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Contamination of workers with ^{241}Am during waste processing operations

State Office for Nuclear Safety
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Foreword

The use of ionizing radiation sources continues to offer a wide range of benefits throughout the world in medicine, research and industry. Precautions are, however, necessary in order to protect general public and radiation workers, workers from the detrimental effects of the radiation. In the Czech Republic 298 workplaces with unsealed sources, including 49 nuclear medicine departments were operating; 4750 equipment with sealed sources, including 50 medical radiotherapy units, 2 industrial irradiators, 7824 X-ray devices (most of them - 6136 in medicine) were used at the end of 2001 year. In spite of the modern, strict legislation based on IBSS (IAEA SS No.115/1996) principles and practically harmonized with the EU legislation (Directive 29/96/EURATOM) extraordinary events associated with the use of ionizing radiation sources continue to occur.

During the second half of June and beginning of July 2001 the alpha dry glove boxes were dismantled in Nuclear Research Institute (NRI) in Rez. The boxes were part of facility for production of smoke detectors of a Czech company producing these sources. Material from these boxes was contaminated by Am-241 and was after the fragmentation put into drums used for storage of rad-waste materials. During the performed operations the dust particles with Am 241 were released and were partially inhaled by the several workers partaking in these operations.

This report compiles information about radiation protection aspects as well as dosimetric and medical investigation of the event and evaluates it considering the views of the licensee (NRI) and the regulatory authority - State Office for Nuclear Safety.

Contamination with ^{241}Am during waste processing operations

During the second half of June and at the beginning of July 2001 three dry glove-boxes which served before as part of a line for manufacturing radioactive sources for smoke detectors from pulverized ^{241}AmO were dismounted and processed as radioactive waste. This dismounting operation occurred in the Nuclear Research Institute Rez plc (NRI) namely in its Fragmentation and Decontamination Centre (FDC) located in the building No. 241 belonging to the service unit for management of radioactive waste. Radioactive waste originating from the dismantled and fragmented boxes was deposited in drums for disposal. In the course of dismounting operation the dust particles with ^{241}Am were incidentally released and due to violation of the radiation protection regulations several workers were internally contaminated. Subsequently this contamination spread through the whole building. Still no health problems were observed and releases into the environment were negligible.

This report consists of following chapters:
- part one - of the licensee for management of radioactive sources, i.e. the employer of contaminated workers – NRI, on the course, investigation and causes of event;
- part two - of the National Radiation Protection Institute (NRPI) in Prague on the results of measurements of incorporated activity and effective dose commitments in workers;
- part three - of the Clinic for Occupational Diseases of the University Hospital in Prague on the treatment of contaminated workers;
- part four - of State Office for Nuclear Safety (SUJB) of the Czech Republic on its co-ordinating activities and inspection results.

1. Course, investigation and causes of the event

The features of the facilities

Fragmentation and Decontamination Centre (FDC)

The handling of radioactive waste (rad-waste) in NRI takes place at the service unit for rad-waste, which is equipped with the installations for the treatment and conditioning of low-level solid and liquid rad-waste and which is operated by the NRI Department No. 406. The handling of solid rad-waste occurs in FDC located in a separate building and comprises following working areas:
- dismantling and dismounting box,
- fragmentation box,
- decontamination box,
- handling and manipulation area,
- access area with clearance and monitoring control-point.

All boxes are provided with sliding closing doors and removable ceiling panels. The inlets of the ventilation system of the building equip boxes and handling area. Additional locally adaptable exhaustion is provided for fragmentation box and handling area.

Radiation Protection System

System of radiation protection for the work in FDC includes:
- the means for personnel dosimetric control (film badges and TLDs),
- the monitoring of the surface contamination of equipment, working area and workers by the means of transportable apparatuses (for α, β, γ radiation) - continuously during working activity and thereafter,
- continuous monitoring of the volume activity of air and subsequent evaluation of aerosols retained on the filters (gross α and β, gamma-spectrometry) – sampling periods corresponding to the working activities,
- monitoring of the surface contamination of workers at the leave of controlled area.

Personnel protective aids

The workers are obliged to use the protective aids appropriate to the character and hazard of the working activity. At the work where release of the radioactive material is imminent, the worker is obliged to avail themselves besides of common protective aids (appropriate garments, gloves etc.) also of protective aids preventing inhalation and ingestion of radioactive material. According to the severity of risk, it is necessary to use respirators, protective masks or breathing device with closed circuit.

The course of the planned operation

Three glove-boxes used for the manufacturing of americium sources for fire alarm sets were to be dismounted. The boxes consist of steel framework in which the Plexiglas walls of 1 cm thickness were inserted. The boxes were provided by openings for gloves and for the communication between each other. When the manufacturing company discontinued the production of americium sources decided to remove the boxes and transferred them for dismounting and waste processing. The manufacturing company declared at the time of transfer following activities in respective boxes:
- box No.1 - 150 MBq of ^{241}Am,
- box No.2 - 180 MBq of ^{241}Am,
- box No.3 - 50 MBq of ^{241}Am.

