UPGRADATION OF INTERNAL DOSIMETRY FACILITIES AT BARC, TROMBAY

Health Physics Division
BARC

INTRODUCTION

Monitoring of occupational workers for possible internal radioactive contamination, is an important part of a comprehensive radiological surveillance programme. Body Burden Measurement (BBM) and Bioassay and Biokinetics (BB) Sections of the Health Physics Division (HPD) BARC, are responsible for carrying out internal contamination monitoring of occupational workers at BARC, Trombay using in-vivo (direct) and/or in-vitro (indirect) measurements as applicable. Direct measurement techniques viz. whole body counting, thyroid counting and lung counting are used, to estimate internal contamination due to fission products, activation products and actinides that emit x or γ ray photons. In the indirect method, urine or faeces of the occupational worker is analyzed, to determine excretion rate from the body of internally deposited radionuclides, which are pure β or α emitters. Results of both the measurements are used, to estimate Committed Effective Dose (CED), using appropriate biokinetic model and internal dosimetry software. For estimation of internal contamination due to actinides in lungs, dual phosphor detector (phoswich) installed inside a steel room at BARC Hospital has been in use, for the last 30 years. In addition to this, recently we have installed a state-of-the-art system for lung counting, which uses HyperPure Germanium (HPGe) detector as has been done at most of the internal dosimetry laboratories around the world.

In the years 2002-06, we participated in an IAEA intercomparison exercise called ‘Intercomparison of radiological measurements for monitoring purpose–Direct Measurement of Radionuclides, in Simulated Organs’. Under this exercise Knee, JAERI, BOMAB and Thyroid phantoms (representing human body/organisms) distributed with unknown amount of radionuclides, were received. Measurement and estimation of each radionuclide were carried out, using appropriate detection system and results reported to IAEA. In the year 2005, the division also participated in IAEA web-based workshop viz. “Intercomparison exercise on internal dose assessment” called IDEAS. This web based intercomparison exercise consisted of six cases covering wide and complex exposure scenarios for internal dose calculation. These cases were solved using various dose evaluation software and results reported to IAEA. Monte Carlo techniques have been employed, for calibration of various direct monitoring systems, using size-dependent mathematical phantoms, representing Indian and ICRP reference man. Computer software was developed/ procured for biokinetic studies of various radionuclides, using the latest Human Respiratory Tract (HRT), Gastro Intestinal Tract (GIT) and element specific biokinetic models.
In the indirect methods, Fission Track Analysis (FTA) technique has been standardized, to detect ultra trace levels of U and Pu in urine and faeces. Thoron-in-breath measurement technique, for estimation of internal contamination due to thorium, has been standardized for regular use. The division has initiated intercomparison exercise for response of shadow shield bed, whole body counters, in operation at various DAE facilities. All these activities have helped in upgrading and strengthening of internal dosimetry infrastructure at BARC Trombay. A brief report of these activities is given in this article.

**UPGRADATION OF LUNG COUNTING FACILITY**

Permissible limit of intake through inhalation for actinides such as U, Pu and Am for an occupational worker is very low. The direct method of measurement of internal contamination due to these radionuclides, is based on the measurement of activity in lungs, by measuring x/g ray photon emission from them.

Detection of Low Energy Photon (LEP) emitting radionuclides like $^{239}$Pu (17 keV), $^{241}$Am (60 keV), and $^{238}$U (63, 93 keV) in human lungs, at the desired detection level, is rendered difficult due to low yield of their photons and their significant attenuation / absorption in the lungs and the chest wall. For this purpose, specialized radiation detectors with large area, good energy resolution and very low background are required. In order to reduce detector background, measurements have to be carried out inside totally shielded massive steel room (weight 100-150 tons) with optimized shield thickness of about 20 cm. Further reduction in the background of the detector at the region of interest is achieved by lining the inside of the steel room with graded Z material viz. 3 mm Pb + 2 mm Cd + 0.5 mm Cu in this order.

