGURE 1. Schematic diagram of experimental layout.

The detector signal was amplified with an impedance matched, output buffered amplifier. Various values of the amplifier gain and bandwidth were used. The highest gain employed was 10^6 V/A, with a minimum bandwidth of 250 KHz.

We used two types of filters:

- an interference filter with a transmission bandwidth of 127 nm centred at 1270 nm.
- a gelatine filter (Kodak 87A) with a transmittance of less than 0.1% for wavelengths shorter than 880 nm.

These filters were used alone or together. In some cases several layers of the gelatine filter were used to reduce the transmittance at the unwanted wavelengths.

We have irradiated the sample with a low energy (0.3 mj/pulse), high repetition rate (100 Hz) laser using a boxcar averager to enhance the signal-to-noise ratio by a factor of approximately 100 over that obtained with a single pulse.

Data obtained so far have been inconclusive, as leakage of ambient light has tended to confuse the results.

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DEVELOPMENT OF A UV LASER SOURCE

V Delpizzo and D W Tomlinson

A high power excimer laser has been built and operated. The laser is based on a design described by Scott et al (1982) but it incorporates the "automatic pre-ionization technique" devised by Kearsley et al (1979). The laser head is schematically illustrated in Fig. 1.

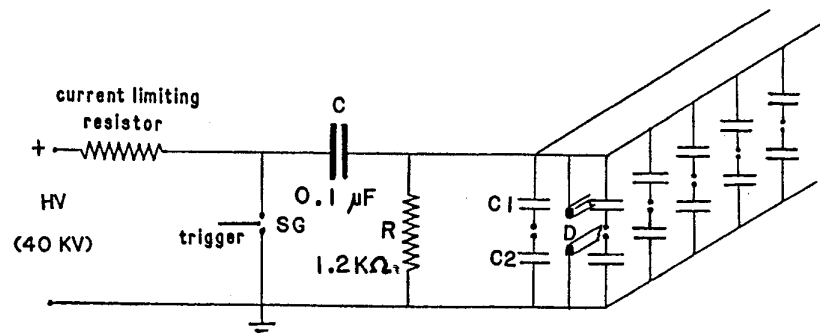


FIGURE 1. Schematic diagram of laser head.

The electrodes consist of two parallel aluminium bars one metre long. They are flanked by four rows of "doorknob" ceramic capacitors (Murata N4700). The top plates of the two top rows (marked C1 in Fig. 1) are electrically and mechanically connected. The bottom plates of the two bottom rows (marked C2 in the figure) are similarly connected. The bottom plates of the C1 capacitors and the top plates of the C2 are 'floating'. The total capacitance of each capacitor row is 36.5 nF. The electrodes and the capacitor rows are mounted in a very compact assembly to minimize inductance and are contained in a 20 cm diameter PVC tube. The ends of the tube are sealed by PVC flanges and quartz windows. The vessel thus obtained is filled with the required gas mixture.

The capacitor C is charged to 40 kV. The spark-gap is then fired thus connecting the positive plate to ground. The charge accumulated on the negative plate causes a large potential difference to appear across the resistor R and, therefore, between the rows of capacitors C1 and C2. The small (typically 3 mm) gaps between the top and the bottom capacitors are then bridged by arcs and the capacitors are charged. Eventually, when the potential difference reaches the breakdown voltage of the main discharge gap (D), the energy stored in the capacitors is transferred to the gas mixture contained in the laser vessel.

In order to achieve laser action it is necessary that the discharge assume "glow" rather than arc characteristics. In an arc discharge ions multiply in an avalanche process and lead to the formation of narrow conducting filaments of low impedance. The energy stored in the capacitors is not efficiently dissipated in these filaments. However if a large number of free electrons is present in the gas before the breakdown voltage is applied, the number of primary avalanches is increased to the point where adjacent avalanche patches overlap. This leads to a reduction of the local gradients of the space-charge field to such an extent that filamentation is prevented (Levatter and Lin (1980)). In our case the large free electron population required to inhibit filamentation is provided by the UV light produced by the arcs appearing between the capacitors of the top and bottom row before the voltage across the main gap reaches its breakdown value. The timing of the pre-ionization arcs with respect to the main discharge can be adjusted by varying the gap between the two rows of capacitors.