The intended dismounting and processing of boxes was notified bz NRI to the SUJB on 12 July 2001.

Before the transport of the boxes from the manufacturing company to NRI the contamination on the walls and on the inside installation was fixed by lacquer. The boxes were separated from each other, the openings were blinded, and the whole boxes wrapped-up in a polyethylene foil. The external surfaces were monitored as to contamination.

The transport of the boxes to the NRI occurred by a truck car and the handling devices were properly checked. One box was transferred on June 19, two boxes on June 28.

The sequence of the dismounting operations was as follows:
- the system for monitoring the volume activity of air in the working area was switched on and the local air conditioning for exhaustion from FDC area was put in operation,
- the covering foil was removed and the box was transferred from the transport palette,

- external contamination and dose-rate on the surface were measured,
- the box was opened and the surface contamination was measured using both wipes and direct measurement,
- dismounting of the box and its internal equipment,
- fragmentation of the material (cut in pieces by hydraulic shears and saw machine),
- deposition of the fragmented radioactive waste into drums volume of 100 litres.
- transport to the area for cementing drums,
- conditioning of rad-waste.

Processing of the box No.1

The dismantling of the box No. 1 and following treatment took place on 20-21 June. On 20 June some preparatory activity occurred, i.e. the check of instrumentation, aids etc. The results of radiometric measurements (both β and γ):

– contamination of internal surfaces 300 Bq/cm^2 (direct measurement) and 9 Bq/cm^2 (indirect measurement – wipes, not corrected for the removable fraction); the difference between these values has been interpreted as a result of firm fixation of the contamination.
– dose-rate on the surface 0,4 – 0,6 mGy/h.

The next day 21 June the dismounting and waste treatment occurred without any disturbing problems.

Processing of the box No.2

The dismantling and treatment procedures with the box No 2 occurred on 2-3 July. On 2 July some preparatory activity took place (the check of instrumentation, aids etc.) similarly as previously with the box No.1.
The results of radiometric measurements (both β and γ):

- dose rate measurement on the internal surface 0,8 mGy/h,
- direct measurement of the internal surface did not exceed 350 Bq/cm^2.

The next day 3 July the dismounting and waste treatment occurred without any disturbing problems.

Processing of the box No.3

The dismantling and treatment procedures with the box No 3 occurred on 9 – 10 July. On 9 July some preparatory activity took place (the check of instrumentation, aids etc.) similarly as previously with the boxes No.1 and 2.
The results of radiometric measurements (both β and γ):

- dose rate measurement on the internal surface did not exceed the background,
- direct measurement of the internal surface did not exceed 280 Bq/cm^2.

The next day 10 July the dismounting and waste treatment occurred without any disturbing problems.

Discovery of accidental conditions, following course of events

On 10 July at 12.15, after the dismounting operations with the third box and subsequent waste treatment were finished, the chief of the NRI Department No. 406 was informed about the

result of the evaluation of the filter of the device for volume activity measurement in air in the FDC. The sampling period of this particular filter covered, however, the time of the previous two operations performed on June 20-21 and July 2-3 (the volume of filtered air was 69,2 m^3, a flow rate of 1m^3 per hour). The filter had been removed from the collecting device only on 9 July in the morning and transferred for measurement in the afternoon of the same day under presumption that no deviation from the background values might be expected. As a result the waste-processing task on 10 July was performed without any warning about possible extraordinary conditions. The obtained values of volume activity exceeded the determined intervention level. No information about the time course of the volume activities could be extracted from their integral value. The chief of the Department ordered to stop all the working activities in FDC area at 12.30.

On July 11 at the morning the filter of the device for volume activity measurement in air in the FDC area was replaced and submitted for measurement to evaluate the air contamination during the processing of the third box on 10 July. The results were presented at 15.30. The determined volume activity (the volume of filtered air was 5,6m^3) again exceeded on the intervention level. The same day the measurement of respirators used by workers revealed some contamination, reaching in the worst case (worker W1) 1000 Bq ^{241}Am (later amended to 2 700 Bq). The chief of the Department No. 406 evaluated the situation as an increase of volume activity above the derived investigation level and *declared at 16.30 an extraordinary event of the grade I in the terms of the Decree of SUJB 219/1997 Coll.*

On 12 July the notification of as extraordinary event was transmitted to SUJB and the media were informed. The worker suspected of the highest internal contamination (W1) was directed to the National Radiation Protection Institute (NRPI) for detailed measurements. The following day 13 July he was hospitalized at the Clinic for Occupational Diseases of the University Hospital in Prague 2. Further workers taking part at the handling of contaminated boxes were sent for measurements in NRPI on 16 July.

On the basis of the first internal contamination measurements in the laboratory of NRPI it was concluded that in some workers the annual limit of effective dose for category A (i.e. 50 mSv represented by the sum of external dose committed effective dose due to internal contamination) was exceeded.