As the background of the detector is dependent on the thickness/volume of the detector, earlier thin NaI(Tl) detectors of 200 mm diameter and a few mm thickness (3 to 12 mm depending on application) were employed. Later on, in early seventies, to further reduce the background of these thin detectors, a new type of detector known as ‘phoswich detector’ was developed. Phoswich is a combination of a thin primary NaI(Tl) (3 to 12 mm thick ) and a thick secondary CsI(Tl) (50 mm thick) coupled to three photomultiplier tubes. Difference in the decay times of the two scintillators is used, to reduce the background of the primary thin detector by about a factor of ten, by using pulse shape discrimination technique. A lung counting facility using phoswich detector is in operation at BARC Hospital for more than thirty years, for routine monitoring of radiation workers.

In mid eighties, array of planar HPGe detectors was developed by some laboratories abroad. Although the detection area of these arrays was much lower as compared to 200 mm diameter phoswich, their inherently superior energy resolution, more than compensated for their smaller area, as the identification of the radionuclides was possible at much lower level of radioactivity. However these systems were prohibitively expensive and because several liquid nitrogen Dewars had to be used for cooling the detectors in most of them, their positioning over the human chest was considered to be little complicated. Moreover, the energy resolution of planar detectors was relatively poor as compared to the expected value and they were not considered as rugged as coaxial HPGe detectors, used for High Energy Photon (HEP) detection ($^{137}$Cs, $^{60}$Co, $^{131}$I etc). In the late eighties / early nineties, an improved technology of growing coaxial HPGe detectors was used, to develop larger diameter crystals with lower thickness. This special coaxial geometry, resulted in a reduction of detector capacitance compared with the earlier conventional 51 mm dia. planar detector. This reduction in capacitance helped in improving energy resolution compared with the best available planar detector. These detectors were designated as LOAX HPGe detectors.
The superior geometry of LOAX detectors, provides lower noise, superior energy resolution, high peak to background ratio and much lower background continuum. Another noteworthy development took place towards the end of the last decade, when 3 or 4 crystals of 70 mm dia. each of LOAX HPGe could be sealed in a disc-like vacuum tight enclosure and cooled to liquid nitrogen temperature, by attaching them from a side to a single large size Dewar. This has considerably improved the convenience in using these systems for routine monitoring of radiation workers. As a result of these developments, the cost of these systems also came down and they became more affordable.

We have procured a state-of-the-art system which comprises three (70 mm dia. x 25 mm thick) LOAX HPGe detectors in one enclosure, with side connection to a single 30 litre Dewar which is kept on a platform fixed to the wall of the steel room. The detector has 0.8 mm thick carbon entrance window, which can transmit all photons above 10 keV energy, to active area of the detector. The signal from each detector can be analyzed separately as well as in any combination with other detectors. The spectrum of individual detector is used, to obtain information about the distribution of the contaminant in the lungs. For this purpose, three separate MCA cards are used. Figs. 1 and 2 show an array of LOAX HPGe, installed inside steel room for lung monitoring of radiation workers. The detector system is movable vertically and the bed can be moved in all the three directions, for positioning of the detector above the chest of the subject to be monitored.
The average energy resolution (FWHM) of the three detector system at 17 keV ($^{239}$Pu), 60 keV ($^{241}$Am), 63 keV ($^{238}$U), 93 keV ($^{238}$U) and 185 keV ($^{235}$U) is measured to be about 505, 650, 590, 740 and 730 eV, respectively. The energy resolution of 650 eV for $^{241}$Am (60 keV) may be compared with the resolution of about 12 keV, obtained with phoswich detector. The excellent resolution and good sensitivity of the LOAX detector system provides a more accurate assessment of internal contamination of low energy X-rays/ g-emitting actinides of interest, even in presence of other gamma emitting radionuclides. Keeping in view these advantages, we have planned to use LOAX HPGe system for special monitoring and continue to use phoswich for routine monitoring. The calculated minimum detectable activity (MDA) of LOAX HPGe system for a monitoring period of 3600 sec is 4 and 5 Bq for $^{241}$Am and $^{238}$U, respectively. Fig. 3 shows the spectra for $^{241}$Am recorded with LOAX HPGe detector.

