Radioactive waste from decommissioning of fast reactors (through the example of BN-800)

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Abstract. Estimation of volume of radioactive waste from operating and decommissioning of fast reactors is introduced. Preliminary estimation has shown that the volume of RW from decommissioning of BN-800 is amounted to 63,000 cu. m. Comparison of the amount of liquid radioactive waste derived from operation of different reactor types is performed. Approximate costs of all wastes disposal for complete decommissioning of BN-800 reactor are estimated amounting up to approx. $145 million.

1. Introduction
The experience of decommissioning of the fast neutron reactor and complex reprocessing of big volume of radioactive waste (RW), including liquid-metal sodium, is quite limited in the world's practice. There are only two fast neutron reactors in operation: BN-600 and BN-800. Reprocessing of the used liquid sodium coolant was performed at experimental facilities in a limited way. Consequently, analyses of the volume, content, activity level of RW and costs of RW disposal will be a prototype for handling RW of liquid sodium cooled fast neutron power reactors, e.g. BN-600, BN-800, BN-1200, and may be applied for the operating water cooled nuclear power plants as well as in projects of new power units.

Purpose of the work: to analyse the volume, content and activity level of operational and decommissioning RW of fast neutron reactors; to compare RW characteristics of the thermal neutron and fast neutron reactors, to evaluate RW peculiarities of fast neutron reactors; costs of wastes disposal for reactor decommissioning.

2. Analysis of radioactive waste
At present the process of decommission of different types of reactors becomes complicated because in case of design of most of them the stage of decommission wasn't considered. It is well known that one of sources of radioactive waste and a source of potential danger to the population and the environment are the neutron induced activity (neutron activation) of the equipment, protective concrete constructions and other materials.

So, under the influence of neutrons the equipment, reactor construction and protective construction materials become radioactive. Activated materials are the reactor vessel and internal components,
pipelines, the equipment and elements which are in reactor space. Important feature of the activated materials is that they aren't decontaminated.

It is established that during decommissioning nuclear power plants up to 50% of the volume of radiation protection, lining and sealing of coatings and structures are activated, i.e. they will belong to the category of radioactive waste not subjected to decontamination. It is worth noting that the containment is a concrete monolith, and performs two functions: protective and bearing, so when removing it is very difficult to separate the active and inactive parts, which is why the volume of radioactive waste due to the induced activity is increased many times [1].

Evaluation of RW peculiarities of fast neutron reactors was performed through comparison of activity, structure, chemical composition and volume of liquid and solid radioactive waste (LRW and SRW) of BN and VVER. The volume of RW accumulated depends not only of the number of power plan units, their power and duration of operation, but also of the reactor type. Thus LRW volume comparison was conducted based on the amounts specified for 1 reactor·year and for 1 MW el·year [2]. For estimation of LWR volume for BN-600 and BN-800 reactors, these reactors characteristics were compared to those of BN-350. The data on yearly average LRW volume are presented in Table 1. The data for BN-350, BN-800 and VVER-1000 is referenced as well for illustrative purposes.

Chemical composition, specific activity, and radionuclide composition of LRW of fast neutron reactors is little different to those of water cooled thermal neutron reactors. Thus, the same methods can be used for LRW reprocessing as for thermal neutron reactors.

| Specified Volume | Reactor Type |
|------------------|--------------|
|                  | BN-350       | BN-600       | BN-800       | VVER-1000    |
| m³/(reactor·year) | 50-75        | 100-150      | 120-180      | 220-350      |
| m³/( MW el·year) | 0.2-0.3      | 0.22-0.33    | 0.17-0.25    | 0.4-0.6      |

As table 1 shows, 4000-6000 m³ of LRW can be accumulated during operation of BN-600 (30+10 years); and 5400-8100 m³ of LRW can be accumulated during operation of BN-800 (45 years).

SRW content is similar for the fast neutron and thermal neutron reactors are comparable. Volumes of SRW of different activity level correlate almost equally excluding the fact that HLW ratio for BN reactors is a little higher in comparison with VVER SRW.

It is worth considering that the volume of SRW significantly decreases during operation due to organizational-technical measures and decontamination of some amount of the waste. However, higher volume of SRW accumulated during operation is typical for fast neutron reactors, namely 1.5-3.5 higher than for VVER reactor type and are comparable to SRW for RBMK reactor type.