Investigation of the extraordinary event and analysis of its causes

The Director General of the NRI nominated on 16 July an Ad hoc Commission to investigate the extraordinary event and to prepare proposals for remedial actions and for possible technical or organizational amendments of safety at the workplace. The Commission of five members could avail itself of all the indispensable information on the accident. Moreover it interviewed the employees who took part on the activities connected with the event. For its task the Commission applied the modified method of ASSET, i.e. it explored shortcomings and their consequences in following areas:

- performance of the installations and devices,
- activities of workers and their management,
- valid documentation.

As the function of equipment and devices is concerned, it was ascertained – with some minor exceptions – that the installations and apparatuses worked satisfactorily in accordance with

the project. It was ascertained, however, that some monitoring devices were not metrologically traced or were used at variance with program of workplace monitoring.

As to the activities of the workers at the event, a series of faults were ascertained. The operation as such should have been considered as non-standard and hazardous, because the boxes were contaminated by dust particles of $^{241}AmO_2$ and their release was imminent. In spite of that no appropriate attention was given to the provisions of the envisaged operation and no special operational approach taking account of all potential risks was developed. Before the onset of the task, the workers performing the operations were not warned with enough emphasis about the enhanced risk.

According to the monitoring program (for the situations when the surface contamination of boxes exceeded 50 Bq/cm^2) protective masks with filters, or even breathing devices with closed circuit should be used during the processing operations. Instead of that only respirators were provided. For the monitoring of surface contamination an inappropriate GM detector (for measuring β,γ) was applied which was not capable of measuring ^{241}Am with adequate efficiency. The detector for measuring contamination α was not used in spite of being available.

The systematic evaluation of the filters of the device for measuring volume activity in air was considerably neglected and this shortcoming belongs to the most serious ones. Frequency of exchange of filters was too low regarding the type of operations. This resulted into detection of the event only after long time delay. The personnel protective aids were not continuously applied during operations. The subsequent a posteriori measurements proved, that the routine of working in controlled area was repeatedly violated (the workers did not changed the garments when leaving controlled area, their surface contamination was not satisfactorily checked). In addition to it, the respirators and rubber gloves were used repeatedly.

The assembly used for the monitoring of internal contamination of the workers of NRI was not capable of detecting the γ photons of low energy, so that the contaminated workers had to be measured at an external institution - at the National Radiation Protection Institute.

All faults ascertained in the activities and behavior of the workers pointed to the insufficient level of safety culture at the workplace.

In view of this the Director General of NRI in Rez issued on 14 September 2001 the "Policy of Safety Culture in NRI" which clearly declared the priorities of nuclear and radiation safety culture before all other tasks of the institute. All employees of NRI were acquainted with this document, which would be commented and explained in detail in training and educational program. The NRI is prepared to publish in 2002 the translations of IAEA Safety Reports No.1 and 11, which aim at the identification of the shortcomings in safety culture and deal with methods for their enhancement.

On the field of regulatory documents no important shortcomings were ascertained. Still some internal regulations and codes of the NRI and the FDC were reviewed and completed following this extraordinary event.

The Ad hoc Commission for the investigation of this event issued on 8 August 2001 an interim report on the causes of this accident. It contains proposals for 40 particular steps for finishing the remedial actions and for the prevention of similar failures. The copying with

these recommendations is discussed and evaluated at the regular meetings of the management of the NRI.

A list of the recommended provisions included namely:

- persons in charge of the workplace were called away; other personal changes will be considered;
- amendments of the routine for the work in the controlled areas will be put in force and the workers will be instructed about the amended requirements;
- equipment of the workplace with measuring apparatuses will be reconsidered and the lacking instruments provided;
- documentation regulating the handling of ionizing radiation sources at the workplace will be amended, namely in following items:
  - ❖ area monitoring program;
  - ❖ use of personnel protective aids during the work;
  - ❖ regulations for management of radioactive waste;
  - ❖ internal emergency plan;
- changes in procedures of workplace radiation monitoring;
- amendments in the documentation of daily operational tasks (eg. dosimetric diary);
- purchase of an assembly for monitoring persons internally contaminated with radionuclides emitting low energy γ photons.

Final decontamination and clearing operations at the spot

The workplace was closed on 11 July and the decontamination of the premises was started on 20 July. The highest level of contamination (α) was found at the spot of dismounting and fragmentation of the processed glove-boxes, i.e. in the FDC. In the box No.2 of the decontamination line the surface contamination amounted to 800 Bq/cm^2. Due to the negligence of the basic principles of radiation protection the contamination spread to the whole building. The area for treatment and conditioning radioactive waste was also highly contaminated as a result. Contamination was found also in the rooms of laboratory unit (up to 10 Bq/cm^2) and even outside of the controlled area (up to 7 Bq/cm^2).

After detailed monitoring of the area including air monitoring, it was decided about the sequence and extent of the decontamination operations.

As the first task the space outside the controlled area was decontaminated with the aim to enable the safe entrance into the building. Next the laboratory area was cleaned. Last the hot area, ie. the FDC was decontaminated. The personnel were provided with protective aids, protective overalls, respirators or full-face masks with the filter against penetrating aerosols.
Surfaces, walls and floors were decontaminated using air exhausters with HEPA filters, and foams, pastes and high-pressure sprinklers were applied.

