Implementation of a triage monitoring program for internal exposure to short-lived radionuclides in Israel - Challenges and recommendations

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Abstract. Monitoring internal exposure to short-lived radionuclides is challenging, due to the frequent measurements required. ISO Standard 16637 and the Swiss Personal Dosimetry Ordinance describe a screening measurement (triage monitoring) conducted in the workplace to identify workers suspected of internal exposure. Based on a previous study that examined the feasibility of using several commonly found radiation monitors in Israel in a triage monitoring program, we conducted a pilot study towards the implementation of triage monitoring in nuclear medicine facilities in Israel. The pilot study was conducted while considering the current Israeli regulations and local safety culture. We implemented the triage monitoring program in 3 nuclear medicine facilities in Israel, with a total of 55 monitored workers. The pilot study consisted of two stages: a short-term stage conducted in the largest manufacture of radiopharmaceuticals in Israel and a long-term stage in two nuclear medicine departments in Israel. During the first stage of the study, participants were asked to conduct a daily measurement at the end of the workday and send a urine sample to the national internal dosimetry laboratory. The second stage lasted 5 months in a major hospital and 18 months in a regional hospital. The workers were asked to perform the measurement at the end of the shift and send a urine sample if a defined threshold had been crossed. The mean participation rate in the long-term stage (>70%) indicates that implementation of the triage monitoring program could be successful in Israel. Based on the findings of the study, practical recommendations are listed: suitable monitoring devices, allocating a monitoring location, time of measurement, training of the workers, record keeping and coordination with a certified dosimetry laboratory. The pilot study recommendations were submitted to the Israel Institute for Occupational Safety and Hygiene at the Ministry of Labor, Social Affairs and Social Services.

KEYWORDS: occupational dose monitoring; triage monitoring; exposure to short-lived radionuclides; internal exposure monitoring.

1 INTRODUCTION

Monitoring occupational radiation exposure is required according to the IAEA International Basic Safety Standards in order to ensure protection and safety of occupationally exposed workers [1]. Exposure to ionizing radiation in the workplace can occur in a wide range of occupations and exposure situations, each requiring an adequate monitoring program. Monitoring internal exposure can be conducted by in-vivo measurements, such as whole-body counting (WBC), or in-vitro measurements, such as analysis of urine samples. Monitoring of internal exposure in the nuclear medicine sector is challenging, due to the use of short-lived radionuclides that require frequent measurements in order to obtain an accurate estimate.

ISO Standard 16637 specifies the requirements from a triage monitoring program intended to monitor the exposure of workers in nuclear medicine facilities [2]. A triage monitoring program is defined as *a programme [that] relies on frequent individual screening measurements performed at the workplace by local staff using standard laboratory instrumentation to detect whether potential intake has occurred* [2]. The goal of the Standard is to ensure the detection of an annual exposure that exceeds 1 mSv. These programs are not intended for personal dose assessment. According to the Standard, dose and intake calculations must be performed by a certified laboratory. The Standard defines the monitoring technique, detection limits, frequency of measurements, documentation and record keeping. The triage monitoring program was also recommended by the European Commission [3].

The Swiss Personal Dosimetry Ordinance (SPDO) also describes a triage monitoring protocol for short-lived radionuclides in the workplace [4]. According to this protocol all workers are required to perform a routine screening measurement to determine if a significant internal contamination occurred [4]. The measurements are conducted in the workplace with commonly used equipment. If a predefined

radionuclide-specific threshold is exceeded, dose assessment should be performed by a certified internal dosimetry laboratory using standard techniques, such as WBC or urine sample analysis.

The Israeli Safety at Work Regulations state that a worker that might be internally contaminated should be routinely monitored, at least quarterly [5]. This requirement is being met by measuring the worker in a WBC or by conducting a urine sample measurement. However, quarterly measurements are impractical in assessing doses from intakes of short-lived radionuclides.

