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RADIOACTIVE WASTE MANAGEMENT AT THE NUCLEAR SCIENTIFIC AND EXPERIMENTAL CENTRE OF THE INSTITUTE FOR NUCLEAR RESEARCH AND NUCLEAR ENERGY – BAS*

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Abstract: *The paper gives an overview of the management of radioactive waste (RAW) generated during the operation and maintenance of the facilities at the Nuclear Scientific Experimental and Educational Centre (NSEEC) of the Institute for Nuclear Research and Nuclear Energy at the Bulgarian Academy of Sciences (BAS). It covers the basic procedures adopted at the NSEEC for the collection of solid and liquid RAW, their classification, categorization and storage as well as the chain of command for RAW tracking, transportation and reporting. The accumulated solid RAW is stored according to the international and Bulgarian regulations in separate safe boxes (in the designated premise of every laboratory on the site of NSEEC), in monitored storage rooms (for the I Class Radiochemical Laboratory) and in a separate building (Reactor Equipment Storage). At present, the largest inventory of discarded sources of ionizing radiation is stored in the Gamma Irradiation Facility. In 2009, the low and medium activity liquid RAW stored in the underground tanks of the IRT-2000 research reactor were shipped for final p to the reprocessing facility of Kozloduy NPP and, at present, there are small amounts of low activity liquid RAW stored mainly in the II Class Radiochemical Laboratory. Among the main steps during the implementation of any RAW treatment activities is the detailed assessment of the doses accumulated by the personnel as well as providing the admissible working conditions - devices and accessories, personal means of protection, measuring appliances for overall dosimetry control, conduct of personnel instructions, etc., so that the collected doses are in the permissible limits determined by the legislation in force in Bulgaria and the internal regulations of INRNE for work with sources of ionizing radiation.*

Key words: *Radioactive, waste, management*

1. INTRODUCTION

Historically, the nuclear site of the Nuclear Scientific Experimental and Educational Center (NSEEC) at the Institute for Nuclear Research and Nuclear Energy (INRNE) is preceding the nuclear power plant “Kozloduy”. The NSEEC site comprises the presently shut down nuclear research reactor IRT-Sofia because of the undergoing reconstruction, two radiochemical workrooms, a ^{60}Co gamma irradiator and a number of other research laboratories that use radiation sources in their work. Radioactive waste (RAW) generated during the operation and maintenance of the nuclear equipment and workrooms emits radiation, which makes it a particular hazard for human health and the environment. Furthermore, the low and medium-level RAW from the partial dismantling of the research reactor is stored on the site. All the storages and facilities convey issues that are imposing requirements for a permanent dosimetric control and radiation monitoring of the environment.

The experience of NSEEC professionals in ensuring the radiation safety and the protection of staff, public and environment was presented recently [1-3]. Here we focus on some key aspects of the safe management of RAW related activities at the NSEEC including their transfer to the repository facility near the town of Novi Han which is operated by the State Enterprise Radioactive Waste. In general, the task of this repository is to accept and store low and intermediate-level radioactive waste generated from activities not related to nuclear energy production in Bulgaria.

2. LEGAL FRAMEWORK RELEVANT TO THE MANAGEMENT OF RAW AT THE NSEEC

Depending on its aggregate state, radioactive waste is classified as solid, liquid or gaseous. The safe management of RAW involves its collection, sorting, packaging, conditioning (concentration, solidification, compaction, incineration), interim storage, transportation, long-term storage and (or) disposal. All the activities must be accomplished in accordance with all applicable national and international laws.

For the purpose of managing the RAW and the spent nuclear fuel (SNF), the Council of Ministers (CM) of Bulgaria has adopted a Strategy for the management of spent nuclear fuel and radioactive waste up to 2030 [4] in performance of the Act on the Safe Use of Nuclear Energy (ASUNE) [5] including a resolution on the foundation of a national repository facility for the storage and/or disposition of RAW. The National Strategy applies to all types of RAW, as well as to all stages of their management (from generation to disposal). This document is reviewed and updated periodically taking into account appropriate technical and scientific progress as well as recommendations, lessons learned and best practices from peer reviews.