After finishing the decontamination operations the area was thoroughly monitored. The premises are again open to normal activities on 8 August 2001, ie. more than one month after the onset of the extraordinary event.

2. Estimation of the committed effective doses due to occupational intakes of ^{241}Am

Introduction

A worker from the Nuclear Research Institute with the suspected intake of ^{241}Am came on 12 July 2001 for the in vivo measurement to the NRPI. Afterwards, it appeared that the leak of ^{241}Am into the workplace was quite significant and another group of people came for measurements. The internal contamination was found in 8 people. In addition to them, 18 others were measured and no internal contamination was found.

Methods of measurement

In vivo measurement

Whole body counting:
Whole body counting with HPGe detector (117 % relative efficiency), person in sitting position was used. For calibration - 3 bottles of 1 L volume each with ^{241}Am gel standard solution placed in the trunk at the position of lungs of the cylindrical vessel phantom, were used.

Skeleton measurement:
Skull measurement - two LEGe detectors (active area each 2000 mm^2), placed 3 cm from left and right side of the head were used; calibration using USTUR skull was carried-out.

Knee measurement - LEGe detector placed near the knee was used, calibration using University of Cincinnati knee was carried-out.

Lung measurement:
There is no special lung counter at NRPI. Ad hoc measurement configuration was set up when two LEGe detectors were placed near the torso of the sitting person. However, this configuration is rather uncomfortable for measured person and does not allow measuring people for longer time. There was no calibration for lung counting last year in NRPI. In the beginning, ad hoc calibration was used which was later on replaced with proper calibration using the IAEA lung phantom.

Bioassay

Urine:
In native state not measurable (even after the injection of DTPA) by the means of gamma spectrometry (it means that in a single portion of urine there always was less than 2,5 Bq), therefore radiochemical separation of Am followed by alpha spectrometry was used.

Faeces:
The first measurement for the rough estimation: By means of gamma spectrometry, in the vessel in which they were collected. Afterwards, still in native state, in the defined geometry in 250 ml cylindrical vessel placed on the detector. When activity of Am decreased below 3 Bq per sample, samples of faeces were dried, ashed at the temperature below 450 ^{0} C and measured by gamma spectrometry using counting times at least 10 000 s. Ash was measured

either on the bottom of cylindrical vessels or in the well of HPGe detector. When using well detector and long time of measurements (up to 3 days), minimum detectable activity was 0,01Bq / sample. According to the mass of faeces, the whole ashed sample or only its part was used.

The sensitivity of gamma spectrometry for the ashed samples of faeces and long measuring time was quite high, however, it was not possible to use it for urine samples because of their large mineral content.

Measurement procedure

Each person was measured by WBC, detector's front viewing the trunk of the measured person, afterwards the head by 2 LEGe detectors was measured, afterwards also knee was measured. In some cases, two LEGe detectors were also used in the contact with the trunk.

People were instructed to collect daily samples of faeces and urine during three days (when staying on the clinic, 12 hours samples of urine were collected). Such procedure was repeated before each in vivo measurement and went on up to November, i.e. 5 months after the first intake.

The surface contamination of people was measured with Digital Contamination Monitor LB 1210 E; however, due to sensitivity of detector, no contamination was established. The people underwent a showering before in vivo measurement was carried-out according to usual procedure.

The decrease of measured values appeared during repeated in vivo measurements could not be explained by the kinetics of the nuclide within the body (Fig. 2), but confirmed the suspicion on the presence of significant surface contamination. The evidence of the surface contamination was provided as well by measurements of a sample of hair from haircut of person W1. In the same direction pointed the uneven counts from measurements of head by two LEGe detectors from left and right side of the head and traces of ^{241}Am activity on pillows from clinic where W1 was hospitalized.

Results

Evaluation of intakes

Numerical values for class M and AMAD 5μm were used according to the Publication ICRP No. 78 on inhalation of ^{241}Am. As to the chemical composition of the contaminant, it was known that in the dismounting glow-boxes americium oxide was processed in the past.

The assessment of intakes and resulting committed effective dose from the internal contamination with ^{241}Am is based on excretion analysis as the in vivo measurements was strongly influenced by surface contamination. On 12 July the first in vivo investigations was performed in subject W1 and were reported as preliminary results to SUJB and to NRI. The necessity for highly conservative estimate was considered because it should serve as a guide for possible remedial steps. From the first two in vivo measurements the body burden of ^{241}Am was estimated at about 5 kBq and considering the date July 10th as the time of intake, the committed effective dose (E 50) was assessed in the order of Sv. It was, however,

recognized that these figures could be overestimated due to the contamination which remained on the body surface in spite of thorough showering before measurements and absence of positive response of surface monitors. Later it was shown from the measurements of a pillow from the hospital and a specimen of hair from a haircut that some contamination indeed adhered to the scalp. In the meantime, it was arranged for the collection of stool and urine.

The repeated investigation (WBC, head, knees) and evaluation of the first excreta analysis soon enabled to decrease the first glance estimates, so that at the time of notification of the event to IAEA on 17 July the committed effective dose in W1 was quantified as 350 mSv.

