Spent Nuclear Fuel and Radioactive Waste Management Strategy for the Republic of Kazakhstan

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1. Introduction

The Republic of Kazakhstan has not adopted a decision to launch nuclear power programme (NPP), however, the possibility to introduce nuclear power cannot be denied due to the intentions of diversifying primary energy sources and reduce dependence on fossil fuel. For countries wishing to start an NPP, the management of spent nuclear fuel (SNF) and radioactive waste (RW) is a major challenge and a possible obstruction.

This study is aimed to develop a strategy for SNF and RW management for the Republic of Kazakhstan taking into account existing policy. The strategy options will be proposed for existing SNF and RW as well as the future volumes arising over the time from NPP.

Currently, the country has large quantities of low- level radioactive waste as a result of medical, research, and industrial activities.

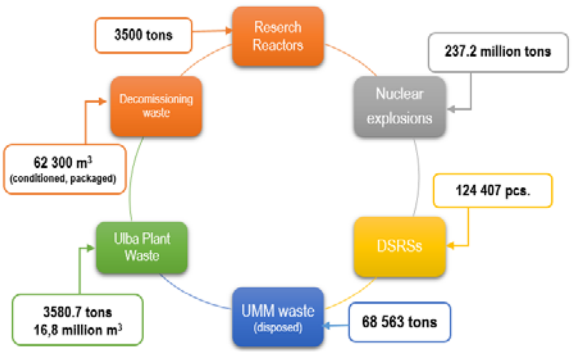

Fig. 1. Amount of RW by sources: stored and disposed by 1 January, 2018 [1]

Generation of SNF has been contributing from the operation of three research reactors.

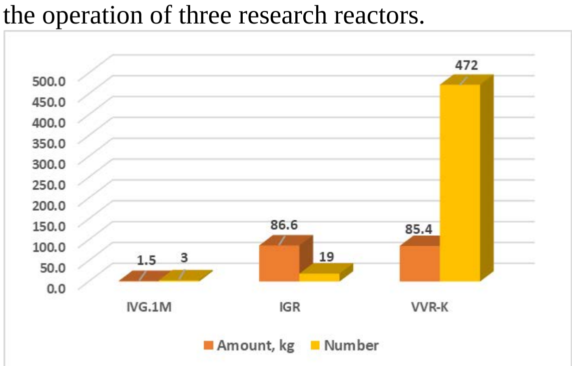

Fig.2.Spent nuclear fuel from research reactors [1]

SNF from decommissioned fast breeder reactor BN-350 also exists. 300 tons of spent fuel was placed in 60 containers and stored in long-term dry storage for 50 years [1].

2. Methodology

Strategic options for SNF and RW management (RWM) are determined based on experience gathered to date in mature nuclear power programmes [2]. The relative costs of SF management options are considered by examining recent projections of costs issues [4,5,6].

Amount of future SNF and appropriate inventory capacities was evaluated by AMORES computer code which was developed by KINS. The code makes possible to evaluate present total radionuclides inventory of SNF management facility based on the real SNF data, and the projection of the radionuclides inventory of SNF management facility in the future [3].

Technical data for VVER-1000 and VVER-1200 reactors is taken from IAEA PRIS data. Technical parameters for OPR-1000 and APR-1400 is given by KINS.

3. Results and Discussion

3.1 Estimation of the amount of SNF and RW arising from future Nuclear power programme.

In this study we assume two units of VVER-1000 and two units of VVER-1200 as two separate cases for the construction in the Republic of Kazakhstan. Design description for VVER-1000 takes similar as for "Belene" Nuclear Power Plant (NPP) design in Bulgaria with reactor plant V-466B while the design for VVER-1200 will be considered as a similar design of V-392 reactor plants which are in operation in Novovoronezh NPP-2. Both types of design belong to Generation III+.

The study assumes the start-up date as 2030 yr. and shut down date as 2090 yr. with overall operation time 60 years. Technical data for the reactors are presented by the following table.

