CURRENT STATE AND PERSPECTIVES OF SPENT FUEL STORAGE IN RUSSIA

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Abstract

Twenty-nine power units at nine nuclear power plants, having a total installed capacity of 22 GW(e), are now in operation in the Russian Federation. They produce approximately 12% of the generated electricity in the country. The annual spent fuel arising is approximately 790 tU. The concept of the closed fuel cycle was adopted as the basis for nuclear power development in the Russian Federation, but until now this concept is only implemented for the fuel cycles of WWER-440 and BN-600 reactors. The WWER-1000 spent fuel is planned to be reprocessed at the reprocessing plant RT-2 which is under construction near Krasnoyarsk. The RBMK-1000 spent fuel is not reprocessed. It is meant to be stored in intermediate storage facilities at the NPP sites. The status of the spent fuel (SF) stored in the storage facilities is given in the paper. The principal characteristics of the fuel cycles of the Russian NPPs in the period up to 2015 is also given in the report. The key variant of the current spent fuel management at RBMK-1000 NPPs is storage in at-reactor and in away-from-reactor wet storage facilities at the power plant site with a capacity of 2,000 tU. The storage capacity at the operating RBMKs (including the increase due to denser fuel assembly arrangement) will provide SF reception from the NPPs only up to 2005. For RBMK spent fuel, intermediate dry storage is foreseen at power plant sites in metallic concrete casks and thereafter transportation to the central storage facility at the RT-2 plant for long-term storage. The SF will be reprocessing after completion of the reprocessing plant at RT-2. In the Programme of Nuclear Power Development in the Russian Federation for the period 1998 to 2005 and for the period until 2010 year, provisions are made for the construction of a central dry storage facility before 2010. The facility will have a design capacity of 30,000 tU for WWER-1000 and RBMK-1000 spent fuel and is part of the reprocessing plant RT-2. The paper considers the status and prospects of spent fuel management at shut down AMB reactors. For the solution of the spent fuel problem of the Bilibino NPP, the concept of the final stage of spent fuel management is developed taking into account the low density of the population and the long distance from main communication ways. Reliable data about the behaviour of construction materials of assemblies and storage facilities under these conditions are necessary. Recommendations on the duration of wet storage are needed.

1. STATUS OF SPENT FUEL STORAGE

Since 1964, 9 NPPs with 33 nuclear reactors of different types were put into operation in Russia with a total installed capacity of more than 21.2 GW(e). At present, there are 29 power units in operation, 11 RBMK- 1000 units, 6 WWER-440 units, 7 WWER-1000 units, 4 EGP-6 units and one fast reactor, the BN-600 unit. Four units are disconnected from the grid, 2 WWER units at Novovoronezh NPP and 2 AMB units (i.e. channel type reactors) at Beloyarsk NPP and their decommissioning is being carried out.

The concept of the closed fuel cycle was adopted as the basis of nuclear power development in Russia, but until now this concept is only for spent fuel (SF) of WWER-440 and BN-600 reactors fully implemented. Spent fuel is transported to the reprocessing plant RT-1 (PO "Mayak") and recovered uranium is used for the fabrication of, RBMK fuel. WWER-1000 spent fuel is transported to the central storage facility at Krasnoyarsk Mining - Chemical Plant (KMCP). After the completion of the reprocessing plant RT-2 construction at the KMCP site WWER-1,000 SF will be reprocessed too. For SF of RBMK and AMB reactors only the initial stage of the fuel cycle is realized: storage at NPP sites in away-from-reactor (AFR) and at-reactor water pools. The status of the spent fuel inventory stored at power plants facilities as of 1 July 1998, is shown in Tables I and II.

One can see from Table II, that the situation at with RBMK and EGP plants is critical, since the amount of spent fuel arisings comes close to the capacities of the spent fuel storage facilities and can maintain the operation of the power plants only until 2005. For other power plants this problem does not exist for the time being. The principal characteristics of the fuel cycle of the Russian NPPs in period to 2015 are shown in Table III.