During the next period some more people suspected of the same type of contamination were measured as given above. Also these workers had significant surface contamination on the bodies. Initial estimation of intakes and committed effective doses were performed conservatively too – it was assumed that the ^{241}Am activity corresponds to internal contamination only. During following days, when samples of excretion were measured and the surface contamination decreased more realistic estimates of the intake and committed effective doses were performed. Fig. 1 the graphs depict the results of the measurements of ^{241}Am activity in heads in workers W1, W2 and W3.

More quantitative data on internal contamination were obtained later, when the results on excretion of ^{241}Am into urine and faeces were available. Still remained an important input information for calculations, which could not be determined with appropriate accuracy. It concerned the date or dates of intake. The contamination could occur on 10 July but on the basis of the available facts it could not be excluded, that some intakes took place already during processing the first and second box, i.e. on 21 June or 3 July. In some followed-up workers an increase of the excreted activities was observed in the later period of investigation, which is hardly interpretable without assuming additional contamination. It happened, e.g. in W1 and 15 October was determined as the possible date of intake. The course of time of the excretion data of W1 is shown in fig. 2. The best estimates of the E (50) for W1 as summarized on 30 January 2002 are presented in Tab.1. The estimate 50 mSv is based only on excretion data. The estimates for W3-W7 are developed with the same approach and vary in the range (5-185) mSv with different level of accuracy depending on the certainty of presumptions about the date of intake.

The worker W2 did not fit fully with the patterns typical for subjects presented above. In this case well measurable activity was found with lung measurement and this activity decreased slowly in the course of time. The activity measured after 100 days was attributed to deposit located in lungs. The figures are presented again in Tab. 1. Here also the data of W3 are included who was most probably contaminated during early phase of post-accident decontamination procedures. The course of time of the excretion data of W 2 together with the W1 a W3 is shown in fig. 2.

In addition to the 8 people with established internal contamination of ^{241}Am, 18 other employees from NRI were measured on WBC. Whole body counting, measurement of head and also measurement of knee in some cases were performed. No measurable internal contamination was found.

Table 1. Estimates of the effective dose commitments in some of contaminated workers

Summary of results, 30 January 2002							
Person	Way of intake	Date of intake	Estimation of E(50) (mSv)				
			In vivo (lungs)	In vivo (bone)	Faeces	Urine	Best estimate
W1	2 inhal	9.7.2001 15.10.2001	<13	< 27	41	65	50
W2	3 inhal	18.7.2001 20.9.2001 2.11.2001	130	-	130	123	130*
W3	1 inhal	18.7.2001	< 16	< 31	43	37	40

* Compilation from results of measurement of lungs and bioassay

The problems connected with the evaluation of intakes, comments to the initial overestimation of doses

Unremovable surface contamination of skin and hair of all contaminated people caused the biggest problems in evaluation. The surface contamination occurred not only on uncovered parts of body but also on knees and trunk. As it is illustrated in figure 1 the surface contamination stayed on the head in some cases for more than 100 days. Therefore, it was not possible to use in vivo measurement from the first days after intake for the final estimation of doses. Also the time of the intake was not clearly established and the possible interval of the intakes was in the range of 3 weeks. In some cases, repeated intakes during the time in which people were followed could not be excluded.

The excreta were not collected from the very beginning of the suspicion on internal contamination as a result of non-adherence to the requirements of the on-site emergency plan. To make an estimate of the effect of the DTPA administration, the data of daily urine excretion of ^{241}Am were used. Because of a very short time of the DTPA administration (two doses in the span of three days) and a lack of background values before administration in part of patients any general conclusion could be taken from the data. Still an elevation of excretion has been observed.

Future steps

The group of in event involved workers will be measured again by whole body counter and by skull counting. Especially skull counting seems important, as the activity of ^{241}Am in the skeleton., according to biokinetic models, should increases in the course of time. Also excreta will be collected as, up to now, they are main source of information. In this aspect, to explain the difference obtained from evaluation of faeces and urine will be one of the most important topics.

To check the ^{241}Am body content via measurement of urine and faeces in other workers is the important task for the employer in the framework of the on-site monitoring plan.

3. Investigation and treatment of persons after inhalation of ^{241}Am

Introduction

In July 2001, six subjects suspected of internal contamination with ^{241} Am were hospitalized at the Health Centre for specialized care of persons exposed to ionizing radiation at the Department for Occupational Medicine of the General Teaching Hospital in Prague. One more person was examined at the Out-patient Department.

Subjects and methods

Characteristics of all patients are given in Tab.2.

Table 2: Characteristics of the patients

Person				
	Age	Sex	Height	Weight
	Years	-	cm	kg
W1	52	male	168	86
W2	62	male	183	68
W3	53	male	183	70
W4	66	male	167	97
W5	44	male	185	85
W6	55	male	170	81
W7	68	male	187	78
Mean	57.6	-	177.6	80.7

First person (worker 1, W1), was hospitalized from 13 July to 19 July 2001. On admission, this patient had no subjective symptoms. Five other persons W2 – W6, were hospitalized from 20 July to 23 July. None of them had fatigue, bleeding problems, dyspnoea and sleeping disturbances, or other symptoms, that could be attributed to the incident. One person W7 was examined on the out-patient basis and was given no antidotal treatment. Subjects W8 and W9 have not been sent to our department for investigation.