The ASUNE [5] entrusted the off-site management of RAW to a specialized State Enterprise Radioactive Wastes (SERAW). The RAWs then become a state-

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owned property and are managed by the enterprise, with the latter being financed by the "Radioactive wastes" fund according to the provisions in the corresponding CM Order.

According the ASUNE, nuclear energy and sources of ionizing radiation can be used by physical persons or legal entities only after obtaining permission and/or license for safe conduct of the activity. Management of radioactive waste and spent fuel is carried out by legal entities only after obtaining a permit and/or license. The licensee bears the full responsibility for the safe management of the time of production to release their adjustment or their transmission to SERAW. The activities at nuclear facilities and sources of ionizing radiation, having an impact on safety can only be performed by qualified and licensed personnel.

One of the most important regulations aiding the implementation of ASUNE is the Regulation for Safe Management of Radioactive Waste [6]. This regulation stipulates that, for activities and facilities for RAW management, an individual effective dose for the critical group members of the public cannot exceed 0.15 mSv per year for new facilities and 0.25 mSv per year for existing facilities. Radioactive waste is stored in a manner ensuring adequate isolation from the environment and the population for the entire planned period of storage and facilitating the subsequent stages of their management. The licensee shall conduct safety assessments to assess the compliance of the facility or activity for RAW management with the objectives, requirements and criteria for safety and to determine whether an adequate level of safety has been attained.

Beside the national legislation, the relevant European Directives [7, 8] as well as the standards and recommendations of IAEA [9-19] are also taken into account in solving problems at NSEEC related to RAW.

3. Basic procedures adopted at NSEEC for the collection of solid and liquid RAW, their categorization, classification and storage

Since 2003, NSEEC, as a division of INRNE, has been implementing a quality assurance (QA) management system in compliance with the international standard ISO 9001 and the international standard for environment protection ISO 14001. At present the integrated management system of INRNE is maintained and constantly improved which is proved in the annual reports of the external auditors. All of the documentation is catalogued and archived both electronically and on paper. The procedure for the management of solid and liquid RAW, including the collection, categorization, classification, and storage as well as reporting is regulated by a distinct document [20].

3.1. Generation and Collection of RAW

Solid and liquid RAW is generated routinely during the operation and maintenance of the facilities and radiochemical laboratories on the NSEEC site, as well as through the implementation of several key activities in the period 2007-2010: preparation and shipment of spent nuclear fuel, partial dismantling of IRT-Sofia reactor, preparation and shipment of high level solid RAW stored in hot cells and spent nuclear fuel pool. Partial dismantling was planned [21] and carefully executed as a step in the implementation of the "General Plan for refurbishment of IRT-2000 into low power reactor" approved by the Bulgarian Nuclear Regulatory Agency. Refurbishment was recognized by the Government in 2001 as a cost-effective method of life extension to enable continued utilization of the aged IRT-Sofia compared with the alternative of the construction of a new research reactor.

At the NSEEC, RAW is collected separately from non-radioactive waste directly in areas where the waste is generated taking into account: categories of waste, aggregate state (liquid, solid), physical and chemical characteristics, nature (organic, inorganic), half-lives of radionuclides in the waste (less than 100 days, more than 100 days), explosion hazard and fire risk, as well as accepted methods of waste processing. Radioactive waste is collected in special containers. Solid RAW may be primarily put in plastic bags, which are then placed in special containers. If necessary, waste collection sites are provided with special shielding to reduce the radiation outside to acceptable levels.

A special sewerage system provides the collection and control of liquid RAW, which must not be used for the disposal of non-radioactive waters. Liquid RAW must not be discharged into sanitary or rain sewer systems. The contaminated waters are directed toward special underground tanks and undergo periodic radiochemical analysis. Providing the limit conditions allowing the emission into the environment are fulfilled, the water will be pumped out as debalanced water. Else, the water will be transferred to a mobile unit for transportation and reprocessing as liquid RAW.

RAW streams, that are identifiers for objects of generation (Reactor Hall, primary cooling loop, etc.) and temporary storage of RAW, are specified for the systematization of data in the RAW inventory in the NSEEC. A qualified employee of NSEEC is responsible for this process, bearing the obligation for the accountability of isotopes. The sequence of activities performed and records kept are described in [20].