Table 1 – General plants' data [8]

Parameters	VVER-1000 (V-466B)	VVER-1200 (V-392M)
Thermal	3000	3200

capacity, MWth		
Average enrichment, %	4.45	4.95
Average discharged burn up, GWd/MTU	52.8	60
Mass of initial uranium, kg	525	534.1
SNF discharged annually	42	42
Fuel type	TVS-2M	TVS-AES-2006

According to the estimations, the total number of SNF produced during the reactor operation lifetime and inventory capacity *for 2 units* of VVER-1000 and VVER-1200 are presented by the data below.

Table 2 – SNF number and inventory capacity.

Reactor type	Number of SNF	Inventory capacity, (MTU)
VVER-1000 (V-466B)	5 040	2 646
VVER-1200 (V-392M)	5 040	2 692

As a second possible general contractor for NPP construction, we assume the Republic of Korea which is one of the leading country in nuclear power and consider two units of OPR-1000 and two units of APR-1400 as different cases.

For investigations, we were used parameters of OPR-1000 (units 1&2) and APR-1400 (units 1&2) which have been operating at the Shin-Kori site.

The research assumes the start-up date for both in 2030, the shut-down date for OPR-1000 in 2070 taking into account 40 years' operation time while the shut-down date for APR-1400 is 2090 after the 60 years. Table 3 shows technical data for two types of Korean nuclear reactors.

Table 3 – General data for OPR-1000 and APR-1400

Parameters	OPR-1000	APR-1400
Thermal capacity, MWth	2 815	3983
Fuel type	ce16x16	ce16x16
SNF discharged annually	47.33	66.67

Specific data in terms enrichment, burn up and mass of initial uranium is given in the table 4.

Table 4 –Specific data for OPR-1000 and APR-1400

Parameters	Minimum	Average	Maximum
Enrichment, %	1,27	3,81	4,66
Discharged burn up, GWd/MTU	9,6	38,7	56,4
Mass of initial uranium, kg	426	431	441

Results of calculations gave the total number of SNF generated during the operation lifetime and appropriate inventory capacity *for 2 units* of OPR-1000 and APR-1400.

Table 5 - SNF number and inventory capacity

Enrichment/ Burn up/ Mass of uranium	Number of SF		Inventory, (MTU)	
	OPR-1000	APR-1400	OPR-1000	APR-1400
Minimum	3 786	8 000	1613	3 408
Average	3 786	8 000	1 632	3 448
Maximum	3 786	8 000	1 670	3 528

3.2 Economics of different SNF and RW strategy options

The typical strategy of SNF management can be implemented in two ways: direct disposal and HLW disposal following to reprocessing

Direct disposal cost consists of three main components: (a) cost of interim storage before geologic disposal, (b) eventual transport to a repository site, (c) encapsulation, conditioning, and disposal of the SNF.

On the reprocessing route, the reactor operator will have to pay the costs of: (a) transporting the fuel to the reprocessing plant; (b) reprocessing; (c) conditioning and disposal of the HLW, ILW, LLW, (d) costs of fabricating the plutonium into mixed-oxide (MOX) fuel.

We assume that the direct disposal option encounters delays, so that all fuel going that route incurs the cost of dry cask storage as well as the cost of disposal.

According to the U.S. Advanced Fuel Cycle Initiative report in 2009 [4], estimated cost of disposal of spent fuel at $650/kgHM ($780/kgHM in 2019 dollars) while the transportation cost is $200/kgHM ($240/kgHM in 2019 dollars).

Harvard University studies in 2003 [5] states that dry cask storage cost is about $200/kgHM ($280/kgHM in 2019 dollars). So, the relative total cost of direct disposal would be about $1300/kgHM in 2019.

The table 6 indicates the cost of disposal (only) and cost of disposal with the contribution of the transportation and dry storage cost constituents.