TABLE I. THE SPENT FUEL INVENTORY AT NPPs WITH CHANNEL TYPE REACTORS

(status 01.07.1998)

NPP number of units	Capacity of AR and AFR storage facilities (FAs)	Number of fuel assemblies (FAs)/amount of tU	Remarks
LENINGRAD	AR -1 - 1,700	940/108	1,784 gas leaking FAs
4 RBMKs	AR -2 - 1,700	1,232/142	Unit No 3 is repaired
the annual discharge	AR -3 - 1,700	0	
from the reactors is	AR -4 - 1,700	1584/182	
~1,800 FAs	AFR - 17,600	29671/3,412	
	(35,200*)	31,843/3,662	
	Total - 42,000		
KURSK	AR -1 - 1,700	324/37.3	663 gas leaking FAs
4 RBMKs	AR -2 - 1,700	1,384/159.2	
the annual discharge	AR -3 - 1,700	1462/161	
from the reactors is	AR -4 - 1,700	1,592/183	
~1,800 FAs	AFR - 17,600	19,8481/2,283	
	(29,600*)	29,934/2,867	
	Total - 36,400		
SMOLENSK	AR -1 - 3,800	2,310/265	258 gas leaking FAs
3 RBMKs	AR -2 - 3,800	3,336/384	
the annual discharge	AR -3 - 3,800	3,170/364	
from the reactors is	AFR 13,600	3,780/436	
~1,350 FAs	Total 25,000	12,596/1,449	
BELOYARSK	AR -1 - 2,500	2,500/95	The number of
3 units	AR -2 - 2,500	2,500/95	defective FAs is
- 2 AMBs under	AR -3 - 2,438	1,228/66	unknown
decommissioning	Total - 7,438	6,228/256	
- 1 BN-600			
BILIBINO	AR -1 - 2,000	1,967/49.4	Defective FAs - 0
4 EGP-6	AR -2 - 2,250	2,244/57.2	
	AR -3 - 2,000	113/2.8	
	Total - 6,250	4,324/108.4	

* The capacity of the AFR after reracking

The data in Table III indicates the dynamic of variation of spent fuel inventory at power plants since the first unit was put in operation up to 2005 year and principal tasks on the maintenance of operation of the power plants. Presented data and measures are defined in compliance with the governmental “Programme of Nuclear Power Development in Russian Federation for the period 1998-2005 and for the period until 2010” and the "Federal Programme on Radioactive Waste and Spent Nuclear Materials Management, their .Utilization and Disposal for the period 1996-2005". Data in Table III shows, that at WWER-440 and BN-600 power plants the rate of spent fuel accumulation corresponds to the rate of its removal from plant sites for subsequent reprocessing.

The reprocessing of WWER-440 and BN-600 spent fuel is carried out at the RT-1 plant (PO "Mayak"). The RT-1 plant was commissioned in 1977 and has a capacity of 400 t spent fuel/year. Up to now, the plant has reprocessed 2,500 t of WWER-440 and BN-600 spent fuel from Russian power plants. It is expected, that it will reprocess an additional 5,000 t SF.

TABLE II. THE SPENT FUEL INVENTORY AT NPPs WITH WWER - TYPE REACTORS

(status 01.07.1998)

NPP number of units	Project capacity of AR and AFR storage facilities (FAs)	Number of fuel assemblies (FAs)/amount of tU	Remarks
BALAKOVO	AR - 1- 376	173/67.5	17 gas leaking FAs
4 WWERs-1000	AR -2 - 359	107/41.3	
	AR -3 - 373	1.62/62.4	
	AR -4 - 596	116/44.8	
	Total - 1,704	558/216	
KALININ	AR -1 - 413	239/96.3	28 gas leaking FAs
2 WWERs-1000	AR -2 - 413	245/98.7	
	Total - 628	4841195	
KOLA	AR -1 - 616	173/67.5	38 gas leaking FAs
4 WWERs-440	AR -2 - 637	188/21.8	
	AR -3 - 662	483/56.0	
	AR -4 - 664	116/44.8	
	Total - 2,576	558/156.1	
NOVOVORONEZH	AR -1 - 1,050	296/36	52 gas leaking FAs
WWER-210 & 365	AR -2 - 300	0	
under decommissioning	AR -3 - 652	293/34	
2 WWERs-440	AR -4 - 665	196/23.2	
1 WWER-1000	AR -5 - 233	66/26.9	
	AFR - 916	171/69.8	
	Total - 3,816	1,022/189.9	