The spark-gap (SG) is an improved version of that described in a previous report (Delpizzo et al (1982)). The laser cavity consists of a totally reflecting aluminium mirror and an uncoated quartz plate. The laser can be used with a number of gas mixtures. We have used nitrogen in helium (20% N_2) and xenon and hydrogen chloride in helium. The highest energy was obtained with a mixture of 0.12% HCl and 0.75% Xe in helium and a total pressure of 260 kPa. The pulse energy was then approximately 35 mj and the pulse duration 5 ns. Higher pulse energies (approximately double) can be obtained with KrF but this mixture has been rarely used to avoid unnecessary corrosion of the quartz windows and of the gas handling system. The laser has been routinely operated and used as a dye laser pump.

Acknowledgement: We are grateful to R L Calvert for his contribution during the design stage of this project.

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ULTRAVIOLET RADIOMETRY

H P Gies, C R Roy and G Elliott

The aim of research in this area is to further develop the measurement and calibration capability in the ultraviolet (UV) region of the electromagnetic spectrum. This will enable the accurate determination of the spectral distribution and dosimetry of sources of ultraviolet radiation (UVR). A number of different measurement systems, both spectroradiometric and radiometric, are now operational, namely:

- (1) Spex 1404 double grating monochromator system for high resolution spectral distribution measurements in the laboratory (600 gr/mm gratings, blazed at 250 nm, 0.85 m focal length, 0.005 nm resolution).
- (2) Optronics 740A spectroradiometer system for laboratory and field measurements of spectral distributions (single grating 1200 gr/mm, blazed at 300 nm, 0.25 m focal length, 1 nm resolution).
- (3) Spex 1680B double grating monochromator, currently dedicated to solar measurements, incorporating a Labsphere 200 mm diameter integrating sphere (1200 gr/mm gratings, blazed at 250 nm, 0.22 m focal length, 0.2 nm resolution).
- (4) International Light 700A radiometer with interchangeable heads and filters for radiometric measurements in the UV-A, UV-B and UV-C regions. An intercomparison of radiometers with NML has provided an absolute detector response curve for the IL700A radiometer.
- (5) Scientech volume absorbing calorimeter for broadband radiometric measurements.

These 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). Systems (1), (2) and (3) all have independent data acquisition systems linked to the laboratory MV8400 main computer.

The following investigations are in progress:

(a) VDTs

Measurements of the electromagnetic radiation emissions from VDTs have continued. At this stage, 78 different colour and monochrome sets have been examined. The complete results and data have been published in a technical report (1) and a research paper has been submitted (2).

(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 (3). A paper examining the hazards of exposure to these sources of UVR has been submitted for publication (4).

(c) UVR Sources

A number of different UVR sources in use in industry and commerce such as blacklights, signature verification units and germicidal lamps were examined and an ARL technical report is anticipated in the near future.

(d) Reflectance Measurements

The development and modification of a technique to measure the reflectance of human skin as a measure of the degree of erythema reddening and pigmentation (5) has commenced. Information from such measurements will be useful in interpretation of results in the Vitamin D3 photobiosynthesis project.

(e) Protection Against UVR Exposure

Measurements of the protective effects of clothing and other materials against UVR have been made. Direct and total transmission measurements have been made with a 300 mm diameter International Light integrating sphere attached to the Spex monochromator. Additional and more detailed measurements will be made at 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).

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SPECTRORADIOMETRIC MEASUREMENT OF SOLAR ULTRAVIOLET RADIATION

C R Roy, H P Gies and G Elliott

INTRODUCTION

The need to determine accurately the spectral power distribution of solar ultraviolet radiation (UVR) at the earth's surface was discussed in the 1983 report. The likely adoption of an Australian occupational standard during 1985 will further increase the need for good solar UV data especially in regard to the UV exposure of outdoor workers.

EXPERIMENTAL DETAILS

A 3.6 x 2.4 x 2.7 m laboratory has been installed in the north-west corner of the laboratory grounds. The insulated and air conditioned room has a hatch in the roof to allow entry of solar radiation. Detection equipment will be installed as soon as laboratory tests have been completed.

The instrumentation incorporates a Spex 1680B double grating monochromator. The monochromator contains two 50 x 50 mm, 1200 grooves/mm ruled gratings blazed at 250 nm, resulting in a dispersion of 1.8 nm/mm and a resolution of 0.2 nm. Entrance and exit slits adjust bilaterally and continuously from 50 to 5000 microns.