A previous study examined the feasibility of using several commonly found radiation monitors in Israel in a triage monitoring program [6]. The work relied on theoretical calculations of radionuclide distribution in the human body and set the requirements for the measurement equipment and threshold for the screening protocol, for two radionuclides: ^{131}I (physical half-life of 8 days) and ^{99m}Tc (physical half-life of 6 hours). For ^{99m}Tc screening, the study found that the Berthold LB 124 B proportional counter and the Rotem RAM GENE 1 Geiger counter were suitable. The Capintec CAPTUS 2000 Thyroid Uptake System was found to be suitable for ^{131}I screening. In Israel, all facilities working with radioiodine isotopes have an Uptake monitor. For both radionuclides, the calculations were made based on an intake that results in an annual dose of 1 mSv, as defined by the ISO Standard [2].

Based on the ISO Standard [2], the Swiss Ordinance [4] and the previous study [6], we implemented in the current study a triage monitoring program in 3 nuclear medicine facilities in Israel to explore the feasibility of replacing the current quarterly internal dosimetry program. The goal of the study was to examine the participation rate and applicability of the method and to draw conclusions and recommendations for a successful implementation of the program. The pilot study considered the triage monitoring program compliance to the Israeli regulations, the safety culture in the facilities and the available instrumentation in relevant facilities.

2 METHODS

For this study, screening protocols were designed for 2 radionuclides: ^{99m}Tc and ^{131}I. The screening was performed in the facility at the end of the workday. For ^{99m}Tc, a daily measurement was performed by turning on the monitor and waiting until a stable reading was received (~1 minute), then placing the monitor in front of the abdomen until the reading was stabilized. For ^{131}I, a weekly measurement was performed at the end of the work week (Thursday afternoon), by measuring the background radiation level, and then placing the monitor in front of the thyroid until a stable reading was received (~2 minutes). The thresholds in this study were defined as 20 cpm above the background level for ^{131}I, and any reading above the background level for ^{99m}Tc, based on a previous work [6]. Employees were instructed to send a urine sample to the Internal Dosimetry Laboratory (IDL) at Soreq Nuclear Research Center (SNRC) if a threshold was exceeded.

All monitors used in the study were calibrated at the Secondary Standard Dosimetry Laboratory (SSDL) at SNRC. The urine samples were measured using high purity Germanium detector systems: Canberra BE5030P EGNC 80-210R, EGPC 30-195-R, and ORTEC GE60-195. The analysis was performed by standard gamma spectrometry methods that meet the requirements of ANSI 42.14 Standard [7] and ISO/IEC 170025:2017 Standard [8].

According to the screening protocols, an initial measurement was conducted to identify external contamination. The workers were instructed to remove personal protective gear such as gloves and robes and to wash their hands prior the measurement. If a reading above the threshold was detected, the worker was instructed to wash the skin above the measured organ (thyroid for ^{131}I and abdomen for ^{99m}Tc) and remove clothing, to make sure all external contamination was removed, and then repeat the measurement. If the monitor reading still exceeded the threshold, the workers were instructed by the Radiation Safety Officer (RSO) to send a urine sample to the internal dosimetry laboratory at SNRC.

The participating employees were selected by the local RSO, based on the potential radionuclide intake and frequency of work. A Certified Radiation Inspector (CRI) conducted the initial training of the

workers. The training included information on the screening protocol, its importance and the correct monitoring handling and documentation. A monitoring place was designated by the RSO and approved by the CRI with consolidation of the authors of this work. A suitable radiation monitor and the documentation forms were placed in the designated area. Each worker was instructed to fill a daily/weekly form, documenting the results of all measurements. The form included the worker's full name, ID, the monitor used, the readings, whether a urine sample was sent, and the worker's signature. The RSO was responsible to send the filled forms periodically to the Radiation Safety Department at SNRC for follow-up.

The pilot study took place during the years 2017-2018 and consisted of two stages. The first stage was conducted in the largest manufacture of radiopharmaceuticals in Israel (called Facility A) for a two-week period. 15 workers from Facility A participated in the study and were monitored for ^{99m}Tc. The screening of ^{99m}Tc was conducted daily using a solid scintillator – ATOMTEX AT1123, a dose rate meter that meets the requirement of the ISO Standard [2]. During this stage, a daily urine sample was sent to IDL from each participating worker for follow-up.