WWER-1000 spent fuel is unloaded from the core and stored in an at-reactor (AR) storage facility for a period to enable the decay heat to reduce to a level, which permits the transportation of the spent fuel from the NPP site (about 3 years). The rates of accumulation and removal correspond to each other, but this fuel is not being reprocessing for the time being, because the construction of the reprocessing part of the plant is not completed yet. The capacity of the storage facility in the Complex of the RT-2 plant is 6,000 t and has at present accumulated 2,120 t SF from Russian WWERs-1000.

At NPPs with RBMK-1000 the key variant of spent fuel management now is storage in at-reactor and in away-from-reactor wet storage at the plant site with a capacity of 2,000 t. Unloading of spent fuel cassettes (two assemblies per cassette) is conducted with the reactor on-load and the number of these cassettes is 8 to 10 per week. After 1.5 - 3 years cooling in an AR storage facility, the spent fuel is transported to an away-from-reactor storage facility for long-term storage. The residual decay heat after 3 years of cooling is 0.22 kW/cassette and it permits to transfer the fuel to an away-from-reactor wet storage facility without water in a special on site cask. Each cassette is placed into a canister filled with water. The detailed description of spent fuel management technology at power plants in Russia is presented in [1]. To maintain the operation of power plants with RBMK-1000, the refurbishment of all storage facilities (AR and AFR) will be accomplished to increase their capacity by a factor 1.8, however, at the cost of the modification of the hanger's construction. This modification permits to decrease the distance between fuel cassettes in ponds with maintaining the established levels of safety.

For RBMK spent fuel, intermediate dry storage at the power plant sites is planned in metallic-concrete dual purpose casks (i.e. for storage and transportation), followed by the transportation to the central storage facility at the RT-2 plant for long-term storage and ultimate reprocessing. The full scale tests of the dual purpose casks were started this year and will be continued in 1999. At the present time, the cask storage facility project, which includes a hot cell for cassette disassembling, a system of radwaste treatment and space for storage of the casks, is under development too. In the "Programme of Nuclear Power Development in the Russian Federation for the period 1998-2005 and for the period until 2010" provisions for the construction of a central dry storage facility with a capacity of 30,000 t WWER-1000 and RBMK-1000 SF by 2010 are foreseen, as part of the reprocessing plant RT-2. On the base of a feasibility study, it was recommended to construct a vault type storage facility. Prior to the vault's operation, spent fuel will be stored in dual purpose casks at the power plants and at KMCP.

TABLE III. PRINCIPAL CHARACTERISTICS OF FUEL CYCLE OF RUSSIAN NPPs UP TO 2015

Type of reactor, stage of fuel cycle	Characteristics of fuel cycle	1998	2005	2015	Remarks
WWER-210, 365, 440 BN-660, 800	Number of units under operation/shut down	9/2	9/2	11/4	
SF is transported to RT-1 for reprocessing	Operation time, in reactor-year	182	231	287	
Annually transported ~ 140 t	SF discharged since 1964, FAs/tU	24,720/ 2,554	30,600/ 3,158	39,380/ 3,425	
First unit was commissioned in 1964	SF stored at NPPs, FAs/tU	3,359/ 393	3,752/ 439	1,821/ 209	
WWER-1000, 640	Number of units under operation / shut down	7/0	8/0	14/0	Dry storage facility at KMCP
SF is transported to KMCP	Operation time, in reactor-year	182	231	287	for WWER and RBMK SF will be
annually transported ~ 125 t	SF discharged since 1980, FAs / tU	3,428/ 1,382	6,125/ 2,470	12,080/ 5,260	commissioned in 2010
First unit was commissioned in1980	SF at NPPs, FAs/tU	1,279/ 515	1,414/ 571	4,069/ 1,670	
RBMK-1000, EGP-6, AMB	Number of units under operation / shut down	17/2	18/2	18/7	2,000 FAs of AMB are stored at RT-1
SF is stored at NPPs	Operation time, reactor-year	308	416	489	It is planned the transportation
First unit was commissioned in1964	SF discharged since 1964, FAs/tU	80,697/ 8,352	113,400/ 12,066	175,770/ 18,878	RBMK SF to KMCP since2006
	SF at NPPs, FAs/tU	78,697/ 8,276	111,400 11,715	111,400/ 11,715	

