RECYCLE AND REUSE OF CONCRETE RESULTED FROM DEMOLISHING OF THE BIOLOGICAL PROTECTION OF THE VVR-S NUCLEAR RESEARCH REACTOR FROM MAGURELE

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ABSTRACT

The implementation of the decommissioning strategy for a VVR-S nuclear research reactor requires the knowledge of the activation and contamination level that occurs during operation or during the transition phase. To identify the activated/contaminated areas which is an extremely useful tool in the decommissioning process, drilling cores from the reactor block were extracted and analysed. This is an important step to evaluate the residual radioactivity present in the concrete biological protection of the reactor block. Because a large amount of concrete will be generated as a result of the decommissioning process and its treatment as radioactive waste, will decrease the capacity of the waste storage and the recycling problem can be taken into account. Reuse of radioactive concrete can be a major solution substituting the virgin aggregates and can reduce the waste volume and environmental costs of natural resources.

1. Introduction

In a nuclear research reactor, neutron-activated materials are by far the main contributor to the total radioactive inventory of the reactor. Designed to absorb neutron and gamma radiation and with a complex structure, the biological shield of the reactor block is one of the most active part of the reactor structure, being classified as Class 3 area.

In decommissioning, large amounts of concrete debris will arise, but generally the total volume will be dominated by non-radioactive concrete. This is the case of the VVR-S nuclear research reactor from Magurele, Romania. The reactor was in operation between 1957 and 1997 when was stopped and passed in conservation until 2001 when the shut-down was decided. The decommissioning project started in 2010 and the demolishing of the reactor block itself was started in 2017. Was estimated that 1000 tons of non-radioactive concrete will be generated during the decommissioning project.

The demolishing process of the reactor block need to be planned and undertaken taking into consideration all measurements and requirements related to characterization and free release of materials.

This paper present aspects related with the recycle and reuse of the concrete resulted from the demolishing of the reactor block. This concrete is proposed to be used in the immobilization of the radioactive waste in 220 l containers. For this purpose, the discussions are based on the radiological characterization of the reactor block prior to demolishing process, the concern regarding the reuse of the radioactive concrete resulted from demolishing and the demolishing process itself.

2. The VVR-S reactor

The VVR-S nuclear research reactor (Fig.1) was of soviet conception manufacture being dedicated to nuclear physics research and radioisotopes production.

The reactor was operated according to a program requested by the users, without major incidents. The main components was the reactor itself: a research thermal reactor using distilled light water as moderator, reflector and coolant. Until 1984, the reactor was operated using EK-10 nuclear fuel type (10% ^{235}U enrichment) and from 1984 this fuel was replaced with S-36 (35% ^{235}U enrichment).

The main features of the reactor installations were: 9 horizontal experimental channels, 16 vertical experimental channels, 1 thermal column, 3 biological channels, 2 radioactive waste tanks, 5 circulation pumps, 4 distilled water tanks and 2 heat exchangers.

Fig.1. VVR-S nuclear research reactor from Magurele, Romania

In Fig.2 is presented a vertical cross-section of the reactor block.
The reactor vessels represents the main part of the reactor in which the reactor core, the ionization chambers, the adjusting rods, the shield channels, the experimental and the transport channels were installed. In order to protect the operation personnel against any radiation, biological protection was provided by 3.5 m thick water layer, the vessel aluminium lid and the 800 mm thick cast-iron rotating lids, in the upper side and by 1.1 m thick water layer, the aluminium vessel bottom and the reactor vessel support plate, in the lower side.

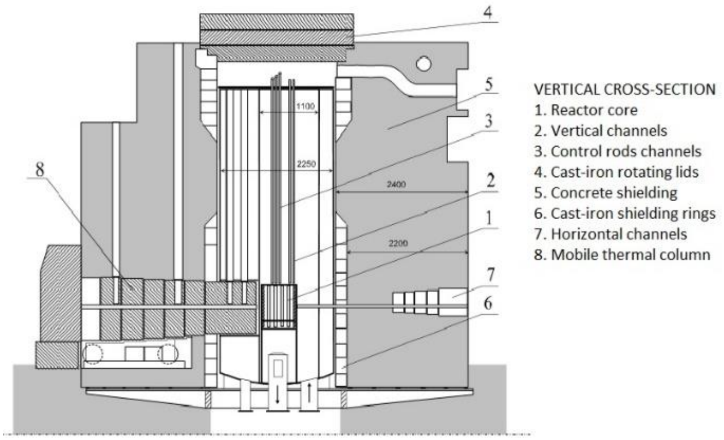

Fig.2. Vertical cross-section of the reactor block

The side protection consisted of: the separator aluminium wall, the inner cylinder aluminium wall, the water layer between the inner and the median cylinder, the median cylinder aluminium wall, the water layer (specially designed for protection) between the median cylinder and the outer cylinder, the outer cylinder aluminium wall, the cast-iron liner and the 2260 mm heavy concrete wall with admixtures of iron and limonite ore.