3.2. Tracking and reporting of RAW

The traceability and accountability of RAW, Figure 1, are defined in [20] and the relevant reporting entries are logged in [22]. Copies of all relevant documents are stored permanently in the "Radiation Safety" Department. The person designated for isotope management at NSEEC and the person appointed to organize and control the radiation safety at INRNE take responsibility for the applicable documentation.

Spent ion exchange materials represent a special type of RAW and pose unique problems in the selection of their treatment options. Because of the function that they fulfill, spent ion exchange materials often contain high concentrations of radioactivity and pose special handling and treatment problems. Organic ion exchange resins are expensive materials that are used with care and regenerated if possible. They are discarded as waste only when this is necessary or economically justified.

Figure 1. Tracking and record-keeping of RAW - measurements of surface contamination of the primary cooling loop premises

3.3. Characterization of RAW

Waste characterization is necessary to ensure the selection and application of appropriate treatments and conditioning options to satisfy the requirements for waste storage and final disposal to protect human health and the environment. At the NSEEC, standardized and well-known methods in the practice are used, such as gamma spectrometry, low background radiometry of total beta activity and isolated radiochemical radioactive strontium, liquid scintillation spectrometry of beta emitters (^{3}H, ^{14}C, ^{90}Sr, ^{63}Ni, ^{55}Fe, ^{241}Pu) and alpha - spectrometry of transuranium elements. Figure 2 and Figure 3 illustrate some of the routinely used laboratory equipment.

Figure 2. a) Universal device UVJ-01, b) α/β counter PIC-MDS-8, c) HPGe – GMX 50P4 detector

In defining the required treatment for stabilization of each waste stream, it is necessary to identify the radioactive and non-radioactive hazardous constituents. For both the radionuclides and the chemically toxic contaminants, it is important to know their chemical forms and concentrations, to have an understanding of their expected behavior in the treatment processes, their toxicity, and the potential release rates of the components from the final waste form.

Besides characterizing the physical matrix of waste, the following characterizations are important: inventory of radioactive elements, their concentrations, their half-lives, their chemical forms that may influence their release rate, and their specific radiotoxicity; identification of chemically toxic inorganic substances (toxic stable elements and inorganic compounds). The stable components may undergo the same release phenomena as the radioactive components, and these constituents may be leached from the waste and released to the environment long after the radioactivity has decayed away. For each component, the original concentration, toxicity, release rate, and potential for adsorption along the release path should be determined. In addition, the identification of chemically toxic organic components (solvents, complex organic compounds, complexing agents, certain monomers or polymers, etc.) is necessary. This class of contaminants is also subject to chemical reaction and release to the environment through common mechanisms.

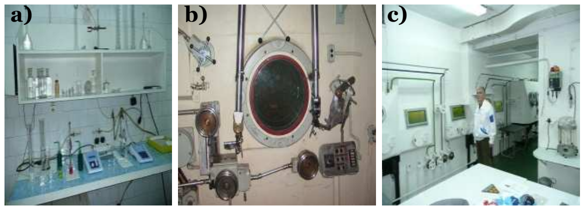

Figure 3. a) pH and conductivity meters, b) class I hot cell, c) heavy glove boxes

Once the presence of hazardous constituents and the probable range of concentrations are defined, then consideration is given to the selection of technologies to separate, stabilize or destroy the risky constituents.

3.4. Classification/Categorization of RAW

The activity for the categorization of RAW, Figure 4, is accomplished according to the National regulations [5] and [6], and is detailed in [20] and [21].