Table 6 – Direct disposal cost for four different nuclear power plants

Reactor type	SNF amount, tHM	Cost of direct disposal (capital, operating, decomiss.), billion $	Total cost of direct disposal, (including transportation, dry storage), billion $
OPR-1000	1 632	$1.273	$2.122
VVER-1000	2 646	$2.064	$3.440

VVER-1200	2 692	$2.100	$3.500
APR-1400	3 448	$2.689	$4.482

For comparison, the probable cost of Finland deep geological repository (capital, operating, decommissioning) is estimated at 4 billion USD or 3 billion Euro (570 euro/kgU, 2006) to dispose about 5500 tons of spent fuel.

Reprocessing and recycling SNF by a foreign service provider can be another option. The service is currently provided by the Russian Federation, France, and the United Kingdom. Japan built a large facility at Rokkasho-Mura with capacity 800 MT/year but still have been undergoing some delays related to the enhancement of safety and safeguards. China also intends to build 200 tHM/year and 800 tHM/year reprocessing plants [6].

The probable cost of reprocessing per kilogram heavy metal of spent fuel is presented in figure 3.

However, Russian RP-1 plant was built in Soviet times, was fully integrated with military activities, and its full costs are neither well documented in the public literature. Therefore, we assume the possible reprocessing cost in Mayak at $1000 [5] converting the number into 2019 dollars. Obtained value is $1400/kgHM.

For illustrative purposes, we will use a $1400/kgHM as a unit of cost for the low-cost estimate for China 800 tHM/year reprocessing plant [6].

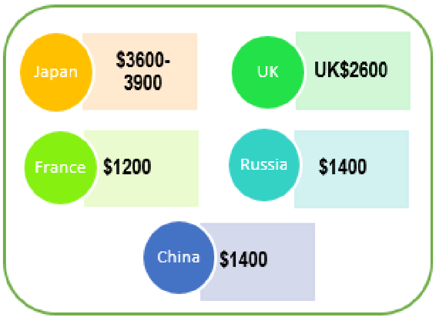

Fig.3 – Probable cost of reprocessing per kilogram heavy metal of spent fuel in commercial reprocessing plants [5,6]

As we mentioned above, transportation cost is $240 while the HLW disposal cost after the reprocessing is about $300 in 2019 dollars [4].

MOX fuel fabrication cost is estimated at 2100 $/kgHM in 2019 dollars, by converting $1500/kgHM which is central estimate from a 2003 Harvard report [3].

Table 7 gives the summary of the reprocessing cost from different service providers for assumed future nuclear power plants for Kazakhstan.

Table 7 – The relative value of reprocessing cost

	Cost of reprocessing, billion				
	Japan	UK	France	Russia	China
OPR-1000	$6.1	$4.2	$1.9	$2.28	$2.28
VVER-1000	$9.9	$6.8	$3.17	$3.7	$3.7
VVER-1200	$10.1	$7.0	$3.23	$3.76	$3.76
APR-1400	$12.9	$8.9	$4.1	$4.8	$4.8

Table 8 contains the results of estimations of the total cost of SNF reprocessing route including transportation of SNF, HLW disposal and MOX fuel fabrication cost.

Table 8 – The relative value of the total cost of reprocessing

	The total cost of reprocessing scenario, billion				
	Japan	UK	France	Russia	China
OPR-1000	$10.4	$8.5	$6.2	$6.5	$6.5
VVER-1000	$ 16.9	$13.8	$10.1	$10.7	$10.7
VVER-1200	$17.2	$14.1	$10.3	$10.8	$10.8
APR-1400	$22	$18.1	$13.1	$13.9	$13.9

In terms of existing spent nuclear fuel, basic strategy options were also considered. According to the feasibility study "Reprocessing and disposal of spent nuclear fuel of BN-350 in Russian Federation" which was performed by national Technical support organization, cost of reprocessing, transport, temporary storage before reprocessing and disposal of HLW in Russian Federation is $ 2057 based on the optimal option. Taking into account the inflation rate current value reaches $2 195/ kgHM.

As we mentioned above direct disposal cost is estimated at $780/kgHM in 2019 dollars. However, if the state will decide to replace old dry storage casks with a new one after 40 years, dry cask storage cost is $200/kgHM [5] and reaches $280/kgHM in 2019. The estimations below show the cost of strategy options for existing SNF amount of which is 300 tHM.