3. Evaluation of the concrete radioactivity

In previous papers [1,2] the results obtained for the radioactive inventory were evaluated based on the results obtained after samples measurements. The evaluation was done for 3 core drills extracted from the biological protection of concrete along the circumference of the reactor block in 2006, and other 12 core drills extracted in 2015 and 2016 from which 3 were extracted at 120^o one of each other and at 41 cm from the channel axis and other 9 from the concrete protection, around the active zone. From each core drill, small samples were taken to establish the degree of activation/contamination of heavy concrete around the horizontal channel. In total, 86 small samples [2] from the closest part to the active zone have been examined through gamma-ray spectrometry. Each sample was uniquely identified knowing as well as possible the start and the end point were the sample was cut.

The radionuclide inventory for the concrete biological protection have been evaluated using: (i) measurement results from gamma-ray spectrometry; (ii) thermal neutron flux distribution in space; (iii) data from literature.
In Fig.3, the radionuclide inventory is presented for biological protection evaluated in 2010 [1] and 2016 [2].

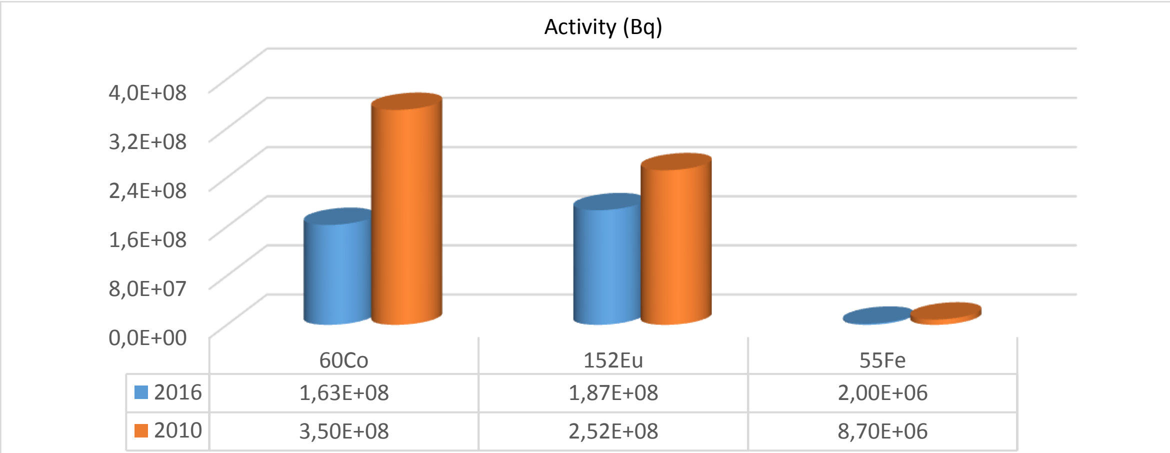

Fig.3. Radionuclide inventory for concrete biological protection

Because of the half-life of the radionuclides, in 2016, the activity of the ^{60}Co was reduces by half, by two half-time for ^{55}Fe, and not even a half-time for ^{152}Eu compared with 2010.
Starting with the demolishing of the reactor block, more analyses were done in 2017 and 2018. 16 concrete sampling were taken on each level of the reactor block, starting from up (level A) down to the floor. A level is considered to have 50 cm thickness. In Fig.4 is presented a horizontal view of the reactor block and the points from where the samples were taken.