Earlier, the lung counting system was calibrated by an in-vivo calibration technique, which involved inhalation of $^{103}$Pd-$^{51}$Cr [20 keV X-ray and 320 keV g-ray] labeled polystyrene aerosols by human volunteers, as part of an international intercomparison exercise. The present calibration factors for assessment of lung burden due to actinides, are based on measurements carried out in the mid eighties using realistic thorax phantom, designed and developed by the Lawrence Livermore National Laboratory (LLNL), USA and again in the year 1997 using JAERI (Japan Atomic Energy Research Institute) phantom i.e. Reference Asian phantom. Recently, the phoswich and HPGe system have been tested again using JAERI phantom as a part of IAEA intercomparison exercise.

**APPLICATION OF FISSION TRACK ANALYSIS (FTA) TECHNIQUE, FOR ESTIMATION OF INTERNAL CONTAMINATION DUE TO PLUTONIUM**

In order to carry out internal contamination monitoring of workers handling plutonium, analysis of urine/faeces is normally carried out, to determine excretion rate of plutonium. The method involves chemical separation of plutonium from the bioassay sample, followed by electro deposition and final activity quantification by alpha spectrometry. Fission Track Analysis (FTA) technique is more sensitive than the above method. Therefore, it has been standardized for measurement of trace levels of Pu in bioassay samples. In this technique, chemically separated plutonium from the sample and a Pu standard are electrodeposited on planchettes, covered with Lexan Solid State Nuclear Track Detector (SSNTD) and irradiated with thermal neutrons in the APSARA reactor of BARC. Pu in the samples undergoes fission and the resulting fission fragments produce tracks in the Lexan film. After irradiation, the Lexan films are chemically etched with 6 M NaOH at 60°C for 1 hour. The tracks thus developed are counted manually, using 400 X magnification optical microscope. The net fission tracks in the Lexan films of the sample and the standard are used, to calculate the amount of Pu in the sample. Presence of uranium in the reagents used for the chemical separation of Pu can lead to interferences in the analysis of Pu at trace level. Therefore, doubly distilled electronic grade reagents...
The minimum amount of Pu that can be determined by this method, using doubly distilled electronic grade reagents, is about 12 mBq/ L. Further efforts are being made, to improve minimum detection limit and to automate the time consuming process of counting of fission tracks manually by using image analyzer.

**THORON-IN-BREATH MEASUREMENT TECHNIQUE FOR ESTIMATION OF THORIUM BODY BURDEN**

Thoron ($^{220}\text{Rn}$) is a noble gas and it occurs in the decay series of $^{232}\text{Th}$. It is possible to estimate thorium body burden of a person, by measuring the thoron content in his breath by using an ElectroStatic Chamber (ESC). The method is based on the observation, that more than 88% of decay products of thoron are positively charged ions at birth and may be collected on an electrode maintained at sufficiently high negative potential. In order to estimate thoron in breath, the person is made to inhale thoron-free air from a delay chamber and exhale into the electrostatic chamber having a collection electrode, maintained at sufficiently high negative potential. The thoron progeny atoms formed due to decay of thoron in the electrostatic chamber are collected on a removable metallic plate, kept attached to the collection electrode and counted by employing a Fission Track Analyzer (FTA). The FTA analyzer is essentially an imaging device that records the fission tracks produced by the decay of actinides. The tracks are then counted, and the number of tracks per area is used to estimate the thoron concentration in the breath. The FTA setup and the tracks observed with the microscope are shown in Figs. 4 and 5, respectively.

Fig. 4: Fission track analyzer set-up

Fig. 5: Fission tracks per field ($1.91 \times 10^{-3} \text{ cm}^2$) observed under 400X magnification
to the electrode, which is later assayed for alpha activity using ZnS(Ag) scintillation detector. By proper calibration of the system, it is possible to correlate alpha activity collected on the metallic plate with thorium body burden. Fig. 6 shows the Thoron In Breath Measurement (TIBM) setup. The minimum detectable level of thorium in the body, for this system is about 4 Bq which is a small fraction of the ALI. A software has been developed to compute thoron in breath, thorium in the body and the resultant dose from the gross alpha counts, obtained from a PC-based alpha counting system. Recently we have started thoron-in-breath measurement on some workers from gas mantle industry, who handle thorium powder.

