AN AUTOMATED SHIELDED CHAIR WHOLE BODY MONITOR

Internal Dosimetry Division

and

M. M. K. Suri
Radiation Safety Systems Division

Introduction

Whole body/organ counting plays an important role in assessing, limiting and controlling the intakes of radioactive materials by the workers of a nuclear research centre as well as of nuclear industry. The Internal Dosimetry Division of BARC, besides designing, developing, supplying and installing the whole body/organ counting facilities at DAE’s nuclear installations, also operates such facilities for radiation workers of BARC and BRIT (1-2). A totally shielded steel room whole body counter located at BARC Hospital is used for the measurements of body/organ burdens of low energy photon (LEP) emitters like Pu/Am and U which emit photons of energy mostly below about 200 keV. For the assessment of internal contamination due to various fission and activation products like 141Ce, 131I, 137Cs, 58Co, 60Co, 125Sb, 106Ru-106Rh, 95Zr-95Nb etc. which generally emit photons of energy greater than about 150 keV, ‘shadow shield bed’ and ‘shielded chair’ types of whole body monitors located side by side at the whole body monitoring laboratory at Modular Laboratories, BARC are used. These systems have been operating for more than three decades. Thousands of measurements on the radiation workers of BARC have been made under different types of internal monitoring programmes. The practice followed here has been that all workers are first monitored in the shielded chair, which serves as the quick screening counter. The selected few, who may show significant internal contamination, are then monitored in the shadow shield bed for detailed information. The shadow shield bed has also been employed to conduct in-vivo biokinetic studies of radionuclides present in the human body even at much lower levels (fractions of Recording Levels).

Thus, of the two whole body counters, the maximum counting load is handled by the shielded chair. This workload can be expected to be even more in radiation emergency situations. If a radiation emergency occurs after office hours, when the system operator / supervisor is not available it may not be possible to operate the counter immediately. At present, whole body counting facilities do not have an operator round the clock.

In view of the above considerations, we have converted the quick monitoring ‘shielded chair’ whole body counter into an automated, computer controlled, unattended, walk-in type of counter for internal monitoring of radiation workers. In this paper, the details of various hardware and software components of this system are presented along with the procedure how a
radiation worker can monitor himself without the system supervisor’s help.

**Materials and Methods**

**Shielded Chair Whole Body Counter**

The shielded chair whole body counter which has been converted into an automated system is shown in Fig. 1. It is a self-shielding chair designed on the basis of the widely used Argonne tilting chair geometry (1-5). In this configuration, the subject sits in a chair, which is shielded with about 15 cm thick mild steel from all around except the front and the topside. A (10 cm dia. X 7.6 cm thick) NaI(Tl) scintillation detector shielded with 5 cm lead all around except the face is mounted on a plate hinged to the side of the shielded chair through ball bearings and views the body from head to knees. Its shield weight is about 3 tonnes and it occupies a floor space of about 1m x 1m. The shielded chair, apart from its compactness, allows the monitoring time of a subject to be adjusted according to the level of activity in the body. Very often, it can provide useful information on the radiation status of a worker in just a counting period of 2-3 min., thus, making it extremely useful in radiation emergencies. However, it cannot provide any information on the location of radioactivity in the body which must be inferred either from the biokinetics of the detected radionuclide or by additional measurements in the shadow shield whole body radioactivity monitor.

**Hardware Components**

For data acquisition and recording, standard instruments for gamma ray spectrometry, like preamplifier, amplifier, and multi channel pulse height analyzer (4K MCA - HPD model) connected to a PC with display unit, have been used. A schematic diagram of the hardware components is shown in Fig. 2. A 110 volts DC shunt motor with 100 mA current was geared down to two rpm and two end micro-switches were fixed for sensing the open and closed conditions of the door. The subject’s sitting position is sensed by a set of micro-switches mounted under the seat on the chair and connected in parallel. Two DC relays (manufactured by M/s O/E/N India Ltd.) are used in the motor control unit for changing the polarity of the armature voltage for reverse movement of the motor. A PC Add-on card type PCL-730 (32 channel opto-isolated digital I/O, manufactured by M/s Advantech Co. Ltd.) senses the status of the chair door (open or close), seat (occupied or unoccupied) and accordingly sends the command signal to motor drive to perform the required operation.