The second stage of the pilot study was conducted in the nuclear medicine departments of two hospitals: a major hospital (called Facility B) and a regional hospital (called Facility C). 40 workers from the two nuclear medicine departments participated in this part of the study. The pilot study lasted 5 months in Facility B and 18 months in Facility C. Monitoring of ^{99m}Tc was performed in both hospitals for all 40 workers, while monitoring of ^{131}I was performed only in Facility B for 10 workers. In order to avoid procurement of costly equipment, the participating departments used the Rotem RAM GENE 1 Geiger counter and the Capintec CAPTUS 3000 Thyroid Uptake System for ^{99m}Tc and ^{131}I monitoring, respectively. These monitors are in routine use in the hospitals.

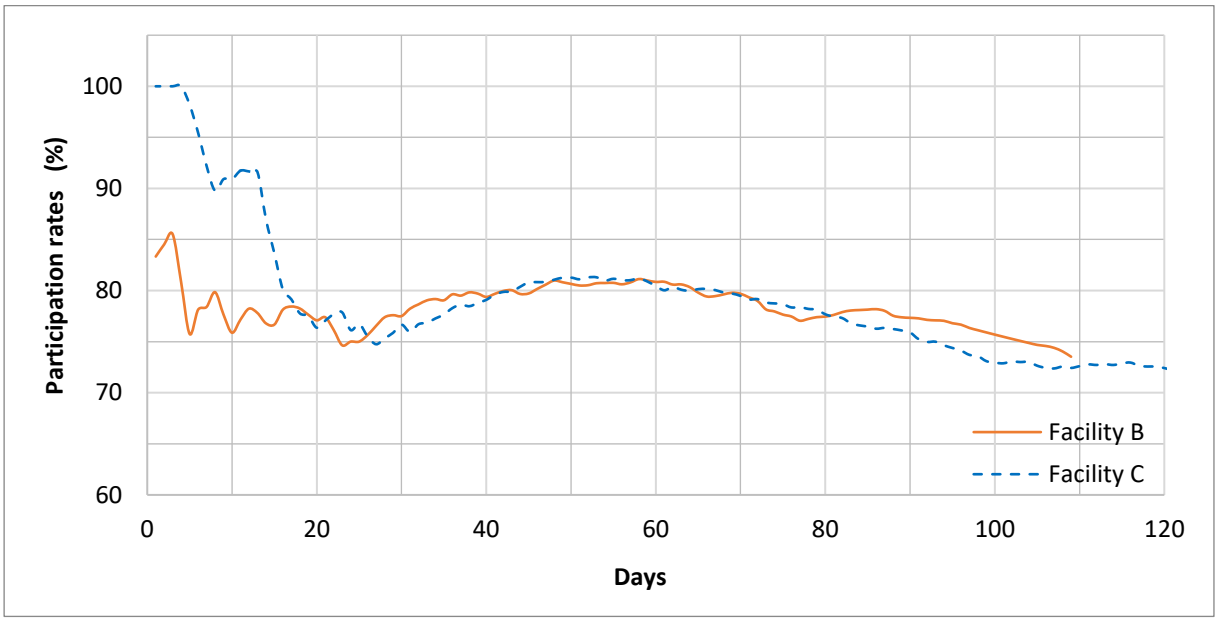
3 RESULTS

During the first stage of the pilot study daily documentation and urine samples were sent to the IDL at SNRC for all participating workers. No intakes were detected by the daily measurements at Facility A and measurements in urine. Based on the RSO and workers' feedback following this stage, the documentation forms were changed and the initial training before the second stage of the pilot study was adapted. A work procedure for coordination with the dosimetry laboratory was also established.

During the second stage of the study, no ^{131}I values exceeding the specified threshold were recorded. It was reported that all the involved workers performed the screening as instructed (10 workers, 100% participation rate). The RSO set a specific time at the end of each work week for all workers to perform the triage monitoring together. The measurement was conducted by the RSO, who made sure the measurement was correctly conducted. The Thyroid Uptake System generated the monitoring reports automatically after the screening, simplifying the documentation process.

