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Development and application of the civil plutonium database in Russia

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Abstract

By now, vast amounts of plutonium have been accumulated in spent nuclear fuel from different types of reactors (power, research, propulsion) as part of the Soviet (Russian) nuclear program. Issues concerned with the future of the accumulated plutonium (or plutonium being accumulated), including its long-term storage, disposal or use as fuel in a closed fuel cycle, require an exact knowledge of where, in what quantities and in what condition plutonium is stored at a particular time point. The existing nuclear material control and accounting system does not provide for the required information. This study deals with the further evolution of a specialized database on civil plutonium (SDBP) in Russia the work on which was started in 2013 and which would allow preparing input data for system analytical investigations to support the decision-making on the future use of civil plutonium in Russia. The prime objective of the study is to enable the selection of technological batches of extracted plutonium for the manufacturing of the BN-800, BREST and BN-1200 fast reactor core loads. The SDBP can be also used to address a broader range of problems involved in justification of the closed nuclear fuel cycle. Cooperation with such powerful software systems as the CYCLE code will make it possible to perform high-accuracy calculations from a single workplace and within a compressed timeframe.

Computer mechanisms were developed for processing and conversion of data, as well as mechanisms for the interaction with computational software systems (CYCLE) to prepare input data for the calculation of scenarios for the nuclear power evolution in Russia and worldwide based on thermal and fast reactors, including the closed nuclear fuel cycle.

Keywords: Closed nuclear fuel cycle; Nuclear fuel; Accounting and control of nuclear materials; Plutonium; Minor actinides; Hardware and software; Input and output data; Compatibility with nuclear material control and accounting system; Specialized plutonium database management system.

Introduction

With present-day price formation approaches, the growing quantities of the RBMK and VVER reactor spent nuclear fuel (SNF) in Russia are expected to turn into a major economic burden on the generating industry as soon as in the near future. The SNF accumulation problem will worsen with regard to the fact that nuclear power plants (NPP) with Russian VVER reactors will be built abroad on conditions attractive to developing countries, providing for the complete fuel cycle support, including the repatriation of SNF.

Issues concerned with the SNF and high-level waste (HLW) handling and the potential of nuclear fuel as a source material can be resolved through the formation of a nuclear power system with a closed nuclear fuel cycle in which, apart from thermal reactors, fast neutron reactors will be evolving. Such two-component NPS include NPPs with thermal and fast neutron reactors for electricity generation and fuel breeding, as well as centralized nuclear fuel cycle plants for the manufacturing of fuel, storage and processing of SNF, multiple recycling of regenerated fuel, and conditioning and isolation of HLW [1–7].

One of the important issues to be addressed in the nuclear fuel cycle closure is to provide plutonium for the initial loads of fast neutron reactors, as well as of thermal neutron reactors in which plutonium is also used.

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Theoretically, all of the accumulated plutonium can be used as nuclear fuel. However, many of the nuclear reactor characteristics, one of the most important of which is the safety of the NPP, depend on the quality, or more exactly, on the isotopic composition of plutonium.

At the present time, Russia has over 180 t of accumulated plutonium in civil nuclear power [6].

Plutonium accumulation sources in the USSR (Russia).

- Commercial reactors for production of weapon-grade plutonium (operated with different intensity between 1948 and 2012). Commercial reactors were shut down at PA Mayak, Siberian Chemical Combine (SCC) in Seversk and Mining & Chemical Combine (MCC) in Zheleznogorsk at different times in the period of 1991–2012. The plutonium produced after 1994 was declared by Russia excessive for weapon making and was monitored by the United States until 2016 under the respective agreement with the USA.
- NPPs based on different types of reactors (VVER, RBMK, BN); altogether, there are 35 units with an installed capacity of about 26 GW in operation in Russia, including
  - 18 units with VVER reactors (12 VVER-1000 and six VVER-440 modifications);
  - 15 units with channel-type reactors (11 with RBMK-1000 and four with EGP-6 reactors);
  - 2 units with BN-600 and BN-800 sodium cooled reactors.

All these reactors have different operating lives and, so, have produced different quantities of SNF with a plutonium content of different isotopic compositions; some of the SNF from these reactors has been removed for processing or further storage, while some remains in onsite spent fuel pools.

- Research reactors of which 22 are in operation and 8 more in the process of decommissioning, exclusive of critical and subcritical assemblies which contain fuel throughout their operation period. Irradiated fuel from these reactors (including SNF removed to PA Mayak from the reactors built abroad with the USSR's assistance) has been processed at Mayak's RT-1 factory or stays in the reactor spent fuel pools.
- Submarine, icebreaker and surface ship propulsion reactors. Some of the unloaded spent cores from propulsion reactors have been removed to PA Mayak and processed, while many stay in intermediate storage.

The plutonium accumulated in the USSR (Russia) as part of the Soviet nuclear program is stored and used at a number of sites. A general description of the plutonium storage places follows.

- Most of the plutonium is contained in SNF (over 135 t as of the end of 2014) [1] being stored at
  - NPPs–77.5 t in SNF (in spent fuel pools);
  - Independent SNF storage facilities–58 t (e.g., at NPPs, MCC, naval bases (unloaded spent cores from submarine and icebreaker reactors), etc.).
- Plutonium extracted from SNF of different reactors at RT-1 (in storage at PA Mayak); this quantity amounted to 52 t as of the end of 2014 [1,6].
- Plutonium declared excessive for use in weapon making and loaded into a special "storage of fissile materials", 34 t (PA Mayak).
- Plutonium extracted after 1994 at MCC and SCC (over 10 t) currently in storage at SCC.
- More than 1 t of plutonium used for different research applications and stored at plants at research centers (NIIAR, IPPE and others).

It shall be noted that the plutonium stored at PA Mayak and SCC has not been currently registered as "civil plutonium".

Understandably, each storage place contains plutonium with a spectrum of typical isotopic compositions depending on the achieved fuel burn-up and the storage time of a particular accounting item (an FA or a cask) after the discharge from the reactor, the extraction from SNF or reprocessing. Experts use their own standard terms to describe the plutonium categories: "high-background" and "low-background". These terms are applied respectively to plutonium with a low content of Pu-239 and a high content of other isotopes (high-background plutonium) and to plutonium with a high content of Pu-239 and, accordingly, a low content of other plutonium isotopes (low-background plutonium).

Evidently, such diversity of stored and newly received plutonium makes the knowledge of the actual quantities and isotopic compositions of plutonium at a given time point (with regard to the time in storage) specifically important for a correct analysis. Effective use of nuclear fuel in the closed fuel cycle technology, minimization of activities to process and reprocess plutonium and to fabricate mixed uranium–plutonium fuel, given the effects of the plutonium isotopic composition on the parameters of the reactor loads and security, requires one to know where, in what quantities and of what quality plutonium is available [8–14].

Information on plutonium is stored in accounting systems immediately at sites. Since there is no standard (uniform) accounting system in Russia, each site develops its own system with regard to the site state and technical capabilities. Plutonium is stored in accounting items (AI) information on which (certificate) includes a set of unique data required throughout the AI life.

Accounting item (AI) is an item containing a nuclear material and having an individual attribute or an individual set of attributes the parameters of which are registered in respective records, and the integrity is confirmed by access control measures from the time of the accounting data registration (determination of general accounting and control rules, OPUK NP-030-12); in our case this is a barrel with plutonium dioxide (extracted plutonium in storage) or an FA (in the event of plutonium in SNF).

It should be noted that the federal accounting and control system (ACS), which collects information from all nuclear fuel cycle facilities and other plutonium storage sites based on a particular standard, deals with only general data (amounts