A microprocessor based scan controller has been built which gives a step resolution of 0.02 nm. Data is initially stored on disc but a daily transfer of solar and calibration data to the laboratory MV8400 computer is anticipated.

The detector is an EMI 9635QA end-on photomultiplier (PMT) which is held at -10°C. The typical dark current is 50 picoamps.

The input optics for the system are still being finalized. A system incorporating a 200 mm integrating sphere with a quartz fibre optic link to the monochromator is planned, but considerable testing is still required.

A typical current versus wavelength plot is shown in Figure 1. The current below the onset (at approximately 293 nm) in the uncorrected plot is due predominately to PMT dark current. In future it will be necessary to average more readings in order to carry out a better dark current correction. The current at 300 nm corresponds to a spectral irradiance of approximately 100 microwatts/m² nm.

OTHER INSTRUMENTATION

Solar UV radiation will be 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 interval. Total sun and sky radiation will be measured with an Epley Precision Spectral Pyranometer. This has a spectral response covering the 0.285 to 2.8 micron region. Both of these radiometers are connected to a datalogger, which has a backup power supply. Stored data will be transferred weekly to the MV8400 computer.

The complete system should be fully functional by the summer of 1985.

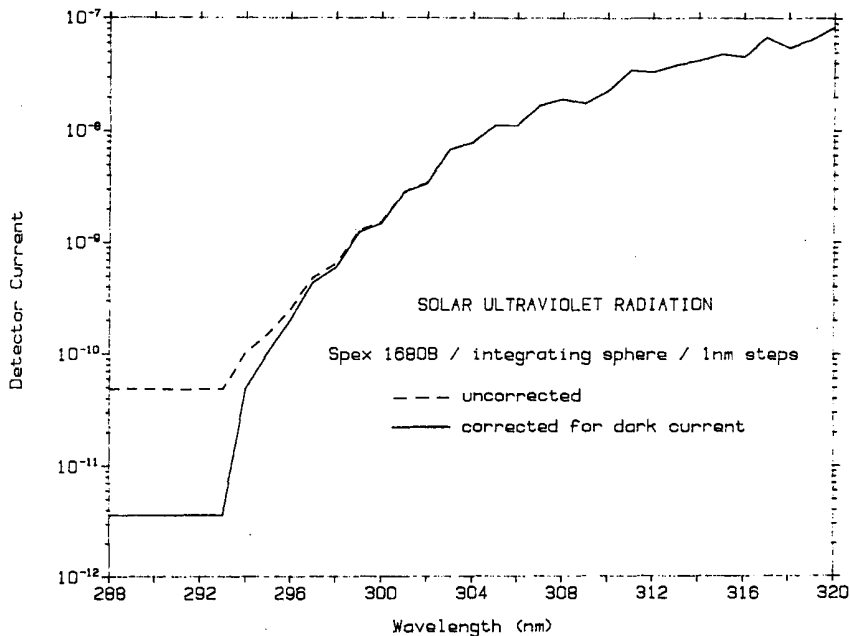


FIGURE 1. Typical solar spectrum scan showing the effect of dark current correction.

THE PHOTOBIOSYNTHESIS OF VITAMIN D3 IN THALASSAEMIC CHILDREN

C R Roy, H P Gies, J A Eisman* and R N Mathews**

INTRODUCTION

A detailed rationale for this project was given in the 1983 Annual Report.

EXPERIMENTAL DETAILS(1) Ultraviolet Radiation Source

A 2 m long sunbed incorporating twenty-six 600 mm long Oliphant FL20SE fluorescent tubes has been built (see Figure 1). A shutter was also constructed so that it is not necessary to turn the lamps off between exposures. Each tube has a dimmer so it is possible to adjust individual tube output so that the UV irradiance is uniform (to within 5%) along the sunbed.