All the persons were internally investigated and biochemical test of blood and urine were performed. Blood count and minerals in blood and urine were measured, urinalysis and lung functions were examined.

Administration of DTPA and results

In subject W1, the physical examination was normal, except Baker´s pseudocyst of the left leg that appeared on the day 5 and was evacuated at the department of surgery. First results of in vivo measurements at the NPRI, as given above, pointed in this person to a possible intake corresponding to the committed effective dose E (50) up to 1000 mSv. This worker was treated with two doses of 1g Ca-DTPA in infusion.

Also physical examination of subjects W2 – W7 did not show any signs that could be attributed to the accident. The preliminary measurements indicated in them intakes corresponding to the committed effective dose at a level similar to W1. On the basis of these results, persons W2 – W6 were given two doses of 1g Ca-DTPA in infusion (on 20 July and 22 July).

The results of haematological and biochemical examinations did not bring any findings that could be caused by ^{241}Am intake.

In worker W3, megaloblastic anaemia and elevation of uric acid in blood was found. This disease was first documented one month ago and it could not be attributed to the incident. In another person, with the history of hyperuricaemia (W4), mild elevation of aminotransferases and mild hematuria was found (both before the antidote treatment). In one patient (W5), there was a mild elevation of aminotransferases (before antidotal treatment), that could be connected with hepatopathy diagnosed in 1997. In one patient (W6), treated for hypertension since the year 1999, mildly decreased creatinine clearance was found.

Lung functions examination in all hospitalized patients was within the reference values.

Blood levels of sodium, potassium, chlorine, calcium, phosphorus and magnesium were measured both before and during the antidotal treatment. All the mean blood concentrations of these minerals were within the normal range. Also the mean urine concentrations of sodium, potassium, chlorine, calcium, phosphorus and magnesium after the treatment were normal.

Zinc and copper blood and urine levels were measured only after the DTPA treatment. Blood copper level was in the reference range, although its elimination in urine was elevated .On the other side, zinc blood level was decreased which corresponded to its higher urine excretion after the DTPA treatment. Apart from these minor changes, no patients showed any side effect of the antidotal treatment. The mental condition of the patients was good, too.

Complete results of the radiochemical examination of the collected urine and stools before and after the antidote treatment were available only after the hospitalization and could not be used as the guidance for the treatment. .

All patients will be followed-up on the long-term basis.

4. Conclusions and lessons learned

On 12 July 2001 at about 13:50 the responsible inspector of State Office for Nuclear Safety (SUJB) received the telephone call of the Head of the laboratory of internal contamination of the NRPI reporting the first results measurements of suspected of internal contamination of a radiation worker (W1). This worker had been forwarded to the whole-body investigation after the measurements on the spot indicating a spread of radioactive material. From the first two in vivo measurements the body burden of ^{241}Am was estimated at about 5 kBq and considering the date July 10th as the time of intake, the effective dose commitment (E 50) was assessed in the order of Sv. It was, however, recognized that these figures could be overestimated due to the contamination, which remained on the body surface in spite of thorough showering before measurements and absence of positive response of surface monitors.

The management of NRI reported the event officially to SUJB on 12 July at 15.55 and classified it as an extraordinary event grade I (according to the Decree No.219/1997 Coll.). The limit for notification of an extraordinary event grade I – up to 24 h after its discovery - was not exceeded (still it seems unsatisfactory that SUJB received the first note about extraordinary event from the NRPI, not from the licensee). The license announced that in the Fragmentation and Decontamination Centre (FDC) located in the building No. 241 at least four workers processing radioactive waste containing ^{241}Am were internally contaminated with this radionuclide.

This same day (12 July) in the afternoon, the responsible officer of SUJB contacted by phone the Radiation Protection Officer of NRI and the plant medical centre to get more detailed information on the circumstances of the event and on the envisaged steps in handling the accident. It was agreed that the W1 will be admitted for hospitalization to the Clinic of Occupational Diseases of the University Hospital in Prague, which is designated by the Ministry of Health as a specialized unit for handling accidentally contaminated persons. It was soon recognized that more co-workers of the subject W1 were suspected of similar contamination. It seemed to be urgent to carry out as soon as possible the surface decontamination of these workers, to start systematic collection of faeces and urine and to organize in vivo measurement of their body burden in the NRPI. The plant doctor of NRI availed himself of DTPA for decorporation therapy via injection or infusion but he hesitated to use it because of the fear of possible side effects.

On 13 July the laboratory of internal contamination of NRPI informed SUJB that the results of the further external measurements of the bone deposit and of the excreta of the patients W1 point to a considerably lower committed effective dose as compared with first glance results of 12 July. This statement should still be considered as preliminary.

As mentioned above, the worker W1 was hospitalized on 13 July and the next day (14 July) received the first intravenous infusion of 1 g Ca-DTPA. While this clinic had not sufficient own experience with the treatment of the internal contamination with ^{241}Am, the head of the clinic turned to the some clinics abroad (U.S.A, France, Germany, Switzerland) with the request for consultation. This incentive was not meant as a request for direct medical assistance.