**Software Components**

Computer software for the unattended shielded chair whole body monitor has been developed to
cater to the different functions, viz., the control of electrical motor driven door mechanism of the chair for human access to the seat, data communication with pulse height analyser (4K-MCA), transfer and processing of gamma ray spectrum, calculation of intake and committed effective dose, maintenance of database for personnel, monitoring information and report preparation. The software uses Windows operating system and is developed by using Microsoft Visual Basic development tool with several modules. The block diagram of software modules for the automated whole body counter is shown in Fig. 3. A brief description of these modules is given below:
Module 1: Motor movement control and chair status sensing: This module is responsible for switching the motor on or off, rotation of motor in forward or reverse direction for opening or closing the chair door and sensing the status of the door and seat i.e. door open/close and seat occupied/unoccupied. This has been done by programming PCL-730 opto-isolated digital I/O card.

Module 2: Data acquisition and communication: This part of the software interfaces the serial communication port of the computer with the multichannel pulse height analyser for configuring various parameters of the analyser, automatic start and stop of data acquisition after sensing the occupancy status of shielded chair and transfer of the recorded spectrum to PC.

Module 3: Spectrum processing and activity calculation: This module helps the system supervisor perform calculation of normal uncontaminated subject background with the aid of weight and height ratio of the radiation worker, analysis of spectrum using simultaneous equations/stripping method and the calculation of retained activities of various radionuclides of interest inside human body using phantom calibration factors stored in the computer database.

To calculate subject background from the system background, empirical correlations between these two parameters and the W/H ratio of the subjects were developed (W- weight (kg), H- height (cm)). For this purpose, a large number of normal subjects of different physiques who worked in an inactive area were monitored. This method takes care of the variation in $^{40}$K contents with body size and daily variation in the system background. The background with a water filled phantom without $^{40}$K contents is also available in the computer memory which can be used for detailed analysis of the body scatter background without $^{40}$K contributions.

Analysis of a photon energy spectrum of body radioactivity requires the identification of radionuclides responsible for its individual features. First, the calculated subject background is subtracted from the subject spectrum and then the net subject spectrum after background subtraction is analysed. The stripping is used for unfolding the spectrum if the maximum number of radionuclides present is two and there is no overlapping of the peaks like in case of $^{131}$I, $^{137}$Cs and $^{60}$Co. This is done by removing, one at a time, the components associated with each energy spectrum by comparison with previously determined calibrated spectral data. In each successive step, one component is removed and the resulting curve calculated, until by this stripping process, the entire curve is analysed. If gamma spectra is complex and has several closely spaced overlapping peaks, then the simultaneous equations method is used for analysis. For this, Compton fractions of photo-peak counts of various radionuclides in other regions of interest are determined using known amount of activity inside BOTTLE MANnequin ABsorber (BOMAB) whole body calibration phantom\(^6\). The number of simultaneous equations, which are equal to the number of regions to be analysed, are solved using matrix algebra. If C is the column matrix of the total counts observed in various selected photo-peak regions and F is the matrix of Compton fractions of these radionuclides in various other regions of interest, then the column matrix P of the net counts due to these radionuclides in their respective selected photo-peak regions is given by \( P = F^{-1}C \); where \( F^{-1} \) is the inverse of matrix F.

For the calibration of shielded chair whole body counter, locally made BOMAB phantom, filled with water, is used. Calibration data were obtained using photon energies, which cover the complete range for high-energy photons commonly occurring at the work place. Using this data, a graph between photon energy (keV) and the system efficiency (cpm. kBq$^{-1}$) is plotted for 100% emission. The calibration factors for other detected radionuclides are interpolated from this graph with the help of the percentage emissions of their relevant gamma ray energies.