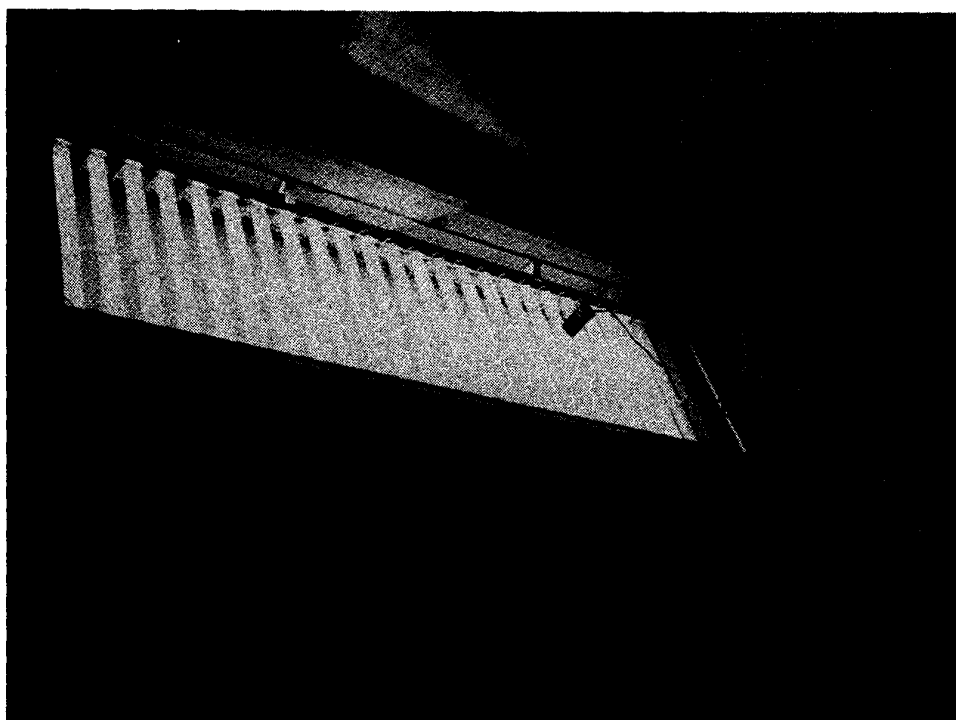


FIGURE 1. Photograph of the UV-B sunbed and International light radiometer used for irradiance measurements. Standing behind the sunbed is a shutter which slides between the lamps and the perspex top.

The unweighted UV-B irradiance, measured at the acrylic plastic surface of the sunbed is approximately 2.7 W/m^2 . Test irradiations on informed volunteers indicate that times for a MED (minimal erythema dose) range from 20 to 50 seconds depending on the skin pigmentation and location of test site. If necessary these times can be lengthened by adjusting the dimmers. This decreases the sunbed irradiance without altering the spectral distribution (see Figure 2).

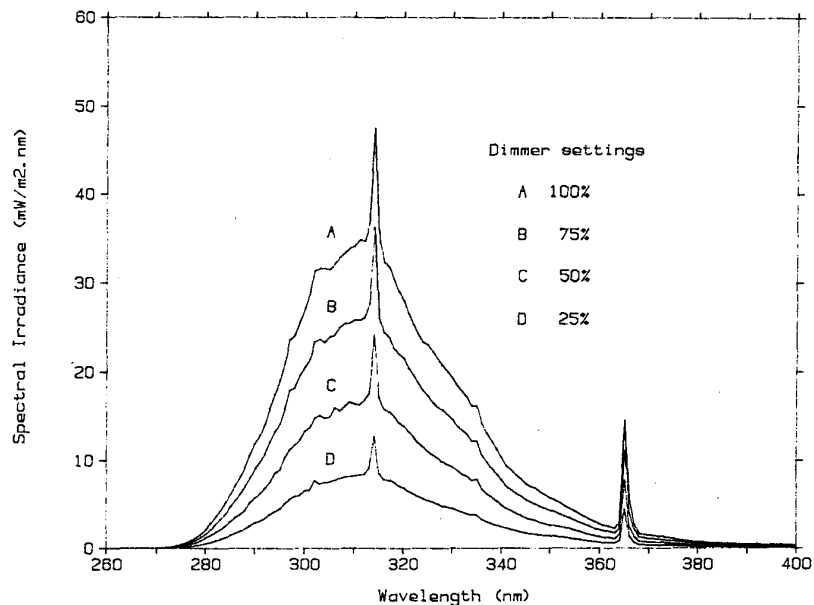


FIGURE 2. Spectral irradiance plots of the Oliphant FL20SE lamps as a function of dimmer setting.

(2) Vitamin D3 Assay

Further testing of the competitive protein binding assay described in the 1983 report was carried out. Calibration curves covering a concentration range of 0.05 to 12.8 nanograms of vitamin D3 are now quite reproducible. Problems are still experienced in the assay of actual samples and this has been traced to the final (HPLC) step in the cleanup procedure prior to the commencement of the actual assay. This problem is holding up the first clinical trials.