For the Beloyarsk NPP, the main problem is ensuring the safety of spent fuel management at the shut down AMB reactors. During the operational period of these reactors, more than 7,000 cassettes (361 t) were unloaded, of which 2,000 cassettes were shipped to the storage facility at the RT-1 plant and 5,000 cassettes were packed into dry canisters accommodating 17 or 35 cassettes. The storage process is complicated by corrosion of 17 sections of carbon steel made canisters with damaged fuel. The paramount task is the creation of additional barriers for the damaged cassettes to prevent the release of radionuclides to cooling ponds and the development of an effective water cleaning system. It is planned to reload the spent fuel from the cooling ponds to steel casks for long-term dry storage and transportation. At the present time, design plans and specifications for these casks are under development and a test model is being fabricated.

Spent fuel of the 4 EGP-6 reactors at the Bilibino NPP is stored in three at-reactor storage facilities. During the operational period, ab[illegible]09 t of spent fuel was unloaded. As AR storage was filled, the spent fuel was converted to a dr[illegible]orage regime after one year of cooling. At the present time, the AR storage facilities are filled and converted to a dry storage regime. For the solution of the spent fuel problem of Bilibino NPP, the concept of the final stage of spent fuel management is being developed taking into account the low density of the population and the long distance from communication lines. The principal idea of the concept is the removal of the spent fuel from the NPP site, but the final stage is not yet determined. Thus, at the present time the main direction in solving the spent fuel management problem for RBMK, AMB and EGP reactors is the organization of long-term storage at the NPP sites and in a central storage facility for WWER-1000.

During the operational period of Russian power plants, 12,286 t of SF was discharged, of which 9,184 t is stored at power plants and 2,164 t was reprocessed at the RT-1 plant (PO "Mayak"). This situation, where the main portion of the spent fuel will be stored at the power plants, will continue over the next twenty years and consequently, the inventory of the spent fuel will increase.

In this respect, it will be necessary to solve the arising problems to ensure the long-term safety of spent fuel storage:

- Redesign of existing AR and AFR storage facilities, to increase their capacity up to the utmost permissible limits. The adjustment of storage projects in compliance with standing safety requirements and application for licences from regulating bodies for the operation of spent fuel storage facilities. This work has been done for the Leningrad and Kursk power plants and is currently under way for the Beloyarsk, Bilibino and Smolensk NPPs.

- Justification of the duration of spent fuel storage. For this purpose, investigations on the zirconium alloy cladding from the upper part of the RBMK fuel assemblies were conducted after 13 years of cooling in water pools. The results of the investigations showed, that dense oxide deposits were formed on the cladding and their thickness increased from the top to the lower part of the examined fuel rods. The change of the cladding thickness along the fuel rod was within allowable limits. The minimal thickness was 680 μm under a layer of deposits, that corresponds to 83% and doesn't cause apprehensions from the point of view of storage reliability. Insignificant hydrogenation of the cladding metal did not cause the deterioration of the mechanical characteristics. On the contrary, the strength characteristics were increased thanks to radiation hardening, but the ductility stayed rather high (16%). Thus, 13 years of RBMK fuel cooling in water pool caused no serious change in mechanical properties.

Full scale tests of zirconium and stainless steel specimens showed that the corrosion had a uniform character on the whole. The corrosion rate for zirconium alloys was 0.7 - 1.0 μm/year and for stainless steel 0.5 - 1.0 μm/year. These rates of corrosion guarantee the safe storage of spent fuel for at least 40 years for the cladding material and a much longer period for canisters and pool lining. The corrosion under the deposit layer causes some apprehension, but in this case it will be possible to guarantee not less than 40 years of safe storage without of special measures.

REFERENCES

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