Module 4: Intake, committed effective dose and report generation: The purpose of this module is
to extrapolate intake from the estimated retained activity of a radionuclide and then to calculate the committed effective dose. A database has been created from ICRP (7) graphs for inhalation, ingestion and injection cases of important radionuclides for the predicted activity m(t) as a function of time for unit intake. Two sizes of aerosols, viz. 1 µm and 5 µm AMAD, have been incorporated. Default value of ‘mode of intake’ is taken as inhalation and that of size of aerosols as 5 µm AMAD (in accordance with ICRP guidelines). If required, system supervisor can select other modes of intake as well as the aerosol size.

The time of intake for special and task related monitoring is known, but for routine monitoring the time of intake is generally, unknown. So, for routine monitoring, following ICRP guidelines, it is assumed that intake took place in the middle of the monitoring interval of T days. The intake is calculated from the measured quantity M (7),

\[ \text{Intake} \, I = M/m(t) \]

The intake is multiplied by the default ICRP dose coefficient value taken from ICRP Publications 68, 78 (7, 8) to get the committed effective dose. An intake in the preceding monitoring interval can influence the actual measurement result obtained. A correction is, therefore, made if more than 10% of the actually measured quantity is found attributable to the previous intervals, for which intake and dose have already been assessed. The calculated committed effective dose is compared with the recording level as well as with the investigation level. If committed effective dose exceeds recording level, then the result is recorded in the worker’s dose record, otherwise it is ignored. If committed effective dose exceeds the investigation level, the reasons for it are examined and further investigations, e.g., follow-up measurements, are suggested for refining the internal dose estimates.

**Module 5: Database handling:** This module is responsible for the creation, editing, retrieval and maintenance of the personal information of the employees. It also stores the subject’s monitoring data and the final results in the appropriate format. By the use of simple data entry screens, personal information can be fed to the computer.

**Module 6: Main screen / system configuration:** The top line of this screen is the pop-up menu. This consists of functions like file, communication, system configuration, user screen, computation, queries, report and quit. In file menu, there are options for loading a subject spectrum, a background spectrum or calibration spectrum for carrying out an analysis based on the earlier counting result. An option is also provided for saving the currently displayed spectrum in a file for future use. On clicking the communication menu, a communication window for interaction between the computer and MCA appears. The system configuration menu has options for energy calibration, selection of various spectral regions of interest (ROI), selection of counting time, background counting, etc. which the system supervisor can adjust according to the requirement. Computation and report options are used for computation of retained activity/intake/committed effective dose and the report preparation. In query option previous monitoring history of a person can be recalled and analysed. Access to the system configuration module is password protected. By clicking user screen (subject interface screen), the system is kept ready for the automatic monitoring of the radiation worker where he enters his computer code.

Fig. 4 shows the main screen. Subject information along with the monitoring information i.e., subject and background counts per minute (cpm) in the selected ROIs, can be clearly seen. The main screen also displays the gamma ray spectrum acquired by 4K MCA and saved in the computer memory. The scale of displayed spectrum has provisions of reduction, enlargement and scrolling of cursor for giving
channel versus counts information. Spectrum analysis includes most of the important radionuclides handled at the site. The 'Isotope handled' information is taken to critically analyse those radionuclides. The list of radionuclides under 'Subject counts' indicates the most commonly handled radionuclides which is built in the computer memory. Therefore, computer first displays the activity contents of these four radionuclides. Details of other radionuclides including those entered by the worker under the heading 'radionuclides handled' can be seen by clicking the pop-up menu 'computation' and 'Retained activity' respectively.