(3) Skin Pigmentation

Some preliminary work has commenced on the 'in vivo' measurement of skin reflectance. If the technique is successful this will enable the quantitative determination of skin pigmentation prior to and following UV irradiation.

* Garvan Institute, St. Vincent's Hospital, Sydney.

** Thalassaemic Clinic, Royal Children's Hospital, Melbourne.

ENVIRONMENTAL RADIOCHEMISTRY AND RADIATION MONITORING

POTENTIAL SOURCES OF RADIOACTIVE CONTAMINATION
ORIGINATING FROM THE MILLING OF URANIUM ORE

M.B. Cooper and M.J. Wilks

In order to assess the environmental impact of uranium mining and milling it is essential to gain quantitative information with respect to the physico-chemical state of long-lived radionuclides during the milling process and in the tailings dam. A previous study, (Ring et. al. 1982), has shown that a significant quantity of ^{230}Th is dissolved during the mill circuit. The solubility of other radionuclides, especially ^{226}Ra , is influenced by the pH at the particular stage of the process and possibly by the sulphate concentration in the tailings dam. The aim of this project is to examine the distribution of radionuclides in the milling of uranium ore and also to examine the mechanisms by which these radionuclides may be leached from solid tailings.

Process samples, both solid and liquid, have been collected from various stages of the mill at the Ranger site in the Northern Territory. Three sets of samples have been analysed, two from single shifts and the third set

Table 1. Concentrations of radionuclides in the acid leaching stages of the mill circuit.

Sample	Radionuclide concentration (solids, Bq/g; liquids, Bq/l)			
	U-238	Th-230	Ra-226	Pb-210
Leach Feed				
solid	31.0	29.3	31.2	29.6
liquid	*	*	*	*
Leach Discharge				
solid	4.4 21500	20.4 6000	29.3 *	28.2 *
CCD No. 1				
Overflow	12000	6700	20	110
Pregnant Liquor	12300	7700	*	79

* - below limit of detection

resulted from compounding four weekly samples from the same locations. Liquid samples were prepared for analysis by co-precipitation to separate radionuclides of the U-238 and U-235 series from the bulk of the solution. The precipitates were dried, mixed with resin and contained in standard pvc packs for analysis by high resolution gamma-ray spectrometry. Solids were mixed with resin and transferred to the standard packs for measurement. Additional analyses for U-238, Th-230 and Ra-226 were performed on selected samples using a liquid scintillation technique.

In Table I data are presented for the acid leaching stage of the mill circuit. At this stage approximately 30% of the original activity of Th-230 is in solution whereas Ra-226 and Pb-210 remain substantially in the solid phase. During the next stage which involves solvent extraction Th-230 remains in the raffinate and does not transfer to the organic phase with uranium (see Table 2).

Table 2. Radionuclide concentrations (Bq/l) in liquids from the solvent extraction stages of the uranium mill circuit.

Sample	U-238	Th-230	Ra-226	Pb-210
Pregnant Liquor	12300	7700	*	79
Barren Organic	17	*	*	*
Loaded Organic	22000	*	*	*
Raffinate	*	7800	4	90
Loaded Strip	26000	*	*	*
Barren Strip	23	*	*	*

* - below limit of detection

The results for the various tails material, liquid and solid, are presented in Table 3. In the acid tails there is a significant amount of Th-230 and Pb-210 in solution. Upon neutralisation the concentrations of both these radionuclides in the liquid phase decrease whereas Ra-226 remains moderately soluble. This latter phenomenon has been ascribed in other studies (Ring et. al. 1982) to a decrease in the sulphate concentration and a dissolution of radium sulphate due to the common ion effect. In the analysis of Ra-226 and Pb-210 in retention pond and tailings dam water we observe (Table 4) that levels of Ra-226 are significant, particularly in the tailings dam.

Table 3. Analysis of treated and untreated tailings samples for long-lived radionuclides.

Sample	Radionuclide concentration (solids, Bq/g; liquids, Bq/l)			
	U-238	Th-230	Ra-226	Pb-210
Acid tails				
solid	6	37	35	35
liquid	280	6100	11	95
Raffinate	*	7800	4	90
Neutralised tails				
solid	4	37	35	35
liquid	1	3	12	*

* - below limit of detection

Table 4. Levels of Ra-226 and Pb-210 in water from the retention ponds and tailings dam.

