SAFE AND ENVIRONMENTALLY SOUND MANAGEMENT OF RADIOACTIVE WASTES IN RUSSIA

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Summary

The development of nuclear power engineering in Russia is based on the concept of the closed nuclear fuel cycle. As a result, enterprises for spent fuel reprocessing produce annually radioactive waste (RW) with total radioactivity of about 100 MCu. One can expect a significant increase in the RW annual production rate in the near future. Russia is the only country implementing, on an industrial scale, deep underground disposal of liquid RW through injection into deep aquifers. There are three sites of RW injection disposal in Russia. A predictive analysis of long-term migration of radionuclides was carried out recently for one of the main disposal sites—"Severny polygon" at the Krasnoyarsk Mining and Chemical Combine (MCC). This study is carried out on the basis of comprehensive analysis of all processes that exert a significant influence on radionuclides migration. The study included computer simulation for the normal evolution scenario and an analysis of hypothetical scenarios (in which unreliability of input data for computer simulation was taken into account, and some catastrophic events were considered). It was shown that deep-well injection disposal of liquid RW can be regarded, with provision of adequate site selection, as an economically efficient and ecologically safe way of removing ecologically hazardous substances from the inhabited environment. In accordance with the current regulations and practice of nuclear waste management in Russia, RW before its geological disposal, should be

conditioned with immobilization in waste forms suitable for safe disposal. Preparation of liquid HLW for disposal should include the following operations: separation of the long-lived (mainly actinide group) and intermediate-lived (mainly of Cs-Sr group) fractions from liquid HLW; solidification of Cs-Sr fraction in vitrified form; solidification of actinide fraction in highly stable crystalline matrices of pyrochlore-zirconolite-murataite composition. After conditioning, RW should be disposed in undisturbed blocks of rocks with suitable geochemical properties that can delay radionuclides transport by groundwater from the disposal zone to the Earth surface. Radionuclides transport should be considered with due account for regional groundwater flow and buoyancy forces caused by heat generation in the RW volume.

1. Introduction

A large body of radioactive waste (RW) has now accumulated in Russia from defense and power engineering programs, as well as from use of fissile materials in industry, medicine and scientific research. Management of these wastes includes disposal of some part of liquid radioactive waste in deep geological formations and storage of liquid, solid and solidified wastes in land-based and shallow land storage facilities.

The most challenging problem is presented by management of high-level radioactive waste (HLW). Presence in HLW of ecologically hazardous long-lived actinides calls for their reliable isolation from the inhabited environment for a residence time comparable to geological periods. Solution of this problem in Russia, as in the other countries with mature nuclear industries, is envisaged through HLW disposition in underground repositories, with the geological medium considered as the dominant barrier in providing the long-term safety of HLW repository. The strategy for safe underground disposal of HLW, that is now being developed in Russia, includes partitioning of HLW isotopes, with separation of intermediate- and long-lived waste fractions, followed by their subsequent separate disposition in underground repositories.

This article presents the main data on types and inventories of radioactive waste accumulated in Russia, on experience gained from underground disposal of liquid radioactive waste, and technological approaches under development, focusing on practical realization of the strategy of safe underground disposition of HLW.

2. Types and Inventories of Radioactive Waste

All types of liquid (LRW) and solid (SRW) radioactive wastes, listed by the IAEA (*Classification of Radioactive Waste* (1994). Safety Series No.111-G-1.1), are stored at the different enterprises in Russia. The sources of these wastes encompass a great variety:

- Uranium ore mining and processing.
- Plants for natural uranium enrichment and fuel fabrication.
- Nuclear power plants.
- Radiochemical enterprises.
- Operation of nuclear submarines and nuclear-powered icebreakers.
- Construction and utilization of nuclear submarines.

- Research nuclear reactors.
- Use of radioactive isotopes in medicine, industry and other fields.
- The nuclear weapons program

The total volume of liquid and solid RW accumulated up to now in Russia is about $6{\cdot}10^8$ m^3. Its bulk radioactivity amounts to approximately $1.5{\cdot}10^9$ Ci. Analysis of the data on RW volume and activity stored at the enterprises of the different Russian departments, given in Table 1, demonstrates that 99.9% of the overall radioactive waste resides at the enterprises of the Ministry of Atomic Energy (MINATOM) of the Russian Federation.

8500 t of spent nuclear fuel (SF) with total radioactivity of $4.5{\cdot}10^9$ Ci, of which 6000 t with activity of $3.0{\cdot}10^9$ Ci is SF from reactors of RBMK type and 2500 t with the activity of $1.5{\cdot}10^9$ Ci is SF from reactors of VVER type, are stored at the interim storage facilities of the nuclear power plants and MINATOM radiochemical enterprises.

The development of nuclear power engineering in Russia is based on the concept of the closed nuclear fuel cycle. Production enterprises operating in the frame of this concept release a large volume of new RW with total annual activity above 100 MCi. Furthermore, a considerable increase of the RW stream is expected in the near future from decommissioning of power production, transport, and research nuclear units after their operational service life.

From the early 1960s, injection disposal into deep aquifers of the low-level (LLW) and intermediate-level (ILW) liquid radioactive wastes was carried out at some radiochemical enterprises: Siberian Chemical Combine (SCC, Seversk), Mining and Chemical Combine (MCC, Zheleznogorsk), and State Research Center (RC) Scientific Research Institute of Nuclear Reactors (NIIAR, Dimitrowgrad).