Figure 4. Categorization of RAW: a) intermediate storage of dismantled equipment, b) measurement of gamma dose rate, c) RAW sorting, d) dismantling of the thermal column

In general, solid RAW, with regard to radioactivity and specific characteristics, is classified as follows:
Category 1 - waste containing radionuclides with low concentration of activity, which do not require the implementation of measures for radiation protection or do not need a high level of isolation and detention; RAW from this category is further divided into:

- **category 1a** - waste that meets the levels for the release and clearance from the regulatory control;
  category 1b - very short-lived waste containing mainly radionuclides with short half-life (not longer than 100 days), whose activity decreases below the levels for the release and clearance from the regulatory control under the ASUNE as a result of the applicable storage on the site for a limited period of time (usually less than several years);
- **category 1c** - very low level waste with levels of activity exceeding by a minimal value the levels for release and clearance from the regulatory control under the ASUNE and with a very low content of

long-lived radionuclides, which represent a limited radiological risk;

Category 2 - low and intermediate level waste: RAW containing radionuclides in concentrations that require measures for reliable isolation and retention, but do not require special measures for heat removal during the storage and disposal; RAW from this category is further divided into:

- **category 2a** - low and intermediate level waste containing mainly short-lived radionuclides (with a half-life not longer than that of ^{137}Cs) as well as long-lived radionuclides at significantly lower levels of activity, limited for the long-lived alpha emitters under $4x10^6$ $Bq.kg^{-1}$ for each individual package and a maximum average value for all packages in the respective facility of $4x10^5$ $Bq.kg^{-1}$; for such RAW, reliable isolation and detention is required for up to several hundred years;
- **category 2b** - low and intermediate level waste containing long-lived radionuclides at activity levels of long-lived alpha emitters, exceeding the limits of category 2a;

Category 3 - high-level waste: RAW with such a concentration of radionuclides in which heat removal must be taken into account when it is in storage and disposal, for this category a higher level of isolation and detention is needed compared to the low and intermediate level waste, through disposal in deep, stable geological formations.

This classification applies to liquid and gaseous RAW in dependence on the characteristics and form of the suitable for disposal solid RAW that is expected to be generated after the conditioning of liquid and gaseous waste.

3.5. Storage of Radioactive Waste

In general, if gamma-radiation dose rate at the surface of the RAW containers exceeds 2 mGy/h, special repositories should be used for their interim storage and hold-up. In the NSEEC procedures, it is adopted that the RAW of various categories in interim storage is stored in a separate room or in a specially allocated area. According to the legal requirements, all storages of RAW are marked with the label for radiation danger. The solid RAW resulting from routine work is kept in separate safe boxes in a designated premise of every laboratory and in monitored storage rooms for the I Class Radiochemical Laboratory. After the preliminary characterization and categorization, this RAW is moved to the reactor equipment storage (RES) and the neighboring Temporary storage (TS), Figure 5.

The RES meets the regulatory requirements for RAW treatment and conditioning and is served by NSEEC personnel under the supervision of the "Radiation Safety" Department. The reduction of the volume of categorized solid RAW is done by cutting the contaminated parts. The "Program for filling up the special steel-concrete containers" should be taken into account under the supervision of an experienced professional in charge of RAW management appointed by the Order of the INRNE Director.

The TS is designed for intermediate storage (prior to disposal) of RAW. It is a specially built surface steel-concrete facility with adequate engineering barriers assuring protection of the operating personnel and the environment. Its capacity is for 6 steel-concrete containers (by 3 pieces in two fields). The container (external dimensions 1.95x1.95x1.95 m^3; weight – 6 tones; net volume – 5 m^3) is licensed for the dry storage, transportation and disposal of conditioned RAW. Presently, the conditioned low and medium-level RAW from the partial dismantling of IRT-Sofia are stored in these containers.

Figure 5. Solid RAW storages: TS (left) and RES (right)

Contaminated liquids are stored in special storages: LRAWSlv (Liquid RAW Storage low volume; 2 stainless steel tanks, 1 m^3 each) and LRAWShv (Liquid RAW Storage high volume; 150 m^3 each, at a depth of 6 m underground, manufactured from reinforced concrete, covered with stainless steel on the inside), Figure 6.

Figure 6. Liquid RAW storages:
Left-LRAWSlv, Right-LRAWShv

The liquid RAW storage facilities are maintained by the personnel from different NSEEC departments. The results from measurements of levels and volumes of liquid waste in LRAWS are logged in [23]. Normally, the generated liquid waste radioactivity is adequately low, so that the discharge to LRAWS may be allowed without any purification. For special cases in which decontamination is mandatory, an ion-exchange filter, a feed pump and auxiliary equipment is provided. The radioactivity of the discharged wastes is continuously measured by the Liquid Effluent Monitor which, when the limit value of $5x10^3$ $Bq.l^{-1}$ is reached, automatically closes the discharge pipe line circuit and the water is to be directed back into the vault.