The notification of this accident to the IAEA Emergency Response Centre occurred through the Point of Contact of the Czech Republic on 17 July on the basis of report submitted by the NRI in Rez and classified on INES Scale at level 2. In this report the circumstances of the accident were briefly outlined and an amended assessment 350 mSv of the committed effective dose E (50) was given.

Inspectors of SUJB started on 13 July exploring the circumstances of the accident at the spot. The investigation was focused to following points:

a) the compliance with the rules for the work in controlled area,
b) the compliance with the requirements for monitoring program,
c) the compliance of the post-accident activities with the requirements of the on-site emergency plan,
d) the detailed analysis and evaluation of the technology and procedures used by the workers during dismantling and processing operations,

e) the evaluation of the performance of the on-site radiation protection supervision, i.e. of the Radiation Protection Officer of NRI,

with following results:

a) The workers were provided by working garments, gloves, shoes, caps and respirators. After finishing the working shift they are obliged to take shower in the access area. There was found some shortcomings in the cleaning procedures. *The check of surface contamination of technical aids and personal protective clothes was not performed systematically*. These items were used repeatedly in successive days without any dosimetric control. *Only with some delay (on 11 July) it was ascertained that the respirator worn by the subject W1 was considerably contaminated***.** On the other hand the workers were adequately instructed about the radiation protection principles and rules.
b) During the dismantling and dismounting operations the requirements for adequate monitoring at the workplace according to the approved monitoring plan were not fulfilled. There were lacking some daily records of the measurements after the shifts and if present they were short of clear view and accuracy. The dismounting of glove-boxes contaminated with ^{241}Am could be considered as a non-standard operation for the workplace and as such required a special monitoring plan with additional arrangements. Such a program had not been developed and submitted for approval to the radiation protection officer of the plant. As a result there were lacking at the spot monitoring devices appropriate for this specific task. As the personnel monitoring is concerned, the measurements of internal contamination before and after the task were not carried-out which should be required in the case of non-standard of handling unsealed sources.
c) Not-collecting the samples of biological material (stool and urine) after internal contamination began to be suspected violated the requirements of the on-site emergency plan. In contrast to the rules set in emergency plan the decontamination of the body surface under systematic dosimetric control was not provided.
d) The better specification of the activities performed by the workers of the FDC during dismantling of boxes started from the assessment of the ^{241}Am activities in three boxes delivered by their former user. The total activities in boxes were declared as follows - box No. 1 - 150 MBq, No. 2 - 180 MBq and No. 3 - 50 MBq.
e) The receiver (FDC) verified these values. The inspection discovered some minor administrative fault, namely the dispatch note on radioactive waste was transmitted from the receiver to the former user with some delay. *An important negligence of the technician responsible for the operation was the failure to measure and evaluate at proper intervals the activity of the filters from the device measuring the volume activity in air.* The measurement occurred only after the dismantling and treatment of the box. The result indicating the exceeding of the intervention level for the workplace was available only on 10 July just after finishing the dismantling of the third box. On the basis of these facts it could not be excluded, that the internal contamination of workers occurred already during processing the first and box No. 2, i.e. on 21 June or 3 July.
f) The shortcomings in the adherence to the requirements of monitoring program and of the routine for the work in controlled areas are clearly attributable to the gaps in the duties of the on-site Radiation Protection Officer. The responsibility for violation the regulations and codes of practice lies not only on the operators and technicians but to a prevailing extent on the supervisory activities of the Radiation Protection Officer.

In the period after the accident, i.e. on 14 and 15 July the workplace was decontaminated under the parallel dosimetric control. During the decontamination of the FDC and adjacent area an interim controlled area was delineated and a mobile module serving as clearing and

measuring check-point was provided. The premises were again opened to normal activities on 8 August. The protocols of these procedures were submitted to SUJB.

It remains to consider the environmental impact of this accident. The filters in the outlet of the air from the FDC building to the stack of the facility detected measurable activity of ^{241}Am released during dismantling operations. Quantitative evaluation of measurements pointed to the activity of 0,185 MBq ^{241}Am as the integral release of this radionuclide during the dismantling and conditioning operations. This release may result in a maximum individual committed effective dose of 3,5 μSv/50 years in a circular area with 400 m radius from FBC. The lung committed equivalent dose in the same territory may achieve 0,1μSv/30 days. The exposure in surrounding of the facility is from the point of view of a member of the public negligible. Under highly conservative assumptions is less than 1/250 of the effective dose limit, which is set at 1mSv/year.

As was mentioned above, the SUJB preliminary classified that event on the INES Scale at level 2. Final estimation of doses obtained by workers and of activity radionuclides released into environment showed, that the classification of the event needs not to be changed:

- Into environment released activity 0,185 MBq of ^{241}Am is less than is supposed in the INES User´s Manual (Final Draft of the 1999 Edition, IAEA, Vienna) for classification at the level 2. A spillage of solid radioactive material of the radiological significance equivalent to the order a few GBq ^{106}Ru (i.e. a few MBq ^{241}Am) is suppose to be released if the event is classified at level 2. From the value of the released activity point of view, correct classification is at level 1.
- The estimated doses of one radiation worker exceeded (more than two times) and of the other was at the level of annual dose limit. For that case the mentioned INES Manual supposed classification of event at the level 2.