Figure 1 presents a simple moving average of the daily participation rates for ^{99m}Tc screening in each department. The simple moving average shows the total participation in the period prior to the sampling date. Staff members who were monitored on an operation-based schedule, such as doctors, were excluded from the average. Only working days are presented, excluding weekends and national holidays. The average participation rate for both hospitals was over 70%, with an average standard deviation $< 5\%$.

Figure 1: Average participation rates for ^{99m}Tc screening in the nuclear medicine departments.



As seen in Figure 1, the participation rates in both hospitals decreased during the initial period and then stabilized after a month. In the next 3 months of the study, the participation rate remained relatively constant at 75-80%, and declined afterwards. In Facility C a decrease in the participation rate further occurred, falling to a minimum of 65% 15 months into the pilot study (not shown in Figure 1). The decrease can be associated with the addition of new workers to the study, faulty radiation monitors and lacking documentation (missing information or wrong classification of external exposures as internal exposures). Afterward, the pilot study was suspended, and resumed after investigation and re-training, leading to an overall average participation rate of over 70% in the pilot study.

It was found that in several cases the monitors were used incorrectly. Incorrect monitor units were used (counts per minute instead of counts per second). On several occasions, thresholds were crossed but urine samples were not sent to the internal dosimetry laboratory. These results can be attributed to misunderstandings of the protocol, which led to reporting external contamination as the screening result. In these cases, a second measurement was not conducted or reported after removal of the contamination. The incorrect use of the monitor was attributed to ineffective or insufficient training. It was evident that when the monitoring is performed in the presence of the RSO or another worker the procedure is correctly conducted.

Table 1 presents the average daily participation rates for ^{99m}Tc screening for the different working days of the week. The participation rates remain relatively constant with a standard deviation < 5% for both departments. However, the maximum and minimum participation rates were recorded on Sundays and Thursdays, respectively, in both hospitals.

Several workers asked to join the study after several months, even when their usual work routine did not require internal monitoring. Their request was examined and approved by the RSO.

Table 1: Average daily participation rates for ^{99m}Tc screening for the different working days of the week.

Weekday (a)	Average daily participation rates (%)	
	Facility A	Facility B
Sunday	79.9	69.9
Monday	74.9	69.6
Tuesday	75.1	69.6

Wednesday	69.4	69.4
Thursday	68.1	66.6
STD	4.3	1.2

(a) The work week in Israel is from Sunday through Thursday.

4 DISCUSSION

4.1 Main challenges

The current work presents a pilot study for the implementation of a triage monitoring program for the detection of intake of short-lived radionuclides used in nuclear medicine. The pilot study was conducted in a radiopharmaceutical manufacture (Facility A), in a major hospital (Facility B) and in a regional hospital (Facility C). The study aimed to identify the challenges in the implementation of the triage monitoring program and provide recommendations for a successful implementation. It studied therefore the feasibility of replacing the current quarterly monitoring program required by the Israeli regulations. Among the factors examined, an emphasis was placed on participation rates, documentation, communication with the internal dosimetry laboratory and timely transfer of urine samples for measurement.

The first stage of the pilot took place for two weeks and was conducted in order to study the implementation of the daily triage monitoring program of ^{99m}Tc in a small-scale experiment and to draw practical conclusions. Following the first stage of the pilot study, the documentation forms were updated and the second stage training was adapted according to questions raised by participants in the first stage.

In the second stage of the pilot, ^{131}I screening was performed as instructed. As mentioned above, facilities working with radioiodine in Israel make daily use of an uptake monitor for routine medical procedures, meaning that the uptake monitor operator is highly trained. We believe that this is one of the main reasons that the screening was fully performed for ^{131}I. Another reason is the time allocated by the RSO for all workers to perform the measurement together, that made sure all workers are measured and results are properly documented.

Lack of workers' understanding of the procedure led to a reduction in the participation rate in the daily ^{99m}Tc screening and to an incorrect use of monitor units. In some instances, values exceeding the specified threshold were recorded, but urine samples were not sent to the dosimetry laboratory. Some of these values were attributed to wrong use of the monitor and documenting external contamination as the monitor reading. It was evident that on average the participation rate decreased throughout the week, suggesting that constant re-training is required. According to the RSOs, routine training and re-training improve workers' compliance and participation rate and ensures that the measurements are conducted correctly.