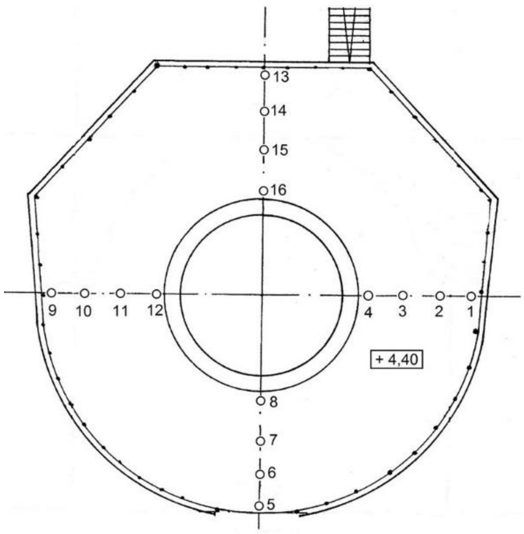

Fig. 4. Horizontal view of a level

All the measurements and analyses are done in the Radiological Characterization Laboratory from Reactor Decommissioning Department. The gamma spectrometry system consist of a high purity germanium detector, model GEM60P4-95, used with a lead shielding, and a DSPEC jr. 2.0 Digital Gamma-Ray Spectrometer. The main performance specifications of the detector warranted by the producer are: relative efficiency 60%, resolution (FWHM) 1.95 keV, peak-to-Compton ratio 70:1, peak shape (FWFM/FWHM) 3.0, all evaluated at 1.33 MeV peak of ^{60}Co.
Monte Carlo simulation using GESPECOR code [3] was used for the efficiency evaluation based on a detector characterization process with point sources [4,5].

These data will provide a more reliable characterization of the concrete biological protection, but this is will be the subject of a future paper.
In Fig. 5 is presented an example of the sampling done up on the reactor block, level A.

Fig.5. Example of concrete sampling

This procedure was done on each level (A,B,…,last level) from 50 cm to 50 cm, down to the floor.

4. Study regarding the recycle of radioactive concrete

Concrete is the common material used for shielding purposes regarding nuclear power plants, particle accelerators, research reactors, hot cells, medical and industrial facilities, as it contains both heavy and light elements. Its composition can be designed according to the specific parameters of each application use. The cement paste contains three forms of water, which is an essential source of hydrogen for neutron attenuation. These are free water, adsorbed (or physically bound) and chemically bound water. Free water is evaporated during cement hydration and, in the conditions of higher temperatures during irradiation, will be ultimately lost. The presence of chemically bound water is therefore of higher importance and depends on the water/cement ratio, curing conditions, the age and mineral composition of the cement paste.
Ishikura and co-authors [6] developed an improved method to utilize radioactive concrete as recycle for mortar to fill void space in waste containers. The tests they maked to demonstrate the fiability of the method have been implemented to increase the fill ratio of low level waste and to reduce the total low level waste disposal volume. In Fig.6 is presented the process they proposed for the method. Various tests made by the Ishikura and co-authors [6] confirmed the applicability of the technique of radioactive concrete utilization for solidifying radioactive waste in waste form. The developed method was estimated to drastically increase the waste usage ratio in waste containers, which is quite effective for decreasing waste disposal volume of radioactive concrete generated during dismantling of nuclear installations.
The reuse and recycle the coarse and fine aggregates obtain from radioactive concrete as mortar for filling containers and stabilization of the radioactive waste is not a simple one, because the immobilisation of the radioactive waste in cement matrix is a complex process which depends on many different parameters.

As aggregate constitute about 70-80% of concrete volume, it has a substantial effect on the concrete properties. For radiation shielding concrete, usually ordinary normal-weight aggregate is used. However, it results in high cross-section of concrete structures to achieve satisfactory shielding parameters and thus, it is not rare to use heavy or other special aggregate according to the desired shielding characteristics at places, where there is not enough space for normal-weight concrete.

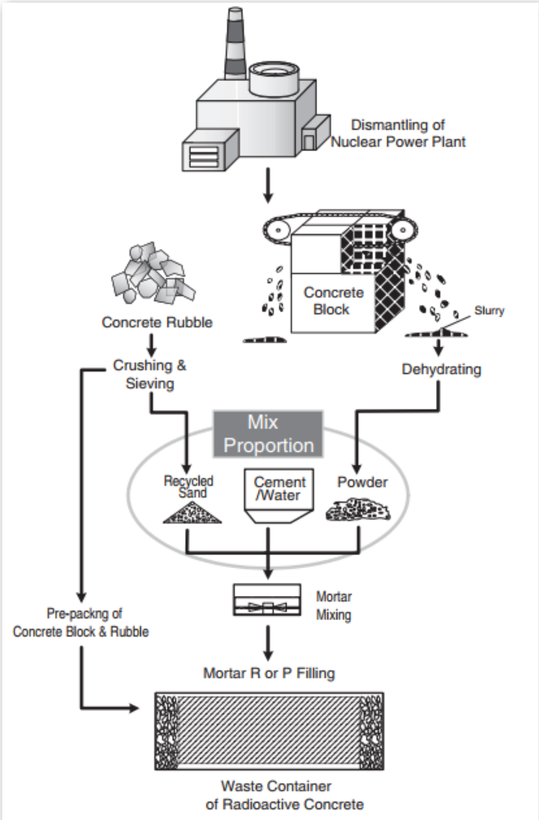

Fig.6. Method of radioactive concrete utilization for mortar [6]

The disposal of low and intermediate level of radioactive waste in shallow land burial is based on encapsulation of the wastes with cement and cement based materials. Radionuclides can escape from the waste matrix through diffusion migration under water-saturated conditions. Hence, there is considerable interest in understanding the diffusive transport of radionuclides through cement matrix.