Figure 7. The ^{60}Co gamma irradiator GOU-1 is operated in batch mode and used mainly for pilot-scale irradiation

The largest activity of discarded sources of ionizing radiation is in the GOU-1 Gamma Irradiator, Figure 7, designed and constructed by the IRT-2000 staff for radiation processing applications [24].There are 16 metal tubes; each one contains five radiation sources set in optimized positions. The individual source is a ^{60}Co metal cylinder encapsulated in a thin-walled stainless steel can. The mean baseline activity was about 2397.50 Ci or 88.71 TBq per tube.

3.6. *Transportation of radioactive waste*

The SERAW accepts RAW in accordance with the national requirements and criteria for admission [6,25]. The removal of waste containers from repositories is done by the means of special equipment and accessories in order to avoid the over-exposure of the personnel. The transportation of solid and liquid RAW (Figure 9) is carried out in a licensed transport container. Before transportation, an application is prepared by the NSEEC and submitted to the BNRA, and SERAW is accredited for the RAW transfer.

Figure 9. Transportation of solid RAW

4. ON-SITE DOSIMETRY, RADIATION MONITORING AND SPECIFIC RAW ISSUES

All employees working with radiation sources or staying/visiting the areas with a risk of radiation exposure are supplied with personal protective means according to the class and type of work to be done. The protective means are made from easily decontaminated materials or can be disposable. If radioactive contamination is established from the regular checks, these means are mandatory decontaminated under the supervision of the Radiation Safety Service personnel and in case decontamination is impossible or impractical, they are obligatory disposed.

Individual dosimetry control of the staff is carried out using two types of individual dosimeters – thermo-luminescent detector (TLD) and electronic direct-reading dosimeter DMC 2000S with an integrated semiconductor detector with the energy response better than ± 20 % from 60 keV to 1.3 MeV for ^{137}Cs and the measurement range between 1 μSv – 10 Sv. Electronic dosimeters are reported wirelessly using the DOSIMAS software and the results are entered into the database. All personnel working in the ionizing radiation environment is provided with TLD and DMC dosimeters, which are reported periodically. At the end of the reporting period, each worker receives written information about the collected individual dose.

In 2009, a wide-scale action was undertaken for the off-site transfer of all liquid RAW to the liquid RAW reprocessing facility located in the NPP “Kozloduy”. To the stream of liquid RAW the main contribution stemmed from the drained down and removed coolant out from the reactor pool, the spent nuclear fuel pond and the cooling systems as well as from the decontamination of those systems and dismantled equipment and the erected constructions [1, 2]. The liquid RAW is generated as a part of reactor operational life including isotope generation, and research and development activities in the laboratories. Water samples from the reactor pool (RP) and spent nuclear fuel storage (SNFS) of IRT-Sofia were measured to assess the possible corrosion of aluminum-clad RP, fuel elements integrity, and the SNFS status before the transportation of SNF as well as to observe the conditions in the IRT water facilities before the transportation of liquid RAW. Main controlled parameters were total beta activity and concentration of activities of ^{137}Cs and ^{60}Co. The total beta activity was determined by the beta counter MK - 30. ^{137}Cs and ^{60}Co concentration of activities were measured by low-level gamma spectrometry (HPGe – GMX 50P4 detector Ortec type with 54.9 % relative efficiency and energy resolution 2.3 keV at 1332 keV (^{60}Co).

The results are displayed in Tables 1 and 2 and show lower values than the recommended limit values in the Safety Analyses Report of NSEEC [26].