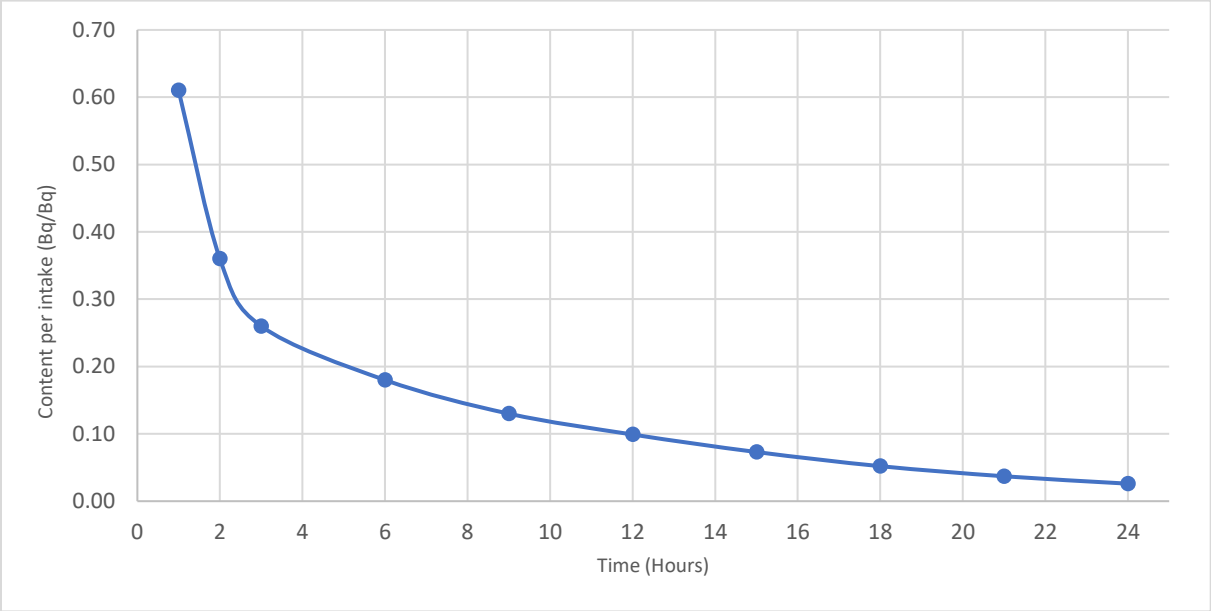
4.2 Practical considerations

The normal shift length for a nuclear medicine employee in Israel is 8 hours. The screening procedure for ^{99m}Tc was conducted at the end of each shift. In the second stage of the study urine samples were not collected and sent to the internal dosimetry laboratory even when thresholds were crossed (also when external contamination was wrongly reported as internal contamination). In an attempt to improve participation rates and allow enough time to collect and send a urine sample to the IDL, it was suggested to move the measurement time two hours before the end of the shift. This would allow the worker to notify the RSO of the screening result, to collect a urine sample and would ensure prompt response of the laboratory.

Fast and efficient coordination with the internal dosimetry laboratory is especially important in the case of ^{99m}Tc screening. Due to its short half-life, activity measurement should be conducted upon delivery of the urine sample to the laboratory. In order to assess the impact of the change in the measurement

time on the detection ability, a calculation of the relative activity in the abdomen was performed as a function of time from intake. The calculation is based on the new models of the ICRP for occupational intakes of radionuclides [9,10]. It was assumed that ^{99m}Tc intake occurred via ingestion, since most of the ^{99m}Tc compounds used in nuclear medicine are non-volatile. Figure 2 describes the activity fraction of ^{99m}Tc intake via ingestion in the alimentary tract as a function of time after intake. Due to the rapid and extensive transfer of ^{99m}Tc to the blood (f_A=0.9), it can be assumed that it is accumulated in the abdomen after a few hours [4,9,10]. Figure 2 demonstrates that early measurements are preferable, due to higher activity in the alimentary tract.