Sample Location	Radionuclide concentration (Bq/l)	
	Ra-226	Pb-210
Tailings Dam	65	2
Seepage Collector	0.2	*
Retention Pond No. 1	0.01	0.08
Retention Pond No. 2	1.10	3.5
Retention Pond No. 3	1.10	2.6
Retention Pond No. 4	0.04	0.04

* - below limit of detection

In addition to the work described above we have commenced an investigation of the characteristics of radium in solution under various conditions in order to explain the chemical behaviour of radioactive species in a uranium mill and to relate the chemical state of a radionuclide to transport mechanisms in the environment. The most likely fate of a soluble radium complex is to be adsorbed on to the surface of particulate material and to date preliminary work has concentrated upon the adsorption profile for radium on to silica colloid. Figure 1 demonstrates the adsorption of radium on colloidal silica in the presence of a low concentration of sulphate. Under these solution conditions radium exists as a soluble sulphate complex however with colloid present this complex becomes adsorbed on to the surface of the silica as the pH of the solution increases. Radium exhibits similar behaviour when the nature of the complexing anion changes. In figure 2 the results of experiments involving solutions of radium carbonate and radium-EDTA are presented. In all cases the effect becomes significant only after the pH of formation of the radium complex with the anion is reached. Radium cations do not adsorb on to the colloid to any great extent.

In collaboration with officers of the Australian Atomic Energy Commission a study of the long term release of radionuclides from tailings has commenced. This work will use accelerated column leaching tests to determine the release rate of radionuclides from various types of tailings, treated and untreated. The content of radioactive species in the leachate will be correlated with levels of other soluble cationic and anionic species.

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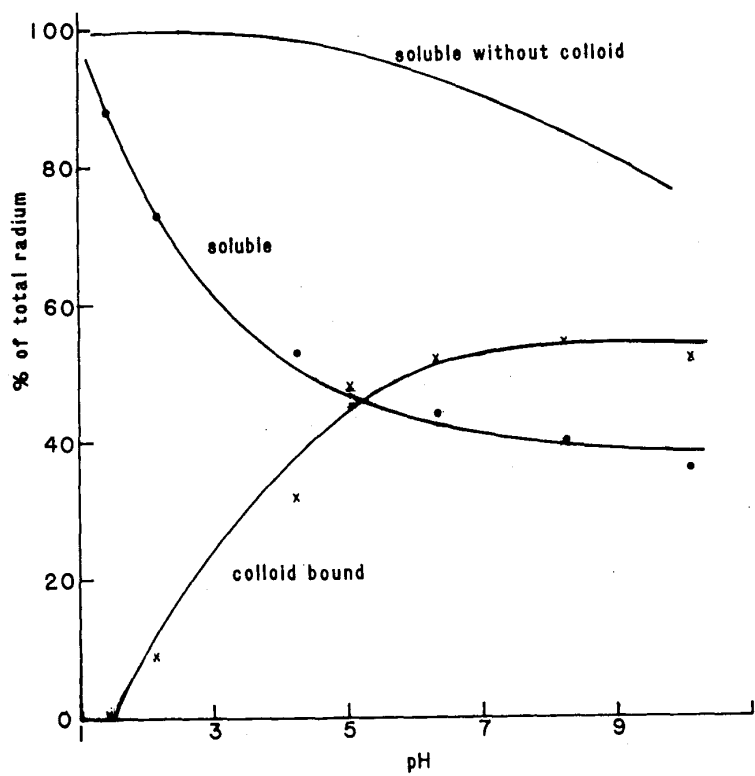


FIGURE 1. Adsorption behaviour of radium on to silica in the presence and absence of sulphate. Supporting electrolyte 0.02M NaNO₃.

