

GOOD PRACTICES IN DECOMMISSIONING PLANNING AND PRE-DECOMMISSIONING ACTIVITIES FOR THE MAGURELE VVR-S NUCLEAR RESEARCH REACTOR

by

Mitica DRAGUSIN*, **Alexandru Octavian PAVELESCU**, and **Ioan IORGA**

“Horia Hulubei” National Institute of Physics and Nuclear Engineering Magurele, Bucharest, Romania

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The VVR-S Nuclear Research Reactor at the “Horia Hulubei” National Institute of Physics and Nuclear Engineering in Magurele, Bucharest, will be decommissioned applying the immediate dismantling strategy. The implementation of the decommissioning project started in 2010 and is planned for completion within 11 years. Good practices in decommissioning planning, organization, funding, and logistics are described in this paper.

Key words: research reactor, decommissioning, decontamination, dismantling, radiological monitoring

INTRODUCTION

The VVR-S reactor is situated in the town of Magurele, about 8 km southwest from the centre of Bucharest. It is a tank-type research reactor using water as moderator, reflector, and coolant (fig. 1). The reactor was initially designed for a 2 MW nominal thermal power and maximum thermal neutron flux of $2 \cdot 10^{13} \text{ cm}^{-2}\text{s}^{-1}$. It is of Russian design and construction and has been continuously in operation since July 27, 1957 to December 30, 1997, without any major events or significant refurbishment. The total thermal energy generated throughout the period was 9.52 GWd [1].



Figure 1. VVR-S research reactor in Magurele

By Governmental decision of April 2002, the VVR-S reactor was permanently shut down for decommissioning and the immediate dismantling strategy selected for the purpose. The implementation of the selected strategy is based on the Decommissioning Plan and on the Project Management Plan.

Numerous other organizations, holders of this type of (VVR) research reactors, have been analysed for their implementation of the immediate dismantling strategy [2-4]. Spent nuclear fuel assemblies resulting from the operation period were removed from the reactor building before the beginning of the decommissioning process.

The concept (design) of isolating the spent nuclear fuel disposal (DCNU) building from the reactor building was applied in a view of implementing the decommissioning project in a safe and efficient manner. Only spent low enriched uranium fuel assemblies of the EK-10 type, stored in the DCNU, remain on the site, until they are sent back to the Russian Federation. Fresh unused fuel has already been shipped back to the Russian Federation.

DECOMMISSIONING – THE APPROACH

The VVR-S reactor is the first major nuclear facility in Romania which will be decommissioned. The site includes some other nuclear facilities as well, to be decommissioned in the future, since the local community is in expansion.

During the approval of the decommissioning documentation by the Romanian Regulatory Body, an

* Corresponding author; e-mail: dragusin@nipne.ro

international peer review of the Decommissioning Plan of the reactor was organized under the national IAEA Technical Co-operation Project, ROM/4/029, involving six international decommissioning experts. After the implementation of the observations made by the international expert team, the decommissioning plan was approved by the Romanian Regulatory Body. This peer review was recognized as good practice by both the operating decommissioning organization and the Regulatory Body.

The project of decommissioning the VVR-S reactor will be carried out in three main phases. In the first 4 years, all EK-10 type irradiated assemblies of low enriched uranium nuclear fuel will be shipped to the Russian Federation. Within the framework of the US Department of Energy Program for the Russian research reactor fuel return – RRRFR [5], all of the highly enriched uranium spent fuel assemblies (type C-36) have already been repatriated from the Magurele site to the Russian Federation in June of 2009 [6]. Over the course of the first three years of the project, the implementation of the Radioactive Waste Treatment Plan (RWTP) at the Magurele site will be upgraded to manage the material generated from decommissioning activities. Dismantling and decontamination activities will be performed by the research reactor operator and engineering teams available. The final stage of the decommissioning project will be the reutilization of the buildings for accommodating a new electron linear accelerator with a maximal energy of 10 MeV which will be used in material science studies and applications [7]. Equipment obtained under the IAEA technical co-operation project ROM/4/029 (2004-2008), a technical co-operation project with the US Argonne National Laboratory (2003-2007), EU PHARE project (2008-2009), US DOE RRRFR program (2004-2009), and national projects will all be put to use during the decommissioning activities.

The decontamination of the primary circuit components will be performed in wet conditions, while dry decontamination will be applied for the rest of the materials. Dismantling activities will be implemented using commercially available mechanical cutting tools. These activities should result in the release of the site from the control of the regulatory body.

RADIONUCLIDE INVENTORY AND WASTE STREAMS

The radionuclide inventory of the VVR-S reactor is due to reactor operation, production of radioisotopes in hot cells, depleted uranium processing, research activities. The radionuclide inventory of the VVR-S reactor contains contaminated materials and neutron-activated materials.