As shown in more detail below, this technology provides a means for the required isolation of these wastes from the environment for the whole period of their potential hazard. Nevertheless, it is planned in the future to stop injection disposal of liquid waste, replacing it by underground disposal of the pre-solidified LRW. Depending on the waste activity, cement and glass waste forms are supposed to be used for solidification.

	Source	**Type**	**Amount:RW - m^3, SF – t.**	**Activity, Ci**	**Storage type**
MINATOM enterprises					
1.	Ore mining and processing.	Sludges and rock heaps.	$1.0{\cdot}10^8$	$1.8{\cdot}10^5$	Surface storage facilities.
2.	Nuclear power plants (NPP)	LRW*, SRW**	$2.72{\cdot}10^5$	$4.4{\cdot}10^4$	Storage facilities, tanks
3.	Radiochemical enterprises.	LRW*, SRW**, solidified RW	$5{\cdot}10^8$	$1.47{\cdot}10^9$	Tanks, storage facilities, reservoirs.
Subtotal			**~ $6{\cdot}10^8$**	**~$1.47{\cdot}10^9$**	
Ministry of Defence (Navy)					
4.	Operation of	LRW*,	$2.7{\cdot}10^4$	$9.8{\cdot}10^2$	Shore-based and

	nuclear submarines	SRW**			floating storage facilities
5.	Operation of nuclear powered ice-breakers.	LRW*, SRW**.	$1.9{\cdot}10^3$	$2.0{\cdot}10^4$	Shore-based storage facilities.
Subtotal			**$\sim 2.9{\cdot}10^4$**	**$\sim 2.1{\cdot}10^4$**	
Former GOSKOMOBORONPROM of Russia					
6.	Nuclear submarine construction and utilization.	LRW*, SRW**.	$4{\cdot}10^3$	$6{\cdot}10^2$	Shore-based and floating storage facilities
MINSTROY of Russia					
7.	Utilization of ionizing radiation sources (IRS).	LRW*, SRW**, solidified RW, IRS in ampoules.	$2{\cdot}10^5$	$2{\cdot}10^6$	Storage facilities of the 16 “Radon” special combines
Total			**$\sim 6{\cdot}10^8$**	**$\sim 1.47{\cdot}10^9$**	
SF					
8.	Fuel assemblages from nuclear power plants, transport and research reactors.	SF from the different type reactors	$8.5{\cdot}10^3$	$4.45{\cdot}10^9$	NPP storage facilities, PA “Mayak”, shore-based and floating storage facilities, research institutes.

* Liquid radioactive waste

** Solid radioactive waste

Table 1: RW and SF amounts stored at the enterprises of the different State departments of Russia (after: [Laverov et al., 2000])

Because of the absence of suitable geological conditions for LRW injection, liquid LLW and ILW at the Production Association (PA) “Mayak” were dumped into man-made ponds and the Karachai lake. Continuous records are kept over the behavior of radionuclides in these reservoirs and in the plumes of contaminated groundwater which form beneath them. Measures are under development for rehabilitation of contaminated subsurface hydrosphere.

Liquid HLW at all radiochemical enterprises are kept in specially designed steel tanks at the interim storage facilities. At PA “Mayak”, some part of this waste is solidified in aluminophosphate glass waste forms; these are stored in specially designed engineering constructions. As of now, about 2000 t of solidified HLW has been produced with a total radioactivity of 300 MCi.

At the nuclear navy bases in the Russian north-west and east regions more than 150 decommissioned nuclear submarines call for utilization. About 60% of these vessels are with unloaded SF. Interim RW and SF storage facilities at these sites are virtually filled to design capacity and work has begun on construction of new interim storage accommodation.

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Biographical Sketch

Nikolai P. Laverov was born on January 12, 1930 in Arkhangelsk region of Russia in a peasant family. His professional carrier is as follows:

1949-1954 — studying in the Moscow Institute of Non-ferrous Metals and Gold;

1954-1958 — Postgraduate of the Moscow Institute of Non-ferrous Metals and Gold;

1958-1965 — Director in the Central-Asian Geological Station of the Institute of Ore Deposits Geology of the USSR Academy of Sciences;

1965-1968 — Deputy Chief of the Research Organization Department in the USSR Ministry of Geology;

1972-1983 — Chief of the Research Organization Department in the USSR Ministry of Geology;

1983-1987 — Pro-rector (and the first pro-rector) of Academy of National Economy at the USSR Council of Ministers;

1987-1989 — President of the Kirghiz Academy of Sciences;

1989-1991 — Deputy Chairman of the USSR Council of Ministers, chairman of the USSR State Committee for Science and Technology;

Since 1991 — Vice President of the Russian Academy of Sciences.

N.P. Laverov is the author or co-author of more than 250 scientific publications including 20 monographs. Many works were published in Germany, USA, Australia, U.K., Canada, Cuba, China, and other countries. He is a well known leader of the scientific school of Russian geologists. In 1990 he headed a new investigation into radiogeological studies. The fundamental principle of these studies lies in the use of protective properties of the geological environment to prevent pollution of the ecosphere by radionuclides. The studies embraced the general problem of radioactive waste disposal in the Earth crust.