The detection systems (Phoswich, Array of HPGe) used for assessment of lung/liver burden of LEP emitters require calibration with realistic thorax phantoms (LLNL, JAERI). The partially and wholly shielded detection systems, employed for the assessment of HEP emitters, are calibrated with tissue equivalent BOMAB phantoms. Attractive alternatives to physical phantoms are the theoretical calibration methods, involving Monte Carlo techniques in conjunction with mathematical phantoms, such as MIRD / Cristy and BOMAB (Fig. 7). An added advantage of theoretical calibration is the fact, that detection efficiencies can be calculated for any photon energy, source distribution, shape and size of the organ, detection geometry and the physique of the radiation workers.

Based on Monte Carlo photon transport techniques, a number of specialized software in FORTRAN language, have been developed in the division. In brief, the software generated different types of source distributions in the relevant organs/whole body and simulated photon transport through different types of tissue media of the mathematical phantom, considering possible interaction processes, namely photo-electric, Compton and pair-production, in proportion to their individual probabilities. A photon is traced in the relevant part of the phantom (head, neck, thorax, whole body), until it either gets completely absorbed or escapes the phantom. The programme finally simulates pulse height response and the corresponding Detection Efficiencies (DEs) of the various detection systems, employed for assessment of internal contamination of radionuclides.

**THEORETICAL STUDIES IN INTERNAL DOSIMETRY**

1. Monte Carlo studies

The Monte Carlo techniques have been utilized with a great deal of success, in the field of radiation protection, particularly in internal dosimetry of radionuclides. At BARC, a variety of detection systems are in operation, for estimation of internal contamination due to actinides and fission/activation products. The detection systems (Phoswich, Array of HPGe) used for assessment of lung/liver burden of LEP emitters require calibration with realistic thorax phantoms (LLNL, JAERI). The partially and wholly shielded detection systems, employed for the assessment of HEP emitters, are calibrated with tissue equivalent BOMAB phantoms. Attractive alternatives to physical phantoms are the theoretical calibration methods, involving Monte Carlo techniques in conjunction with mathematical phantoms, such as MIRD / Cristy and BOMAB (Fig. 7). An added advantage of theoretical calibration is the fact, that detection efficiencies can be calculated for any photon energy, source distribution, shape and size of the organ, detection geometry and the physique of the radiation workers.

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Theoretical studies have also been carried out, for a series of realistic mathematical phantoms, generated by scaling down the Cristy and BOMAB phantoms, to represent radiation workers of different physiques (W/H = 36kg/137cm to 93kg/188cm). In addition to this, based on experimental comparison studies, lungs, liver and skull in Cristy phantom were redesigned to be more realistic and the same were incorporated into the computer programmes. The various Monte Carlo codes developed in the division are: i) ‘FANTOM’ for lung burdens of actinides, ii) ‘FANTLIV’ for liver burdens of actinides and Pm-147, iii) ‘SKULL’ for skull/skeleton burdens of actinides iv) ‘THYROID’ for thyroidal burdens of iodine-125,131 and, v) ‘BOMAB’ for whole body burdens of fission and activation products. These experimentally validated codes, have generated a variety of information not obtainable from the physical phantoms. The calibration factors determined from these codes, for various detector geometries, have been used for assessment of internal contamination, due to LEP emitters. As an illustration, the development of computer programme SKULL is described in the following paragraph.