Highlighted dark bands visible in the spectrum are the energy regions covered for the radionuclides given under the list of 'subject counts'. The energy regions for other radionuclides can be highlighted by activating their ROIs. The bottom of the main screen has buttons, which provide functions like door open, door close, motor stop, emergency exit, etc. Online status of the whole body counting system, such as acquisition ON/OFF, door open/close, seat occupied/unoccupied etc. is displayed on the status line. A monitoring report gets generated from the system at the end of a counting schedule for communication to the worker’s work place authorities. Detection limits (minimum detectable activity equivalent to 3σ of background) of this system for the important radionuclides like $^{131}$I, $^{125}$Sb, $^{106}$Ru, $^{137}$Cs, $^{95}$Zr-$^{95}$Nb, $^{59}$Co and $^{60}$Co are 0.2, 0.275, 0.692, 0.230, 0.106, 0.2 and 0.121 kBq respectively for a counting period of 10 min. The detection limits for four commonly handled radionuclides are usually given in the monitoring reports.

Module 7: Subject interface screen: This module provides interface between the worker and the whole body counter. When the subject interface screen is on display, the worker to be monitored enters his computer code. If the personal record information of the radiation worker already exists in the computer memory, it will be retrieved and displayed on the screen. The personal details of a subject stored are - computer code, name,
division, work place, date of birth, date of joining
the department, radionuclides handled or
expected in the workplace and weight and height
of the subject. If the subject’s information is not
available in the system, it has to be entered by
the individual. Additional information required to
be entered is subject’s identification number,
monitoring type, i.e., routine, operational or
special. If the subject has been involved in
handling $^{131}$I, then it will ask for the date of iodine
handling because of its short physical half-life
and importance from the viewpoint of radiation
hazard. If these parameters are not entered, then
the system takes the in built default values. Once
this information is complete, the worker goes for
automated mode of monitoring by pressing start-
counting button.

General Methodology

The automated whole body counting system can
be considered as consisting of two parts- the first
being system configuration and the second
subject – system interface. The system
configuration is password protected where the
system supervisor can perform the operations
like energy calibration of the system, selection of
regions of interest, background counting, analysis
of spectrum, calculation of retained activity of
radionuclides of interest inside human body,
calculation of intake and the committed effective
dose by entering the type of monitoring and
finally, the preparation of monitoring report for
communication to the respective plants/divisions.
After performing operations like energy
calibration, selection of regions of interest and
counting time by the supervisor, system is ready
for monitoring of workers. If the new calibration
has not been performed, then the system will
take the latest calibration data stored in the
computer.

The monitoring of a subject in the absence of the
supervisor is performed in the following
sequence. The subject, ready for counting (after
a thorough shower and change over to
premonitored clothes), enters his computer code
through the computer terminal attached with the
system, (having ‘subject interface screen’
displayed) which then displays the subject’s bio-
data if available in the record and asks for
modification/entry. After this, on clicking the start
counting button motorized door opens, and the
system asks the worker (audio instructions) to sit
in the chair. The door then closes and the
counting starts automatically for a preset time. At
the end of counting, the door opens and the
subject gets the message that the monitoring is
over. The subject’s monitoring information is
saved in the database for future processing. After
the subject leaves the chair, the door closes
automatically and the system is ready for the
monitoring of next subject. The system supervisor
can assess and analyse all the data at any
convenient time, and recommend further actions
for those exceeding the recording levels.

Conclusion

A standard shielded chair whole body counter
has been developed as a computer controlled,
unattended, walk-in-type of whole body monitor
for assessing internal contamination of radiation
workers due to gamma emitting radionuclides.
The system does not require the presence of an
operator for in-vivo monitoring of the worker. The
radiation worker himself initiates the processes
for whole body monitoring by entering his
personal computer code through the attached
computer terminal. After the counting is over, he
can simply walk away. The system supervisor
can come at any convenient time and get the
monitoring report printed for mailing to the
appropriate authorities. The system has the
required database and the software for
calculating intake and the committed effective
dose from the measured retained activities. The
hardware and software developed are of
generalized nature. With some modifications,
they can be employed for automation of similar
systems elsewhere. This type of system with
trained staff is expected to be of immense value
in case of emergencies as a quick monitoring
system.

References