A big amount of SRW forms upon decommissioning of the Nuclear Power Plants. For instance, from 20000 to 30000 tons of SRW forms upon decommissioning of the average 1000 MW reactor [3]. According to preliminary estimates, about 11180 tons of SRW (from which 36% are low-level, 41% are intermediate-level and 23% are high-level) will be produced upon decommissioning of BN-350 reactor. We can estimate from the above that the volume of SRW produced upon decommissioning of BN-800 reactor, the data on SRW volume is presented in Table 2.

Distinctive SRW is the main peculiarity of RW of BN reactors: sodium metal, highly-active adsorbers and cold traps containing sodium. It is also important to consider that the volume of decommissioning SRW and correlation of SRW of different groups on activity and especially HLW depends on the accepted concept of decommission – immediate or deferred dismantling. The volume of SRW will be higher in case of immediate dismantling compared to deferred one.
Table 2. Amount of SRW upon decommissioning of BN-800.

| Amount of SRW, m³ | Low-level waste | Intermediate-level waste | High-level waste | Total SRW: |
|-------------------|-----------------|--------------------------|-----------------|------------|
| Amount of SRW     | 12240-14688     | 13940-16728              | 7820-9384       | 34000-40800|

3. Costs of RW handling upon Decommission

Upon development of Decommission preparation programs it is necessary to consider the costs of waste handling and implementation of measures for ensuring radioactive and ecological safety. Costs of RW and radioactive materials handling (approx. 30-50%) and disassembly of radioactive equipment are significant part of the total Decommissioning costs [4].

International experience of reactor decommission shows that costs connected with decommission may amount up to 37% [5] on estimation of the leading Russian specialists [6] costs of decommission of one reactor may amount to half a cost of its construction (i.e. $1-1.5 billion).

At the time of power unit decommission for determination of activity levels and volumes of radioactive waste it will be necessary to know composition of all constructional and protective materials near-reactor zone which during all period of operation were subject to radiation. It is also necessary to note that there is a practical possibility of lowering of activation levels of materials by a purposeful choice at design and construction stages of the least activated components and substances that will lead to lowering of the neutron induced activity activity, and finally – to lowering of volumes of radioactive waste. Such approach is also recommended by the International Atomic Energy Agency (IAEA) [7-8].

Utilization and disposal of the RW produced during operation as well as RW produced during decommission is required upon decommission of the reactor unit.

In summary, approximate volume of RW upon decommission for low-level waste will sum up to 29000 m³, intermediate-level waste – 25000 m³, high-level waste – 8500 m³. Costs of RW disposal upon total decommission of BN-800 reactor unit, based on 2016 RW disposal rates [9], will sum up as follows: low-level waste – 1100 million rubles, intermediate-level waste – 3318 million rubles, high-level waste – 4819 million rubles. Therefore approximate cost of disposal of all waste types will amount to 9,25 billion rubles ($145 million).

According to the Ministry of Energy of the Russian Federation the construction cost of the power unit No. 4 of the Beloyarsk NPP with the fast neutrons reactor BN-800 is estimated at 145,649 billion rubles [10]. Based on the calculations, the cost of disposal of all kinds of waste upon the BN-800 decommissioning will be about 6.4% of the costs for the construction of the power unit. However, it necessary note that the treatment of radioactive waste during decommissioning is the collection, sorting, processing, conditioning, transportation of waste and disposal. These items of expenditure in the calculations is not taken into account except for disposal, but they can have a serious impact on the final cost of RW management during decommissioning.

4. Conclusion

Based on the results the conclusion can be made that content of LRW and SRW as well as their activity levels in fast neutron and thermal neutron reactors are almost similar. It was also determined that the volume of LRW in BN reactors is approx. twice less than those of VVER reactor; and volume of SRW is higher and is dependent from the accepted concept of decommission. SRW peculiarities require special decisions on their handling as well as development of special technologies of its reprocessing. Also do not forget that the modern approach to the design of nuclear power plants requires consideration of the stage of decommissioning at the stage of designing, with the aim of reducing the radiation exposure on the population and the environment, mainly by reducing the
volume of radioactive waste and ensure a more secure environment, the dismantling of buildings and structures.

Approximate cost of RW disposal will amount to 9.25 billion rubles ($145 million).

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