SUJB conservatively confirmed former event classification on the INES Scale at level 2.

The SUJB as the regulatory t authority decided to penalize the NRI by a fine amounting to 150 000 Czech Crowns. The serious violation of the radiation protection requirements (as stipulated in the national legislation) and non-compliance with the approved documentation - Monitoring Program and On-Site Emergency Plan were the reasons SUJB for this administrative step.

The conclusions of the SUJB inspection can be summarized as follows:
The considerable underestimation of the hazard of the dismantling and fragmentation of the dry glove-boxes has been identified as the main failure leading to the internal contamination of workers by ^{241}Am.

Fig. 1: Measurement of ^{241}Am activity in heads

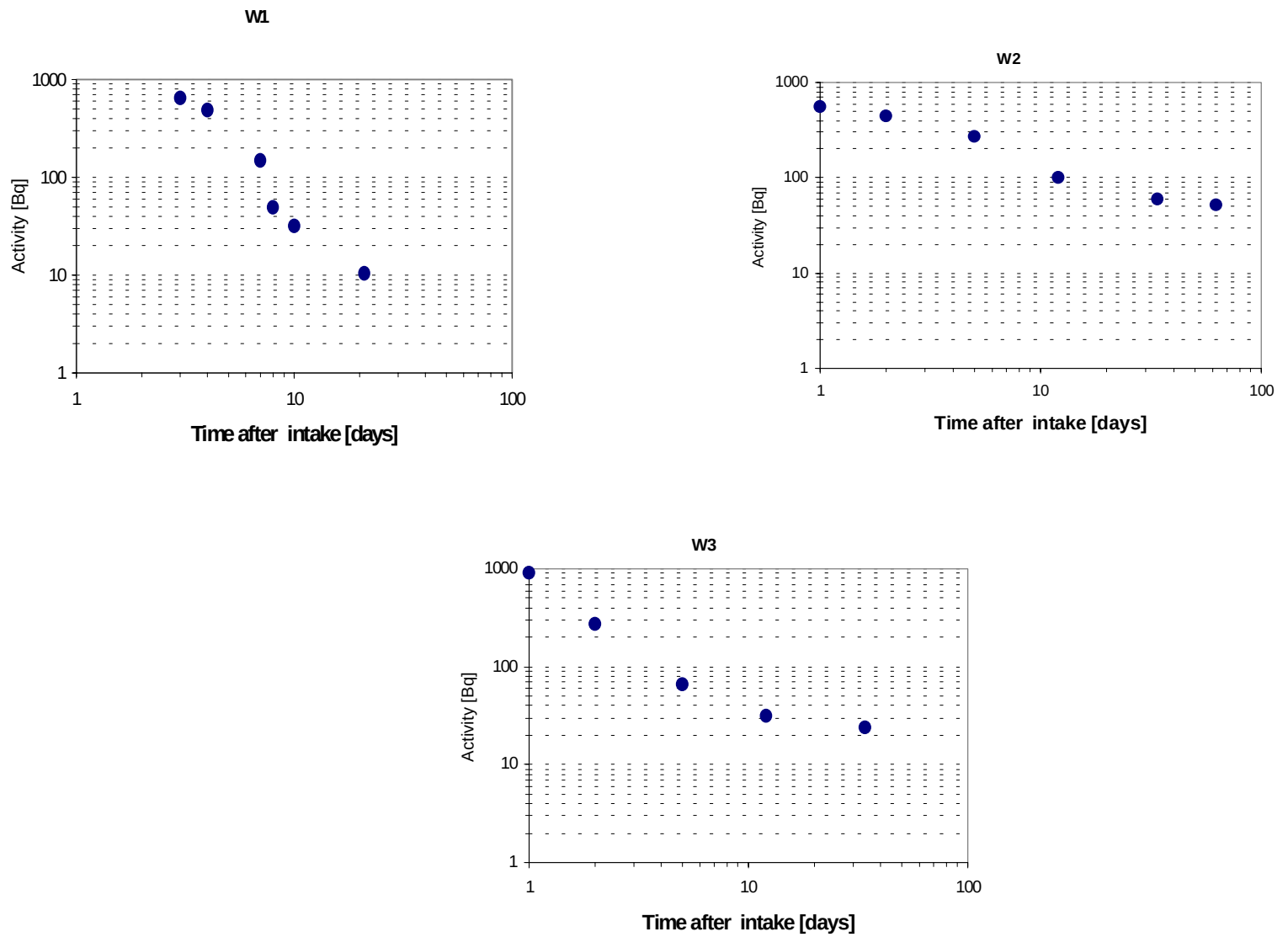

Fig. 2: Time-course of daily excretion of ^{241}Am activity in faeces and urine