Table 1. Data from water quality analyses for SNFS

Parameter	Experimental (main ±SE)	Range	Limit value
Total beta activity, [Bq.l^{-1}]	128 ± 74	24–249	≤ 400
^{137}Cs [Bq.l^{-1}]	49 ± 12	40 – 57	≤ 400
^{60}Co [Bq.l^{-1}]	2.0 ± 0.5	1.6 – 2.3	≤ 100

Table 2. Data from water quality analyses for RP

Parameter	Experimental (main ± SE)	Range	Limit value
Total beta activity, [Bq.l^{-1}]	83 ± 26	26–113	≤ 400
^{137}Cs [Bq.l^{-1}]	1.09 ± 0.16	0.98–1.20	≤ 400
^{60}Co [Bq.l^{-1}]	3.8 ±0.2	3.6–4.0	≤ 100

Ten courses of a tank truck with a volume of 20 000 l were executed. The maximum individual dose received during all this activity was 0.014 mSv. The total beta activity of transported radioactive liquids was 14.51 MBq for 244 cubic meters. The main isotopes in the radioactivity inventory of contaminated liquid RAW were ^{60}Co and ^{137}Cs. For the total volume of 244 m^3, the measured activity amounted to 244.8 kBq for ^{60}Co and 1785.6 kBq for ^{137}Cs.

The control of RAW is currently carried out mainly with portable equipment (radiometer for the measurement of alpha, beta, gamma and neutron sources as well as aerosol detectors). The only automatic equipment is mounted on the transport gate of the site and used for control of RAW transported by a truck. According to the approved document “General Plan for refurbishment of IRT-2000 into low power reactor”, the forthcoming management of RAW relies on an appropriate set of detectors connected to the ARMS in the following locations and associated premises: primary cooling loop, LRAWSlv, LRAWShv, RES and TS.

Summarized data for the period 2008–2012 when the partial reactor dismantling and related RAW activities were planned and to the great part implemented very intensively [2] show that the average individual dose was 0.133 mSv and the maximum individual dose was 0.518 mSv. This means that the maximum individual average dose was 0.104 mSv/year.

All annual individual doses collected in the entire period (1961-2015) are below the regulation limit of 20 mSv per year. This fact and gamma background data (0.10 - 0.13 $\mu Sv.h^{-1}$) recorded for the controlled area since 1961 indicate the quality of organization of the radiation safety control at the NSEEC site.

The radiation environmental monitoring of the nuclear site is carried out in a grid of pre-selected observation posts including locations and boreholes in proximity of the radiation facilities and the adjacent laboratories [3]. Also, combined detector systems are placed at selected locations for the assessment of the workplace environment. In the reactor, premises are mounted gamma detectors for the control of radiation conditions. These sets of detectors are a constituent of the Automatic Radiation Monitoring System (ARMS) which is in continuous operation. Exceeding of preset warning or emergency levels is indicated by acoustic and optical signals. Real time evidence for the gamma dose level can be displayed on the INRNE website.

Details for the long-term evaluation based on taken samples and determination of radionuclide contents in air (aerosols), water (groundwater and rainfall), soils and in selected plants are given elsewhere [1-3]. All the findings are decidedly in support of the final conclusion for the lack of anthropogenic radiation impact on the environment.

5. Emergency plans and conduct of personnel

In accordance with the quality assurance management system, separate emergency plans are elaborated for the premises with radiation hazards specifying the chain of commands, principles and methods undertaken by the personnel in case of emergency. The entire NSEEC site holds the General Emergency Plan [27] as the major focus is on events at the reactor. Additionally, specific rules and guidelines are developed for safety concerns in regular operation. At a given site, every employee is obliged to follow them. For non-compliance with those rules and instructions, an employee may be isolated from work and be prohibited from entering the place. The ban on work may be imposed by the Head of NSEEC, Chief Engineer and the "Radiation Safety" Department.

6. Concluding remarks

The radiation measurements and site monitoring conducted in long term at the NSEEC provide evidence that the RAW management as developed and adopted meets all the requirements for radiation safety of personnel and prevents any radiation consequences to the environment. The majority of technological issues were noted to have been satisfactorily addressed, but social issues, including public acceptance and current political endorsement to reactor refurbishment remain unresolved. And, last but not least, whilst radiation waste management is probably the most technically difficult issue, everything depends on adequate funding and the professional conduct of the RAW management.

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