PROJECT “ALMAZ” PHASE 1: VERIFICATION OF SPENT FUEL CANNING AT FAST BREEDER REACTOR BN 350

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Abstract

Large projects involving intensive handling of nuclear material have a substantial impact on the way this material is safeguarded. These projects are a challenge for the Agency with respect to finding and allocating the needed resources. Furthermore, new technical means have to be developed or adapted for the implementation of safeguards in these facilities which can enhance the Agency's capabilities in this field. This paper will describe in detail how the Agency managed the implementation of safeguards, in particular the verification of spent fuel canning, during a continuous campaign in which the operator of the BN350 fast breeder reactor in Aktau, Kazakhstan prepared all the spent fuel assemblies at the reactor for long term storage. Emphasis will be given to organizational issues, the provision of resources, both financial and human, and to the specific new techniques that were developed for this project.

1. INTRODUCTION

The BN-350 Spent Fuel Canning and Transfer Project, called “ALMAZ”, resulted from a trilateral agreement between the Governments of Kazakhstan and USA and the IAEA, signed on 18 November 1997 (the starting date of the Project). The objective of the Project was to ensure safe and secure storage of all irradiated BN-350 reactor fuel by packaging individual fuel items together into canisters, and to transfer the canisters to a long-term dry storage facility. Under the agreement, Kazakhstan was granted the financial and technical support for the task by the USA; the IAEA received from the USA special equipment for safeguards and extra-budgetary funds used, in addition to the regular budget, for financing Project-related verification activities.

BN-350, a sodium cooled fast neutron reactor in Aktau, Kazakhstan, operated from 1973 until 1998, sharing its power between electricity generation (350 MW) and steam production for water desalination. The reactor loading consisted of two parts:

- the inner part with “driver” assemblies containing enriched uranium in the central part and depleted uranium in the top and bottom parts; and
- the outer part with blanket assemblies containing depleted uranium.

Irradiated assemblies contain large quantities of plutonium. These assemblies presented security and safety concerns as there was no appropriate long-term storage facility at the BN-350 site. The government of Kazakhstan decided to launch the “BN-350 Spent Fuel Disposition Project” with the ultimate goal of canning the irradiated assemblies and transporting the material to a secure dry storage facility. The USA has provided technical and financial aid for this project under the 1993 Cooperative Threat Reduction Umbrella Agreement.
The following two phases of the Project were subsequently identified:

- Phase I: Canning of fuel (packaging the fuel into 4 or 6-pack canisters, filled with inert gas, welded and placed in baskets for temporary storage at BN-350); and
- Phase II: Construction of the dry storage facility and transfer of the canisters in transport casks to the facility for long-term storage.

Taking into account the high strategic value and large quantities of nuclear material involved and the duration of the Project, IAEA safeguards activities in connection with it represent one of the most effort-intensive and complex verification campaigns undertaken by the IAEA Safeguards Department.

2. CO-ORDINATION AMONG PARTIES

The Atomic Energy Committee of the Republic of Kazakhstan, formerly the Atomic Energy Agency of Kazakhstan, is the governmental body directly involved in the Project.

From the USA side, the Department of Energy (DOE) is the coordinating agency for the Project. The Nuclear Assurance Corporation (NAC) was engaged in carrying out technical and project management work on fuel packaging. Four national laboratories: Argonne (ANL), Los Alamos (LANL), Pacific Northwest (PNNL) and Sandia (SNL) are technical contributors to the Project, developing and providing specialized measurement and monitoring equipment and techniques.

Under the safeguards agreement with Kazakhstan (INFCIRC/504), the IAEA has the obligation to apply safeguards to all nuclear material in Kazakhstan. In the IAEA, the Division of Operations C, Department of Safeguards, is responsible for implementing safeguards verification measures at all stages of the Project. The Division of Technical Services of the Department of Safeguards provides technical assistance in matters regarding surveillance and NDA equipment and measurement methods.

Given the number of involved organizations on the US and Kazakhstan sides, efficient co-ordination of activities among the Project participants has been of crucial importance. Formal trilateral coordination meetings were regularly held (altogether five until the end of June 2001). In addition, four trilateral technical review meetings and several bilateral IAEA – USA consultations on specific technical issues have taken place. The co-ordination was also assured through direct contacts at the working level.

3. IAEA VERIFICATION ACTIVITIES DURING PHASE I

Phase I of the Project was initiated in November 1998 and continued until the canning of irradiated fuel was completed on 18 June 2001. The canning operations involved the fuel stored in the spent fuel pond: both “normal” (non-defective) assemblies and “abnormal” fuel items (defective, fragile, cut assemblies and groups of fuel rods), and also the unloading of the reactor core and canning of the unloaded fuel assemblies.
In order to assure effective and efficient verification in connection with the Project, the Agency took the following basic measures:

- Arrangements were made locally for the extended stay of inspectors (accommodation, transportation, availability of medical services, etc.);
- Working places for IAEA staff were organized within the facility, and specialized safeguards and general-purpose office equipment was delivered;
- Safeguards procedures covering the IAEA verification in connection with the fuel canning activities were developed and documented;
- Sufficient person-power to implement verification in shifts was assured, *inter alia*, by hiring persons with adequate experience using the US extra-budgetary fund;
- Underwater Spent Fuel Neutron Coincidence Counter (SFCC), developed and provided by the USA, was installed and calibrated in the spent fuel pond area;
- Unattended Multi-Instrument Monitoring System (MIMS) composed of radiation detectors and surveillance equipment, developed under the US Support Programme, was installed;
- Unattended Fuel Flow Monitor (UFFM), installed earlier with the assistance of Japan to monitor the core fuel flow, was incorporated into MIMS;
- Containment and surveillance measures applied to irradiated fuel were upgraded to a dual Containment/Surveillance (C/S) system.

The regular verification activities in connection with Phase I of the Project included:

- verification of all irradiated fuel items with the underwater SFCC for partial defects prior to their canning;
- the application of continuous C/S measures to maintain the continuity of knowledge (CoK) in respect of the items verified; and
- after the BN-350 reactor core was unloaded, special inspection activities to verify the completeness of the core unloading.

### 4. CANNING

The fuel packaging campaign of Phase I of the Project was completed on 18 June 2001 when the last canister was welded and loaded into basket number 69; on the same date the basket was moved to the spent fuel pond and placed under the dual C/S system. The overall extent of the canning activities are summarized in *table 1*:

*Table 1. Summary of canning activities*

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal fuel assemblies canned</td>
<td>2537</td>
</tr>
<tr>
<td>thereof from the reactor core</td>
<td>681</td>
</tr>
<tr>
<td>Abnormal fuel items¹ canned</td>
<td>251</td>
</tr>
<tr>
<td>Abnormal fuel stabilizing containers used</td>
<td>196²</td>
</tr>
<tr>
<td>Canisters loaded with fuel</td>
<td>478</td>
</tr>
<tr>
<td>Baskets loaded with canisters</td>
<td>69</td>
</tr>
</tbody>
</table>

¹ Damaged fuel assemblies, parts of assemblies, groups of separate fuel rods, etc.
² More than one abnormal fuel item can be placed into one stabilizing container.
5. VERIFICATION OF FUEL BEFORE CANNING

The IAEA Safeguards Criteria require a quantitative measurement of the irradiated assemblies before their canning (which renders them practically inaccessible for high accuracy measurements). The underwater SFCC, developed, tested and put into routine operation as a result of the cooperative effort of the IAEA, ANL and LANL, has been used to verify the fuel items by performing a “partial defect” measurement of plutonium (Pu) in the items.

SFCC exploits the unique feature of the fast breeder reactor spent fuel - the neutron emission is caused by plutonium isotopes only, thus making it possible to use well established neutron coincidence counting techniques for quantitative plutonium measurements. SFCC is a collar type underwater counter containing 20 He3 tubes imbedded in polyethylene and shielded by a 7 cm thickness lead ring to protect the tubes against spent fuel gamma radiation. Standard neutron coincidence electronics and INCC software collect the data. Because direct measurement of the plutonium isotopics of the spent fuel was not possible, the relative plutonium isotopic abundance determination is based on an ANL validated BN-350 burn up code. The neutron measurement results are used in a calculation algorithm which includes the physical modeling of the BN-350 reactor and irradiation history dependent distribution of elements and isotopes in both driver and blanket assemblies fuel pins. The system was calibrated in LANL using plutonium-uranium mixed oxide fuel with adaptation to the actual BN-350 fuel through Monte-Carlo calculations. It should be noted that the SFCC is the first NDA system used for the Agency safeguards purposes which is capable of direct quantitative plutonium measurements in spent fuel. This achievement was possible due to the unique characteristics of the spent fuel from the BN-350 reactor, the SFCC detector design, and the advanced analysis software.

The combination of MCNP modeling of various BN-350 assembly types with specially developed iterative software allowing the harmonization of all multiplication correction algorithm parameters for estimation of the verified assembly plutonium content was validated through a comprehensive calibration exercise at BN-350 with all types of fuel assemblies. Interactive measurement controlling software (IPANIC) performs all required calculations and guides the user through all measurement, evaluation and decision making (accepted/rejected) processes.

The rejection limit for the verification of the operator’s data on the Pu content was set in the IPANIC software of the SFCC at a 3\(\sigma\) level, using the conservative estimate of 16% for measurement uncertainty, as estimated for ‘normal’ fuel.

From November 1998 till mid-June 2001, all 2537 assemblies and 251 ‘abnormal’ fuel items were measured by the SFCC prior to their canning. Statistical evaluation of data for fuel assemblies resulted in the relative measurement error (random plus systematic) estimated to be from 10.4 to 13.0% (depending on fuel assembly type). For ‘abnormal’ fuel items measured in January – June 2001 the average relative deviation between the operator-declared Pu content and the measured Pu quantities (excluding “outliers”) amounted to 16.4%. Reasons for any “outliers” were investigated, and the items were canned only after the operator’s data and the SFCC measurement results could be reconciled.
For items with non-standard fuel composition (e.g., MOX), the SFCC measurements required ‘manual’ evaluation by NDA specialists before the results were used for comparison with operator’s data. For several essentially fresh (only slightly irradiated) fuel items the verification consisted of confirming the operator’s declared zero Pu content of the items.