Based on Monte Carlo photon transport technique a computer programme SKULL was developed, that generates surface sources of actinides on the skull and simulates response of a 20 cm dia phoswich detector, positioned on the top/side of the head of the Cristy phantom. The skull in the Cristy phantom consists of an ellipsoidal cranium and facial skeleton, which has a shape of elliptical cylinder. For Monte Carlo simulation of uniform surface sources of bone seeking actinides (Pu/Am) on the skull, the probability density function governing the elliptical/ellipsoidal distributions.
and the corresponding calibration factors of the detector for different counting geometries. Fig. 9 depicts the generated PHS of a 20 cm dia. phoswich detector, positioned on the side of the head of the Cristy phantom, from uniform surface distribution of $^{241}$Am source.

In addition to the several developed codes, a general purpose Monte Carlo code MCNP 4A has also been used, for calculation of several important detector

![Flow chart of the computer program SKULL developed for computing the response of a phoswich detector to actinide source distributed on the skull](chart.png)
parameters such as photo fraction, intrinsic efficiency, Iodine K-shell escape probability for NaI (Tl) detectors of different sizes in addition to the calibration of in vivo monitoring systems of the division. The results from the Monte Carlo studies have been used, for the assessment of organ/whole body burden of several radionuclides of interest for radiation workers of different physiques, as well as for the estimation of uncertainties associated with various detection parameters such as source distribution, shape and size of the source-organ and detection geometry.

2. Internal Dose Calculations, Biokinetic Studies and Relevant Software

In the past few years, ICRP has made major revisions in it’s recommendations regarding protection from ionizing radiations. It has developed a series of biokinetic and dosimetric models, for calculating radiation doses from intake of radionuclides in the body. It has also developed new Human Respiratory Tract (HRT) and Human Alimentary Tract (HAT) models for this purpose. The new models have been developed, to enable dose estimates for radiation workers as well as for the general public, including children of all age groups. These new models are considerably more complex as compared to earlier ones and as a consequence they present considerable difficulties in their implementation.

A computer programme has been developed and standardized by the division, for dose assessment and biokinetic studies of various radionuclides. The method incorporates the compartmental form of the new HRT, Gastro-Intestinal Tract (GIT) and new biokinetic model of several radionuclides of interest. HAT will be incorporated in future software. The method provides solution from the complete compartmental model and can calculate the daily urinary excretion and the amount of radioactivity in various organs at any time, for both acute as well as for chronic intake by inhalation and ingestion. The method can be used for any radionuclide, by incorporating it’s biokinetic model in compartmentalized form along with it’s transfer rate constants. The programme also calculates the total number of disintegrations ($U_S$) over any time interval in any organ and enables computation of committed effective doses. The programme has been used to evaluate the material specific clearance and absorption rates from the measured lung retention of $^{125}$Sb. Using these material-specific data and default ICRP parameters, the programme enables computations of committed effective doses for different types of compounds. In addition to this, computations of Inhalation Dose Coefficients (Sv Bq$^{-1}$) for absorption Type $S$ compounds of $^{125}$Sb for occupational exposures (default size 5 im AMAD aerosol) have been carried out. These values are not available from any of the ICRP publications. The results obtained with material specific data instead of default ICRP parameters, are expected to yield more realistic internal dose estimates for the radiation workers. This method has been used to solve the biokinetic models of several radiologically important elements like Pu, U, Th, Sr, Cs, I and Sb. The result obtained by solving biokinetic models,

![Fig. 9: Generated pulse height spectrum of a phoswich detector for uniform distribution of $^{241}$Am activity on the skull of Cristy phantom](image)
was compared with the experimentally obtained values. This was also used to find out uncertainties in ICRP biokinetic parameters.

Many software packages like LUDEP, MONDAL/MONDES, IMIE and IMBA are commercially available for internal dose evaluation. Among them the most advanced software package is Integrated Modules for Bioassay Analysis (IMBA) Professional Plus. This incorporates latest biokinetic model of various radionuclides. The division has recently procured this software. The software is having many advanced features for standard calculations and all of the ICRP default values can be selected from built in database at the touch of a button. For more detailed calculations, the user can enter individual parameter values. The IMBA has enhanced the capabilities of internal dosimetry laboratory further, since certain types of exposure scenarios can only be handled by this software. Calculation of internal dose for few case studies have been carried out using IMBA and compared with ICRP-78 methodology. The IMBA allows the user simultaneous fitting of more than one measured data types i.e. urine, faeces and whole body of radiation worker, for best estimate of intake. As a result, it gives realistic estimate of intake and committed effective dose.