Table 9 – The strategy options for existing SNF

№	Strategy options	Cost, million $
1.	Reprocessing in Russia	$658.5
2.	Direct disposal nationally	$234
3.	Long-term dry storage (100 yr.)	$84

3.3 Proposed strategy for SNF and RW management

A strategy is the organizational and technical means for achieving the goals and requirements set out in the *national policy*. The national policy normally defines national rules and responsibilities and are established by the national government [7].

In terms of the Republic of Kazakhstan, the current policy is adopted for managing institutional waste and a small amount of SNF. If the state will plan to launch NPP, the existing policy should be transformed into *a Nuclear Power Programme Policy* as well as strategies for its implementation.

The management of institutional waste, including disused sealed radioactive sources (DSRS), needs to be included as part of the Integrated Strategy.

The study emphasizes the key points of RW management policy/strategy for the Republic of Kazakhstan.

1. No import or export of radioactive waste;
2. Centralized, permanent accountancy of RW;
3. Disposal of RW depend on their classification;
4. All RW disposal facilities must be licensed
5. Wastes producers are liable for all costs RWM;
6. DSRSs to be returned to supplier if possible;
7. RR SNF to be returned to the owner if possible.

Institutional RW management as a part of Integrated strategy should cover all phases between waste production and ultimate disposal proposed as the following algorithm.

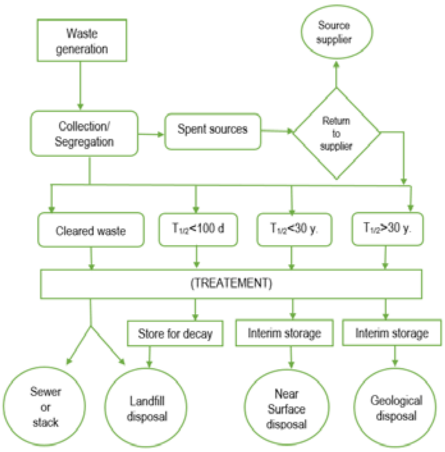

Fig.4 Waste management strategy for decommissioning small industrial, medical and research facilities

Analyze among available SNF strategies for the Republic of Kazakhstan in the scenario of launch NPP and without it is performed.

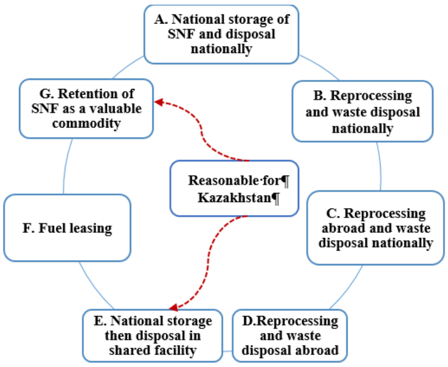

Fig.5. Illustration of the assessment' results of the suitable SNF strategy options for the Republic of Kazakhstan

According to the cost estimations analyses and consideration of the experience of mutual nuclear power programmes, Strategy A (adopted by Sweden, Finland), Strategy B (UK, France, Japan, Russia), Strategy C (Japan, Germany, Switzerland etc.), Strategy D (Bulgaria) *are economically unfeasible* for countries with small or new nuclear power programmes. Strategy F (Iran, Turkey) *is not politically applicable*, because it is deemed that fuel will be supply nationally since Kazakhstan is one of the leading country in uranium production. Strategy E (Not manifested) *is more economically attractive* for small nuclear power programmes and can remove the needs for implementation of a deep geological repository in each country. Strategy G (Not promulgated) may become favorable for existing SNF from fast breeder reactor *with its much higher fissile content*.

4. Conclusion

The purpose of this study was to determine appropriate SNF and RW strategies for the Republic of Kazakhstan. As a starting point, the current status of SNF and RW management is analyzed. AMORES was used to estimate the radionuclide inventory in spent fuel from future national nuclear power programme. The economics of basic SNF and RW strategies is examined. Proposed strategies were comprehensively discussed in the whole research work and deemed will be useful to develop actual national SNF and RW strategies.

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