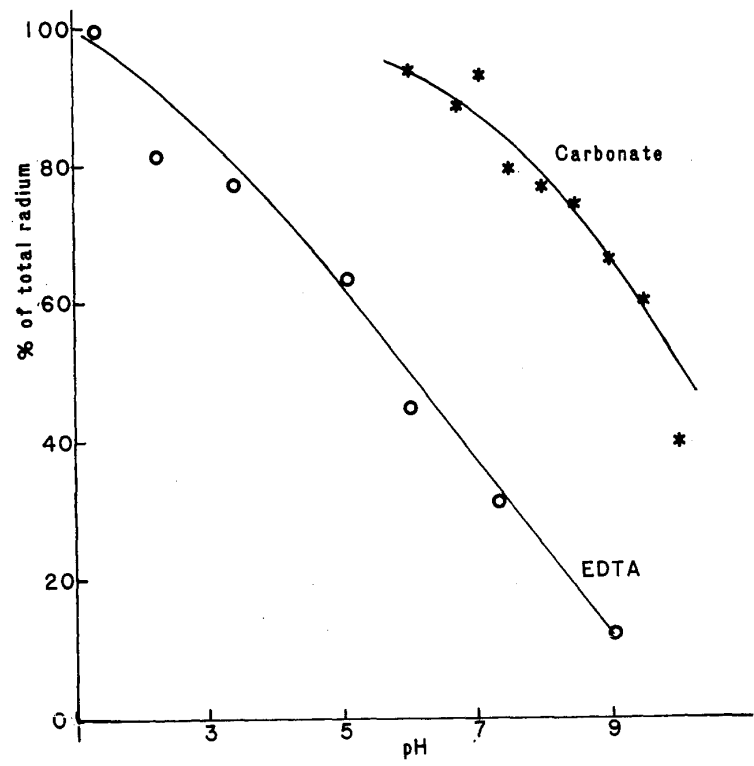


FIGURE 2. Adsorption of radium on to silica in the presence of carbonate (0.001M) and EDTA (0.001M) Supporting electrolyte 0.02M NaNO₃.

APPLICATION OF LIQUID SCINTILLATION COUNTING TO THE ASSAY
OF NATURAL RADIOACTIVITY IN SELECTED SAMPLES

M B Cooper and M Wilks

Investigations into the application of liquid scintillation counting to the analysis of alpha emitting nuclides are continuing. In many cases the technique offers certain advantages over the more conventional methods due to the comparatively simple chemical procedures involved and the higher counting efficiencies. Liquid scintillation counting has been exploited in the analysis of a diversity of environmental materials, viz., vegetation, soils, sediments, uranium mill tailings and mineral sand dusts. Also considerable effort has gone into developing suitable procedures for nuclide separation with compatible extractive reagents and scintillants. Depending upon the requirements of the analytical program it has been possible due to the versatility of the technique to present samples for measurement in a variety of ways; two phase systems, extractive scintillant mixtures and direct addition of scintillant to filters.

Analytical procedures

Radium - The procedure for the assay of ^{226}Ra using a two phase system is now well established and the original method (Cooper and Wilks 1981) has since been adapted to un-processed water samples and different scintillant solutions. It has been shown that any commercial scintillant mixture is applicable provided the solvent is immiscible with water and if there is a large number of samples to be analysed a commercial beta liquid scintillation counter is adequate. Currently a method is being developed to enable the simultaneous assay of ^{226}Ra and ^{228}Ra .

Thorium - The low resolution of the liquid scintillation counting system has restricted the application of the technique to total isotopic thorium except in situations where ^{230}Th levels greatly exceed those of ^{232}Th and ^{228}Th , for example, in uranium mill samples. In this case the developed method has been quite successful although problems arise due to the beta emissions from the short-lived decay products of ^{238}U , ^{234}Th and ^{234}Pr , when the uranium content of the original sample is high. The procedure is straight-forward, provides chemical recoveries of $95 \pm 2\%$ and is not operator sensitive. One unsatisfactory aspect has been that prepared sources have a life of approximately 3 weeks. Whilst it is possible to extract the thorium if a repeat measurement is required, work is continuing in an effort to produce a more stable system.

Uranium - The three isotopes of uranium, ^{238}U , ^{234}U and ^{235}U , are only partially resolved in liquid scintillation counting. However the method is useful for determining the activity of uranium in an environmental sample if it is assumed that ^{238}U and ^{234}U are in equilibrium and that the isotopic abundance of ^{235}U is 4.6% of natural uranium by activity.

Background reduction

A serious limitation to the application of liquid scintillation counting in the determination of alpha-emitting nuclides is the relatively high limit of detection of the technique when compared with conventional alpha spectrometry. In order to achieve a significant reduction in the beta-gamma background of our system and to overcome the effect of beta-emitting species which may be present in the source we are investigating the use of pulse shape discrimination circuitry in our counting system. The current arrangement of electronic modules which is designed to separate beta/gamma and alpha pulses is shown in Figure 1. To date we have achieved satisfactory separation of events as displayed by the time analogue spectrum in Figure 2. Further work will be necessary to improve this time resolution, to increase the stability of the scintillant/sample solution and to simplify the electronic circuitry.