**IAEA Intercomparison exercise: Reference Asian-JAERI Phantom**

Assessment of lung burden due to actinides such as plutonium and uranium isotopes and $^{241}\text{Am}$, is based on the detection of low energy photons and x-rays emitted in their decays. These Low Energy Photons (LEP < 100 keV) suffer severe attenuation due to soft tissues and rib bones overlying the lungs. Therefore, it is necessary to calibrate the detection systems used for lung monitoring of radiation workers, using realistic phantom. The JAERI phantom is a realistic phantom representative of thorax of Reference Asian man as against LLNL phantom which is a representative of a Caucasian man. The JAERI phantom was received by the division under IAEA sponsored intercomparison exercise viz. “Intercomparison of Radiological Measurements for Monitoring Purposes – Direct Measurement of Radionuclides in Simulated Organs”.

Under this exercise, various phantoms were received for intercomparison purpose viz. Knee, JAERI, BOMAB and Thyroid phantoms. Knee and JAERI phantoms are realistic phantoms simulating human knee and torso of the reference man respectively and are used, for calibrating the detection systems for the actinides such as $^{239}\text{Pu}$, $^{241}\text{Am}$, Nat. and Enr. U. The BOMAB and Thyroid phantoms are used for calibration of detection systems for HEP emitters such as $^{131}\text{I}$, $^{137}\text{Cs}$ and $^{60}\text{Co}$. IAEA circulated two sets of phantoms among participating laboratories and phantoms were designated as JAERI I or JAERI II depending on the number assigned to the set.

The JAERI core phantom contains a full rib cage, spine and scapula at the back side. The torso plate of this

![Fig. 10: JAERI phantom with it’s internal parts](image)
phantom is constructed of an adipose-muscle substitute mixture and contains synthetic bone and cartilage. The overlay plates of the phantom are constructed of different adipose-muscle substitute mixtures, to simulate different Chest Wall Thicknesses (CWT). The torso cavities contain lungs, heart, liver and other organs. Six lung sets were provided with the phantom, which contained

Table 1: Summary of measurements carried out at BARC on JAERI phantom with various lung sets. Detection systems and counting geometries used are also given.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Detection systems</th>
<th>Counting Geometries</th>
<th>Reference Asian JAERI phantom</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Phoswich (20 cm dia. x 1.2 cm thick) detector with 0.5 mm Be window</td>
<td>Trombay Standard Geometry (TSG)* Twin geometry in supine and prone position</td>
<td>$^{140}$Pu (low) 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$^{140}$Pu (high) 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$^{241}$Am 11</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Nat. U 16</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>3% Enr. U 15</td>
</tr>
<tr>
<td>2.</td>
<td>Phoswich (20 cm dia. x 0.3 cm thick) detector with 0.5 mm Be window</td>
<td>TSG, Twin geometry, supine and prone position</td>
<td>Same as 1.2 cm thick phoswich</td>
</tr>
<tr>
<td>3.</td>
<td>Square Phoswich (10 cm x 10 cm) detector with 1 mm Be window</td>
<td>Four detectors array (Two phoswich over each lung), TSG, in supine, prone and lateral position</td>
<td>$^{241}$Am 58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nat. U 61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3% Enr. U 50</td>
</tr>
<tr>
<td>4.</td>
<td>NaI(Tl) (12.7 cm dia. x 1.27 cm thick) detector with 1 mm Be window</td>
<td>TSG, Twin geometry and tilted geometry in supine, prone and lateral position</td>
<td>$^{241}$Am 73</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nat. U 71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3% Enr. U 73</td>
</tr>
<tr>
<td>5.</td>
<td>NaI(Tl) (20 cm dia x 10 cm thick) detector with 1 mm thick SS window</td>
<td>Static &amp; scanning geometry</td>
<td>$^{232}$Th 20</td>
</tr>
<tr>
<td>6.</td>
<td>An array of three LOAX HPGe detectors (7 cm dia. x 2.5 cm thick) with 0.8 mm carbon window</td>
<td>TSG and tilted geometry in supine and prone position</td>
<td>$^{138}$Pu (low) 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$^{138}$Pu (High) 15</td>
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<td>$^{241}$Am 16</td>
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<td>Nat. U 16</td>
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<td>3% Enr. U 16</td>
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<td></td>
<td></td>
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<td>$^{232}$Th 15</td>
</tr>
</tbody>
</table>