For the VVR-S reactor which has undergone normal operation, the principal component of the

radionuclide inventory is the activation of construction materials. In our case, contamination due to reactor operation has arisen from the activation of corrosion and erosion products conveyed by the coolant and fission products. In addition, contamination resulted from leakages in the primary circuit, processing and storage of radioactive effluents and waste, maintenance and repair activities, fuel-discharge operations, and working incidents. Contamination by actinides was found to be negligible because the fuel rods and the cladding tubes of the reactor were not subject to major damages [8]. The VVR-S reactor was shut down 13 years ago and, therefore, a significant contribution to the radionuclide inventory can only come from radionuclides with a half-life higher than one year.

The majority of radioactive contaminants generated by the operation of the reactor are beta-gamma emitters. They can easily be detected and measured by gross beta-gamma counting and gamma spectrometry. As a result, these methods of measurement have been used extensively in the radiological characterization of the VVR-S reactor. The activity of hard-to-detect radionuclides is difficult to be measured, but it can be correlated with the activity of those radionuclides that emit strong gamma rays such as: ^{60}Co and ^{137}Cs . Radioisotope production generated a significant contamination in the reactor's main building, ventilation system and radioactive leakage drainage, overflow, and collecting system. Major radioactive contaminants generated by these activities with a half life higher than one year are: ^{60}Co , ^{134}Cs , ^{137}Cs , and ^{241}Am . Radioactive contaminants generated by depleted uranium processing and research activities are: ^{238}U and ^{241}Am .

The reactor block components' mass was calculated as follows: aluminum 4.78 t, cast iron 143 t, concrete 550 t, and graphite 5.3 t. The activity for each component was assessed as well: aluminum $5.87 \cdot 10^{11}$ Bq, cast iron $7.64 \cdot 10^9$ Bq, concrete $1.17 \cdot 10^9$ Bq, and graphite $1.32 \cdot 10^{10}$ Bq. The total activity is $6.09 \cdot 10^{11}$ Bq. The estimated quantities of solid radioactive wastes resulting from the reactor block will be: aluminum 2 t, cast iron 43 t, concrete 38.4 t, and graphite 4 t – for a total of 87.4 tonnes [1].

Radioactive waste streams will be safely managed, taking into account the already existing RWTP situated in the immediate vicinity of the VVR-S reactor and the Baita-Bihor National repository for radioactive waste (NRRW) which are to be enhanced as a part of the refurbishment program. The radioactive waste streams were estimated by direct and indirect measurements. Thus, at the end of the decommissioning project, the radiation dose is estimated to be about 0.1 mSv per year (as an individual dose limit) in order to achieve the release of the VVR-S nuclear facility building from the control of the regulatory body and a maximum collective dose/practice of 1 man Sv per year resulting from residual radioactivity in the build-

ing [9]. Within the frame of the radiation protection program, the radiation dose limit is 20 mSv per year for professionally exposed personnel, 1 mSv per year for the general population, and 10 μ Sv per year for the free release of the materials resulting from the decommissioning. Aluminum and graphite-activated wastes will be stored in the existing storage facilities of the RWTP.

DECOMMISSIONING PHASES

The decommissioning project is to last 11 years and financing mechanisms will be based on public funds deposited into a reinvestment-like program. The IFIN-HH has been entrusted with all responsibilities related to the finalization of the decommissioning process and nearly all assignments related to it. Contractors will be engaged to carry out activities surpassing the technical capabilities of the Institute.

The preparatory phase of decommissioning and the three implementation phases include following principal activities.

Preparatory activities:

- completion of the PHARE project for the research reactor (2008-2009),
- meeting the requirements of the EURATOM Treaty, Art. 37,
- approval of the quality manual for decommissioning (2009),
- repatriation of HEU spent nuclear fuel within the US DOE RRRFR Program (2009),
- obtaining the funding for the decommissioning project and starting the decommissioning project (2010), and
- radiological characterization for determining environmental radioactivity at the site [10, 11] and much more detailed data of the decommissioning area (including land, soil, subsoil, groundwater, *etc.*) incorporated into technical documents forming the Environmental Impact Assessment.

Phase 1 (3 years, starting from 2010):

- implementing the isolation concept for DCNU, elaborating the decommissioning plan for DCNU, obtaining the license for DCNU. The funding is to come from governmental allocations reserved for a national nuclear installation,
- upgrading of the RWTP and of the NRRW – (2010-2012),
- implementing task assignments from phase 1 for the research reactor (2010-2012), and
- repatriation of LEU SNF to the Russian Federation (2010-2013).