6. MAINTAINING THE CONTINUITY OF KNOWLEDGE

A combination of human and unattended optical digital surveillance, MIMS and sealing systems (VACOSS, Cobra and E-type) was used throughout Phase I of the Project to maintain the CoK on the fuel items verified. The Multiple Instrument Measurement System (MIMS), which worked in both attended and unattended mode, enabled the Inspector to observe what was occurring at all stages and to verify nuclear material movements and their direction in the non-accessible hot cell areas though the use of neutron and gamma radiation monitoring graphs and triggered surveillance images.

Initially, integrated surveillance and radiation monitoring also covered the reactor area. It was discontinued only after the completeness of the reactor core unloading was verified by the IAEA, and the reactor fuel transfer equipment rendered inoperable by the operator (inter alia, by removing the fresh fuel drum from its position in the fuel-handling route).

The review of surveillance (DMOS system) and MIMS data was performed on a daily basis until the completion of fuel canning activities on 18 June 2001.

7. REACTOR CORE UNLOADING

Discharging the last assembly on 17 October 2000 completed the unloading of fuel from the reactor core. On 14 November 2000, the IAEA carried out special inspection activities to confirm the completeness of the unloading.

The procedure used was developed by the IAEA specifically for BN-350 and included the verification of the core content by loading an imitator, under observation of an IAEA inspector, into various positions in the core and fuel handling mechanisms. The imitator was moved sequentially through the entire fuel-handling route within the difficult-to-access area of the reactor. The CoK on the imitator movements throughout the operation was achieved by means of direct observation by inspectors of the fuel-handling equipment inside the reactor containment.

One blanket assembly remained in the fresh fuel load drum (it was stuck there some 20 years ago) until 14 March 2001 when it was finally removed after the removal of the drum from its position in the reactor area. This operation resulted in the reactor area being emptied of all fuel and the official start of facility decommissioning activities.

8. EQUIPMENT

Overall, the safeguards equipment installed at the facility (SFCC, MIMS, DMOS and various types of seals) performed reliably throughout Phase I. In particular, the SFCC was heavily used for fuel measurements, and the daily use of MIMS data facilitated the efficient and
effective application of C/S measures. Any malfunctions and other difficulties could be remedied by the IAEA staff in cooperation with the equipment developers.

Following agreement with the State Authority, satellite and communication equipment was installed at BN 350 in January 2001 for a remote monitoring (RM) test to assess the technical and economical feasibility of RM for safeguards at BN-350. After some initial problems caused by strong winds in the area, a protective housing was built for the roof-mounted antenna, and video and radiation data were received successfully at the Headquarters, Vienna. The RM test campaign is planned to continue until the end of 2001.

9. WORK EFFORT DEPLOYED

To perform the verification activities in connection with Phase I of the Project, the IAEA relied on both its regular budget and the extra-budgetary funds provided by the US Government. Verification activities during Phase I represent one of the most effort-intensive safeguards campaigns ever conducted by the IAEA. Since the beginning of Phase I until the end of the second quarter of 2001:

- Regular IAEA inspectors expended almost 1090 person-days of inspection (PDIs) on the activities under the Project,
- Non-inspection staff (hired persons and some staff of the Safeguards Department and UNSC Action Team) spent over 1460 field working days (FWDs), and
- The total effort deployed by specialists of the Division of Technical Services amounted to 60 FWDs.

10. CONTINUATION OF THE PROJECT

With all fuel-packaging activities completed in the second quarter of 2001, Phase I of the Project has been accomplished. In preparation for Phase II, a calibration campaign remains to be conducted for a new Spent Fuel Attribute Monitor (SPAM), which will be used for fingerprint measurements of canisters containing fuel assemblies. The calibration of SPAM will involve testing the measurement procedures and performing measurements of a number of selected canisters in order to prepare the technique for routine implementation during Phase II of the Project. No specific timing for those activities has yet been fixed, but it is hoped to complete this work before the end of 2001.

The initiation of Phase II activities (transportation and long-term storage of the canned BN-350 fuel) depends largely on Kazakhstan’s final decision on the long-term storage location, and the US financial assistance for the project. So far, no definite date for the beginning of Phase II has been agreed. For the IAEA, activities under Phase II of the Project are expected to require a considerable amount of human and budget resources.

11. SUMMARY

Throughout Phase I of the ALMAZ Project excellent co-operation between the parties has been maintained at all levels, which has allowed:
1. the development of unique equipment systems, such as the underwater SFCC for a quantitative measurement of plutonium in irradiated fuel, and MIMS which integrates data from radiation detectors and surveillance cameras; and

2. the completion of a complicated task of successfully verifying, canning and maintaining the CoK on large quantities of weapons-grade nuclear material without any major problems and in a relatively short time span.

REFERENCES