Figure 2: Fraction of content in the alimentary tract per intake of ^{99m}Tc as a function of time after intake via ingestion.



5 CONCLUSIONS AND RECOMMENDATIONS

The current pilot study showed that implementation of a triage monitoring program for workers with short-lived radionuclides could be successful in Israel. The overall participation rate in the pilot study was 70%. The design of the program should ensure optimal conditions for a successful implementation and elevated participation rates. These conditions include allocating suitable monitoring location and devices, establishing suitable work procedures, constant coordination with a certified internal dosimetry laboratory, documentation and record keeping, as well as training and periodic re-training of the staff.

5.1 Monitoring devices

In order not to impose any financial burden on the participating departments, solid scintillator monitors were not a requirement for the pilot study. The radiation monitor used for ^{99m}Tc screening in the current study was a Geiger counter. We recommend that the screening procedure should be conducted with a dose rate meter to meet the requirements of the ISO Standard [2]. The ^{131}I screening was conducted with an uptake monitor and was found to be compatible with the ISO Standard requirements and convenient, due to the automatic documentation and operation experience.

5.2 Coordination with a certified internal dosimetry laboratory

The certified internal dosimetry laboratory shall be prepared to perform radiotoxicology measurements with short notice in order to ensure adequate detection of activity in urine samples. According to the ICRP bio-kinetic model, activity in the abdomen is expected to be detected a few hours after intake, as seen in Figure 2. The RSOs of the nuclear medicine departments reported that most of the procedures

that may cause radionuclide intake are performed during the first half of the workday. As a result, it is recommended that the screening procedure should be performed six hours after the start of the shift and at least one hour before the end of the workday. The time of measurement will be set according to the work procedures at each facility and in coordination with the internal dosimetry laboratory. This recommendation will allow prompt transfer to the internal dosimetry laboratory for performing the measurement quickly, which is crucial in the case of short half-life radionuclides such as ^{99m}Tc.

5.3 Work procedures

A detailed work procedure should be designed prior to the implementation of the triage monitoring program. This procedure will specify the screening protocol for each radionuclide; the monitoring location; the responsibility for correct implementation of the program; the responsibility for urine samples collection and coordination with a certified internal dosimetry laboratory; the documentation and record keeping; and training. The RSO will oversee compliance with the work procedure.

It was reported that the presence of an RSO or a designated officer during the screening increased participation rates. As a result, it is preferable to appoint an officer to be in charge of the correct implementation, who will offer guidance and training on the correct monitoring protocols and documentation process.

5.4 Training

The workers should receive a training prior to the beginning of the monitoring program, and re-training should be conducted periodically. The training should include the monitoring procedure, with an emphasis on practical handling and placement of the monitor, defined threshold for each radionuclide, documentation, and the importance of collecting a urine sample and sending it to an internal dosimetry laboratory in case the threshold is crossed. The training should be designed to suit all relevant employees – including contractor workers, cleaning personnel, or any worker without prior knowledge in radiation safety. Language barriers should be addressed in multilingual groups of workers.

5.5 Documentation

Documentation should be kept according to the national requirements. The Israeli regulations state that all dosimetry records shall be kept for 30 years after termination of work in the national dose registry [6]. The dose registry data is sometimes used for legal claims against employers and social security. Thus, we recommend that when considering an update of the current regulations, record keeping of daily monitoring data should also be addressed and its legal validity assured. We recommend that the record keeping of the measurements should be the responsibility of the employer. The daily records should be inspected as part of the annual inspection of the facility by a certified radiation inspector.

The pilot study recommendations were submitted to the Israel Institute for Occupational Safety and Hygiene at the Ministry of Labor, Social Affairs and Social Services. The recommendations emphasize the needed adjustments and practical considerations to implement the triage monitoring program in order to change the current regulations. The adjustments include setting the time of measurement as two hours prior to the end of shift, periodic training, and coordination with the internal dosimetry laboratory.

6 ACKNOWLEDGEMENTS

The authors would like to thank the Radiation Safety Officers and the workers of the radiopharmaceuticals manufacture and the nuclear medicine departments that participated in this study for their cooperation.

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