*In this geometry detector is placed in the central region of the chest, above the lungs with upper edge of the detector touching the sternum bone below the neck.
natural thorium, natural uranium, uranium with 3% $^{235}$U enrichment, $^{241}$Am, and two $^{238}$Pu sets with significantly different amount of radioactivity. The JAERI Phantom with its internal parts is shown in Fig. 10. About 700 measurements were performed with JAERI phantom in various geometries using several detection systems viz. phoswich, LOAX HPGe and NaI(Tl). Table 1 gives a summary of these measurements.

Estimation of activity in JAERI II was carried out using calibration factors obtained from the earlier measurements carried out on JAERI I phantom during on earlier IAEA CRP. As the JAERI II phantom was not provided with the blank lung sets, normal subject background (subject having weight and height similar to the JAERI Phantom) was taken to estimate the activity. The results and other data were reported to IAEA for intercomparison.

Fig. 11a shows $^{241}$Am spectrum with Phoswich (1.2 cm thick) detector for a point source kept at a distance of 10 cm from detector and Fig. 11b shows Phoswich spectrum with JAERI core phantom (CWT = 1.91 cm) with $^{241}$Am lung insert. The attenuation of 18 keV peak and peak broadening because of scattering due to the chest wall thickness of 1.91 cm are observed in Fig. 11b.

**IAEA / IDEAS Intercomparison Exercise**

IAEA had organized various intercomparison exercises at national and international levels, for the assessment

![Fig. 11: Spectra of $^{241}$Am with phoswich (1.2 cm thick) detector for (a) a standard point source at 10 cm from detector and (b) source distributed in the lungs of JAERI phantom.](image)
of internal dose, due to intakes of radionuclides. These exercises revealed significant differences in the approaches, methods and assumptions used and consequently in the results obtained by participating laboratories. This led to the development of ‘General guidelines for the estimation of committed dose from incorporation of monitoring data’ by IDEAS project (A European Union project). The guidelines provide well defined procedures to obtain best estimate of dose from the available data, depending upon the expected level of exposure and the complexity of the case.

For harmonizing the methods of assessing the committed effective dose to workers after an intake of radionuclides using these guidelines, a joint IDEAS/IAEA intercomparison exercise viz. “Intercomparison exercise on assessment of occupational exposure” was organized. The division has participated in this exercise, which consisted of six cases covering wide and complex exposure scenarios. The cases given were (i) acute intake of HTO, (ii) acute inhalation of fission products $^{137}\text{Cs}$ and $^{90}\text{Sr}$, (iii) acute inhalation of $^{60}\text{Co}$, (iv) chronic intake of $^{131}\text{I}$, (v) enriched uranium intake and (vi) intake of Pu and Am. The cases were solved using LUDEP, MONDAL/MONDES and IMBA dose evaluation software and results were submitted to IAEA. Eighty one participants from forty two countries submitted the results to IAEA. Out of these, only thirty five participants had solved all the cases. Our laboratory is one of them. IAEA statistically analyzed the results