Phase 2 (2 years, starting from 2013):

- decontamination and dismantling of the primary circuit,

- decontamination of the hot cells,
- dismantling of the secondary circuit, and
- dismantling of the internal components from the core zone.

Phase 3 (6 years, starting from 2016):

- dismantling of the internal components of the reactor block,
- demolition of the reactor block, dearator (the device for the removal of air and other dissolved gases from the feedwater to steam-generating boilers), and hot cells,
- dismantling of the active underground drainage pond with a total volume of 30 m³,
- final radiological survey, and
- completion of the project.

The detailed Work breakdown structure (WBS) of the decommissioning project was elaborated. It includes 5 work packages (WP), namely: pre-decommissioning activities (WP1), dismantling activities (WP2), decontamination activities (WP3), demolition activities (WP4), and radiological characterization, packaging, transportation, disposal, storage, free release, final survey, and archiving – which are all comprised within the WP5 [1].

After the completion of the project, the building will be reused as a radiation processing facility for research, development and production of water soluble polymers and recycling of other types of polymeric materials. Research and development projects in materials science are to be carried out in the building released from regulatory control, as well.

EXAMPLES OF GOOD PRACTICES IN PRE-DECOMMISSIONING ACTIVITIES

Storage of paper and electronic archives

Complying with legal requirements, three different locations in the reactor building were set up for the permanent placement and keeping of documents. In the initial project, these locations were destined to house research laboratories. Two of these locations are provided with controlled air humidity and temperature, prevention and fire-fighting means and with metallic cabinets outfitted with fire protective shelves. They house the original project documentation and its copies, as well as current documents elaborated within the Quality management system. The electronic archives with storage media and data security are situated at the third location where they will remain for the next 50 years. Another location is specifically dedicated to the reconditioning of original documents, electronic scanning and printing of documents which are sent directly to the electronic archives.

Setting up the decommissioning team

The VVR-S nuclear reactor decommissioning team was set up over a period of 9 years from specialists in various fields necessary for the implementation of the project. From 2002 to 2010, the reactor staff grew from the original 15 to a total of 36 members. The decommissioning team benefited from the appropriate training organized within different co-operation projects, resulting in greater skills in the safe use of the equipment purchased under international and national projects. The results of this training should ensure a safe decommissioning of the reactor carried out by home-grown personnel, while only a small portion of these activities is to be entrusted to external contractors.

Establishment of a radiological characterization laboratory

The radiological characterization laboratory was organized in a 5 year's time in order to support detailed decommissioning planning and so as to manage, organize, and analyze samples and materials from the clean up, pre-decommissioning and activities resulting from the actual decommissioning process. Supervised by a team of 6 specialists in spectrometric and radiometric measurements, the laboratory performs direct and indirect measurements with mobile and fixed devices. A free release material measurement device with a maximum capacity of 300 kg or 1 m³ was installed to support the material management during the pre-decommissioning and decommissioning activities [10]. Equipment for spectrometric measurements of samples will be installed in a building next to the reactor for better protection against increased radiation background, noises, and vibrations generated by the decommissioning activities. Preliminary spectrometric analyses of radioactive waste stored in 220 and 420 l casks are being performed in the extension of the reactor hall [12]. At the time the reactor was in operation, this extension housed neutron time-of-flight experiments.

Various types of gamma spectrometers used for measuring the contents of radioactive waste packages and of the free release of solid materials from the reactor are shown in figs. 2-5 [10, 11].

For clearance of material released during the clean up in the pre-decommissioning and decommissioning stages, procedures based on existing equipment are in place at the VVR-S site. Destructive techniques of materials sampling measured by gamma spectrometry have been used and consequently filed into the archives [12]. Non-destructive methods of measurement will be applied for systems to be used in the following phases of decommissioning [13].



Figure 2. NaI portable gamma spectrometer



Figure 3. GeHP portable gamma spectrometer



Figure 4. Gamma spectrometer GeHP for large radioactive waste packages



Figure 5. Gamma spectrometer with 12 plastic scintillators for free release measurements, capacity 300 kg or 1 m³ of materials

Selection of decommissioning technologies and tools

Equipment used for the decommissioning can be operated either with electric power or compressed air. Thus, for the decontamination of concrete, solid areas, in order to avoid the electric shock, we will use pneumatically operated scarifiers with compressed air. As has been demonstrated in practice, the screwing/un-screwing approach has proved to be more efficient if the tools are operated with compressed air rather than with electric power, thus providing a reduction in the exposure of the personnel to radiation. Mobile devices for cutting with scissors and splitting, hydraulically and electric power operated, are not only more rapid, but also reduce the collective doses of the personnel without generating secondary wastes. The dismantling equipment selected and purchased at the very beginning of the project involves low gauge dismantling machines with remote radio-controlled and mixed electric and hydraulic operation with drive heads such as pick hammers, buckets, cutters, splitters, and scissors. The selection of equipment with electric, hydraulic, and compressed air drives has been argued in technical assessments of the work procedures. The dismantling and demolition of equipment with various supply/operating modes is shown in figs. 6-9.