Following this aspects, many parameters like: the properties of fresh mortars and the resistance to compression, the filling modality influence on the filling degree of container with rubble, the compressive strength of composite cubes, the container filling degree with mortar and the leachability index, and so on, were tested by several authors [6÷14]. They reported the temporal distribution of radionuclides in the leaching medium using different methods.

They observed that the recycled radioactive concrete can be used as rubble and fine powder aggregates. It has been found that for different composition of the fine recycled aggregate, the mortars that use this type of aggregate can be easily optimised from the point of view of the flow characteristics and resistance to compression.

These tests demonstrate that the concrete resulted from decommissioning, such as the concrete resulted from the demolishing of the reactor block can be used for the immobilization of the radioactive waste in the 220 l container. The reuse of the radioactive concrete can be a major solution in reducing waste volume and can help save natural resources and protect the environment.

5. Demolition of the reactor block

Large amounts of concrete debris will arise from the decommissioning of the VVR-S nuclear research reactor. The total volume will be dominated by the cleared concrete. Although we have evaluated the distribution of radioactivity inside the reactor block (see section 3), we are forced by the regulations to measure the surface and/or mass activity for all the materials that result in decommissioning project. Only after that, the concrete can be treated as conventional rubble and recycled accordingly.
The use of concrete as backfilling material can be an attractive solution for recycling concrete from decommissioning. For example, up to 15 tonnes of concrete were used to build the base of a road that leads from IFIN-HH at ELI-NP in Magurele, Romania. This was done after the regulation approved a free release report made by the laboratory.
The demolition operations were carried out from the outside to the inside, from the top (starting at +5.98 m) to the bottom, i.e. in the cylindrical part first, then in the cone section, and finally in the area of the round floor. The demolition robots, Brokk 160 and Brokk 800 were used.
In Fig.7 are presented some picture from different stages of the demolishing the reactor block.

Fig.7. Stages of reactor block demolishing

During the demolition of the reactor block, the concrete structures were cut in smaller pieces or sometimes were crushed on-site and placed in big bags prior to clearance which is in duty of the Radiological Characterization Laboratory. Metallic components existing in the concrete rubble were removed, crushed, if necessary, and packed separately. Then, the concrete rubble was filled into big bags and transferred outside the building.
In Fig. 8 is presented segregation of the materials.
In 2017, 400863 kg of concrete was demolished from the reactor block, resulting a number of 813 of bags. Around 304407 kg of concrete will be measured and treated for free release and approximately 96456 kg of contaminated concrete was transferred in the waiting zone.

During the demolishing of the reactor block, 32596 kg of metallic waste was resulted, from which: 17229 kg of steel was scanned using the portable contaminometers and send to Radiological Characterization Laboratory, 3477 kg of contaminated steel was cut and put in drums for sending to the Radioactive Waste Treatment Facility and 11890 kg of low contaminated cast iron rings are stored in the waiting zone.

Fig.8. The segregation of the materials

The demolition operation of the reactor block will be considered completed when the activated/ contaminated area will be removed and the results of the samples taken from the floor around the reactor block will show that there are no activated/ contaminated areas.

6. Conclusions

The unconditional clearance of building rubble and concrete blocks from nuclear areas is a challenge for national regulations and experience shows that special arrangements have had to be made at a local level between the operator and regulator to achieve a practical clearance methodology. Building rubble and concrete unconditionally cleared is generally released to industrial recycling facilities or conventional disposal sites. Once material is unconditionally cleared, it is free from any regulatory control and may be used without regard to its nuclear origin often as fill material in the construction of roads.
The recycling of the old concrete can substitute virgin aggregates and can reduce the environmental costs of natural resources. The clean concrete resulted from decommissioning can be used in walkways providing a walkable surface and at the same time providing gaps for rainwater to reach the soil. By doing this, the amount of runoff water will also be reduced, resulting in a smaller storm sewer system.
The international experience shows that concrete can be recycled and reused in many ways but it all depends on how large that piece of concrete is and what is the shape of the concrete. Can be a way to reduce the cost for a construction and at the same time providing

some benefits to the environment. It can be used as excellent aggregates for road bases, slope protection, and earth retention structures.

Acknowledgments

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