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Cases</th>
<th>Reported results</th>
<th>IAEA compilation of the results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Acute intake of HTO: urinary excretion data of 0 – 274 days was given. CED is estimated using direct method of dose estimation given in guidelines.</td>
<td>- 23.36 mSv</td>
<td>- 25.7 ± 1.4 mSv</td>
</tr>
<tr>
<td>2(a)</td>
<td>Acute inhalation of fission products $^{90}\text{Sr}$ and $^{137}\text{Cs}$: Whole body counting data for $^{137}\text{Cs}$ and urinary and fecal excretion data from 0 to 634 days for $^{90}\text{Sr}$ were given. $^{137}\text{Cs}$ results.</td>
<td>118 kBq 0.789 mSv 103.2 kBq</td>
<td>0.666 ± 0.1 mSv</td>
</tr>
<tr>
<td>2(b)</td>
<td>$^{90}\text{Sr}$ and $^{137}\text{Cs}$ results.</td>
<td>60.8 kBq 4.68 mSv 106.57 kBq</td>
<td>8.97 ± 5.61 mSv</td>
</tr>
<tr>
<td>3</td>
<td>Acute Inhalation of $^{131}\text{I}$: Whole body counting data and urinary excretion data from 10 to 1010 days were given.</td>
<td>40.4 kBq 5 mSv 396 kBq</td>
<td>5.2 ± 1.7 mSv</td>
</tr>
<tr>
<td>4</td>
<td>Repeated intake of $^{131}\text{I}$: Thyroid monitoring data for 0 – 8 days has been given following repeated intake of $^{131}\text{I}$.</td>
<td>116 kBq 2.33 mSv 109.66 kBq</td>
<td>2.58 ± 0.17 mSv</td>
</tr>
<tr>
<td>5</td>
<td>Acute intake of Enr. Uranium: Lung monitoring data and urinary excretion data were given.</td>
<td>3.368 kBq 23 mSv 9.719 kBq</td>
<td>39 ± 33 mSv</td>
</tr>
<tr>
<td>6(a)</td>
<td>Single intake of Pu isotopes and $^{241}\text{Am}$: $^{241}\text{Am}$ chest, lung, liver, bone measurement data &amp; urinary and fecal excretion data were given. $^{241}\text{Am}$ results.</td>
<td>4.59 kBq 34.7 mSv 4.3 kBq</td>
<td>69.3 ± 62.2 mSv</td>
</tr>
<tr>
<td>6(b)</td>
<td>Single intake of Pu isotopes and $^{241}\text{Am}$: $^{241}\text{Pu}$ urinary and fecal excretion data were given. $^{241}\text{Pu}$ results.</td>
<td>13.8 kBq 114 mSv 14.2 kBq</td>
<td>155 ± 78 mSv</td>
</tr>
</tbody>
</table>

Table 2: Our reported values of Intake and CED for various cases and the compiled results of IAEA
reported by the participating laboratories, using Log-
Normal distribution for Geometric Mean (GM) and
Geometric Standard Deviation (GSD) and for better
g graphical representation of the data. Our results were
found to be in good agreement with the IAEA results.
Table 2 shows the Intakes and CED values estimated
by our laboratory and the results compiled by IAEA
for the six cases given in the intercomparison exercise.
This table includes only a brief description of the
exposure cases. The CED values given by IAEA are the
GM of all the values reported by the participating
laboratories. These values are given in this table along
with their GSD.

The detailed results of the participating laboratories
for Case No. 6 (Mixed exposure to two important
radionuclides $^{239}$Pu and $^{241}$Am) as reported by IAEA
are given in Fig. 12 (a & b). The results of our laboratory
are shown by a red arrow. It is seen that the results
have excellent agreement with mean values.

Fig. 12: Results of the individual participants as reported by IAEA for (a) $^{239}$Pu and
(b) $^{241}$Am Results of our laboratory are shown by red arrow
Intercomparison of shadow shield bed whole body monitors

Shadow shield bed Whole Body Counters (WBC) using a NaI(Tl) detector have been installed at various DAE units like BARC Trombay, Environment Survey Laboratories attached to Nuclear Power Plants (NPP), Health Physics Laboratory and also at some of the other facilities of DAE. The WBCs are used to estimate internal contamination in workers due to high energy photon emitters such as $^{60}$Co, $^{131}$I, $^{137}$Cs etc. The division initiated an intercomparison exercise to compare the response of WBCs at BARC, Trombay, ESLs of NPP and Health Physics Laboratory Tarapur. The work is nearing completion.

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Publications