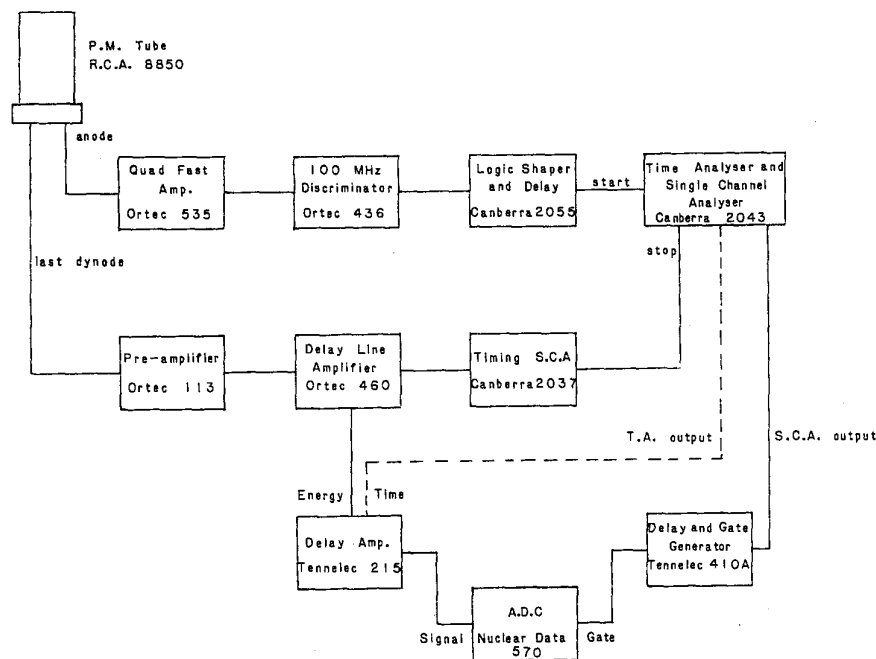


FIGURE 1. Schematic arrangement of modules for pulse shape discrimination of beta/gamma and alpha events in liquid scintillation counting.

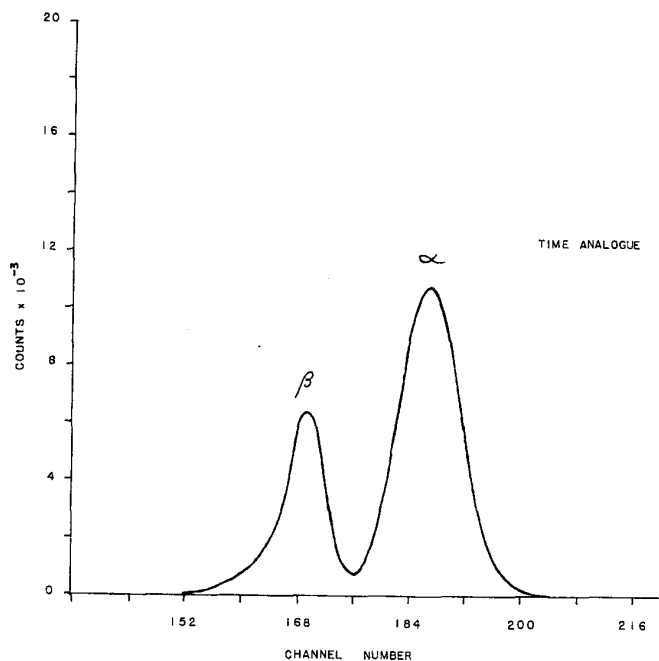


FIGURE 2. Time analogue spectrum obtained using pulse shape discrimination.

Dust monitoring

Another useful application of liquid scintillation counting has been in our investigation of the radiological hazards associated with the processing of mineral sands (Mason et al 1984). Analysis of dust samples from cascade impactors required the development of a simple procedure to measure the activity on a large number of filter papers or other substrates. The method involved the transfer of a filter containing the dust sample to a liquid scintillation vial with a suitable scintillant. This procedure has proved to be extremely useful for the measurement of thorium activity in dust when used in conjunction with a commercial beta liquid scintillation counter.

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