Dry, wet, or semi-wet decontamination

Decontamination technologies, along with the related equipment used in the clean up phase (removal of the used research equipment from the reactor hall and removal of materials used in the production of radioisotopes), were based on dry and/or semi-wet blasting methods with metallic, plastic, or dry ice missiles (see fig. 10). The same technology will be applied during the decommissioning phase.

Demolition and dismantling equipment

In order to support timely training and periodical retraining of the decommissioning staff, it is necessary to develop work procedures for the demolition and dismantling of the equipment on time. A good idea is to ensure redundancy for key equipment and possibilities for prompt repairs and maintenance services avail-



Figure 6. Cutting equipment with electric or hydraulic supply



Figure 7. Remote radio-controlled demolition equipment



Figure 8. Sampling of the reactor block concrete by a core drilling machine



Figure 9. Scarifying equipment for the decontamination of floors and walls by compressed air supply



Figure 10. Dry, wet, or semi-wet decontamination machine

able as close as possible to the nuclear facility. Demolition and dismantling equipment for the VVR-S decommissioning project will be purchased in phase 1. Similar equipment with bigger power will be needed in phases 2 and 3. The VVR-S reactor decommissioning team is also involved in the elaboration of the decommissioning documentation for other facilities at the Institute (sub critical assembly, zero-power reactor, and heavy ions accelerator). All equipment to be used for the VVR-S' decommissioning (for radiological characterization, decontamination, and dismantling of structures, systems, equipment and components) will be appropriate and, in the future, available for the decommissioning of these facilities.

Equipment for radiological monitoring

The key equipment used in the implementation of the Radiation protection program of the decommissioning plan, namely the instrumentation for monitoring and surveillance, is presented in figs. 11 and 12.



Figure 11. Area gamma monitoring and beta airborne monitoring instruments



Figure 12. Alfa, beta, and gamma airborne monitoring and whole body monitor

DESCRIPTION OF THE ACTUAL WORK

In Phase 1 of the decommissioning, the spent nuclear fuel will be released from the site [1]. In phases 2 and 3, dismantling and decontamination activities of the reactor's structures, systems, equipment, and components will be carried out.

The training and experience gained in this very first decommissioning project of a complex nuclear facility in Romania, the VVR-S decommissioning team will use as a core for the establishment of a future Nuclear Decommissioning Centre of Excellence for the whole country. For good and efficient project management, WBS and WP for the advancement of technical specification sets, procedures, instructions and training programs on adequate decommissioning equipment and activities have been elaborated [7].

An intensive training and professional specialization program was developed at the beginning of the project (2010). As for material management, waste routes are organized in such a manner that their interruption is made virtually impossible.

CONCLUSIONS

This paper presents examples of good practices identified at various stages of the VVR-S research re-

actor decommissioning project; these examples and lessons learned could represent useful input for other decommissioning projects. Several essential preconditions for a successful start of the decommissioning project may be pointed out:

- establishment of the decommissioning team and proper decommissioning training,
- good decommissioning planning,
- removal of the entire quantity of the irradiated and fresh nuclear fuel from the site,
- establishment of a characterization laboratory for samples, materials, and waste,
- upgrade of the waste management infrastructure to support decommissioning activities (RWTP), and
- international cooperation and close co-operation with the Regulatory Body.

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Митица ДРАГУСИН, Александру Октавијан ПАВЕЛЕСКУ, Јоан ЈОРГА

**ДОБРА ИСКУСТВА У ПЛАНИРАЊУ ДЕКОМИСИЈЕ МАГУРЕЛЕ
ВВР-С НУКЛЕАРНОГ ИСТРАЖИВАЧКОГ РЕАКТОРА И
ПРЕДЕКОМИСИОНИМ АКТИВНОСТИМА**

Нуклеарни истраживачки реактор типа ВВР-С у “Хорија Холубеји” Националном институту за физику и нуклеарну технику, који се налази у Магурели крај Букурешта, биће декомисиониран применом стратегије непосредног растављања. Реализација пројекта за декомисију почела је у 2010. години, а планирано је да се оконча у наредних 11 година. У овом раду описана су добра искуства стечена у планирању декомисије, организацији, финансирању и логистици.

Кључне речи: истраживачки реактор, декомисија, деконтаминација, демонтажа, радиолошки надзор
