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RETURN OF 80% HIGHLY ENRICHED URANIUM FRESH FUEL FROM YUGOSLAVIA TO RUSSIA

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Abstract — The transport of almost 50 kg of highly enriched (80%) uranium (HEU), in the form of fresh TVR-S fuel elements, from the Vinča Institute of Nuclear Sciences, Yugoslavia, to the Russian Federation for uranium reprocessing was carried out in August 2002. This act was a contribution of the Government of the Federal Republics of Yugoslavia (now Serbia and Montenegro) to the world's joint efforts to prevent possible actions of terrorists against nuclear material that, potentially, would be usable for the production of nuclear weapons. Basic aspects of this complex operation, carried out mainly by transport teams of the Vinča Institute and of the Institute for Safe Transport of Nuclear Materials from Dimitrovgrad, Russian Federation, are described in this paper. A team of IAEA safety inspectors and experts from the DOE, USA, for transport and non-proliferation, supported the whole operation.

INTRODUCTION

All the fresh highly enriched uranium (HEU) fuel elements at the Vinča Institute were aquired from the former USSR in the period 1976–1985. These fuel elements have been used for the operation of the 6.5 MW heavy water research reactor RA[1] and for experiments at the RB heavy water critical assembly[2]. Fuel elements of the same design were also used at the TVR heavy water research reactor[3], operated by the Institute for Theoretical and Experimental Physics (ITEP) in Moscow, Russia, in the period from 1964 until the reactor was shut down permanently in 1984. In fact, the TVR reactor was the generic one for two other similar reactors built in Beijing (People's Republic of China) and in Vinča near Belgrade (Federal Republic of Yugoslavia) at the end of the 1950s. The reactor in Beijing commenced operations in 1958 and, after modernisation, it is still operational. The RA reactor in Vinča reached the first criticality in December 1959 and was operational until 1985. Since 1985, the RA reactor has been in an extended shut down. The RB critical assembly is still in operation.

Since the autumn of 2001, Yugoslav Government officials have carried out negotiations concerning the return of fresh fuel to the country of origin with the USA administration and non-governmental organisations and experts designated by the Ministry of Atomic Energy (MINATOM) and responsible expert transport organisations from the Russian Federation. An agreement to return all unused HEU fuel elements to their country of origin — the Russian Federation — was reached during the spring of 2002. Appropriate decisions on the final shutdown and decommissioning of the RA research reactor and the transport of HEU fresh fuel were also made by the Government of the Republic of Serbia and the Government of the Federal Republic of Yugoslavia during July and August 2002. Preparations for the transport of more than 5000 HEU fresh fuel elements were made at the Vinča Institute of Nuclear Sciences, Belgrade, Yugoslavia and in the Branch Federal State Institute 'Safe Transport of Nuclear Materials' (STNM Institute), Dimitrovgrad, Russian Federation. The safety department of the International Atomic Energy Agency (IAEA), Vienna, Austria, and non-proliferation specialists from the Oak Ridge National Laboratory, working for the Department of Energy (DOE), USA, took part in the preparations and transport of the HEU fuel elements, as well. The transport took place in mid-August 2002 under the highest security measures available at the Vinča Institute and during the transport of the fuel elements from the Vinča Institute to Surčin — the airport for Belgrade. Two Yugoslav military aircraft escorted the cargo plane en route from Belgrade to the Yugoslav border, and Russian military aircraft escorted the cargo plane en route from the Russian border to Ul'yanovsk airport.

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TVR-S FUEL DESCRIPTION

The HEU fuel elements, known as the TVR-S type of fuel elements ('slug')[4], were produced in the Novosibirsk Chemical Concentrates Plant (NCCP), Novosibirsk, Russian Federation. The TVR-S fuel element is an 11.30 cm long hollow cylinder with a 3.72 cm outer diameter (Figure 1). The fuel layer of the TVR-S HEU element contains 80% enriched uranium in the form of uranium dioxide dispersed in an aluminium matrix. The aluminium matrix is designed as a hollow cylinder, 100 mm long with inner/outer diameters 31/35 mm. The mass of ^{235}U in TVR-S fuel elements is 7.7 g $\pm$ 0.3 g. Approximately 1 mm thick aluminium cladding on the inner and outer sides covers the fuel layer. The inner tube of the TVR-S fuel element, made of aluminium, is known as the 'expeller' or 'ejector'. It serves to adjust the coolant flow rate at both sides of the fuel layer of the slug. The top and the bottom of the slug are covered by 3 mm thick (aluminium) 'stars' with sprockets, so that the total length of the slug is 11.30 cm. The aluminium used in the construction of the TVR-S fuel slugs is known as the SAV-1 alloy. The average mass of a TVR-S slug is 162 g. The detailed material composition of the TVR-S HEU fuel element is given elsewhere[5].

During the operation of the RA reactor, about 1400 HEU slugs were spent by the end of 1984[6]. The total amount of the fresh HEU fuel elements at the RB and RA reactors at Vinča Institute since then was 5046. The fresh and spent nuclear fuel elements at the Vinča Institute are under regular (monthly) safety inspections by the IAEA. The HEU fresh fuel elements were stored at the fresh fuel storage rooms of the RA and RB reactors in original Russian-made packages. These containers, the older type and newer type SU/086/B(U)F, were used for transport and storage (Figure 2) in the 1970s and 1980s. In addition to police guards engaged for physical protection of the reactors' building, the storage rooms for fresh HEU elements at the RA and RB reactors were also under continuous surveillance by an automatic electronic alarm system used since 1996, according to the DOE (USA) recommendations.

IP-2 TRANSPORT PACKAGES

The US DOE experts from the Oak Ridge National Laboratory (ORNL) and the Los Alamos National Laboratory (LANL), along with the Russian experts from the MINATOM (the ATOMSPECTRANS and the STNM Institute) inspected the existing packages in which the HEU slugs were stored at the Vinča Institute in spring 2002. Experts established that the containers did not fulfill the current standards and requirements[7] for the planned transport of fissionable nuclear material. The representatives from the STNM Institute proposed the use of Russian industrial packages, IP-2 type TK-S15 and TK-S16, produced by the NCCP, Novosibirsk, Russia, for the transport. The TK-S15 and TK-S16 containers are designed and used for transport of fresh fuel

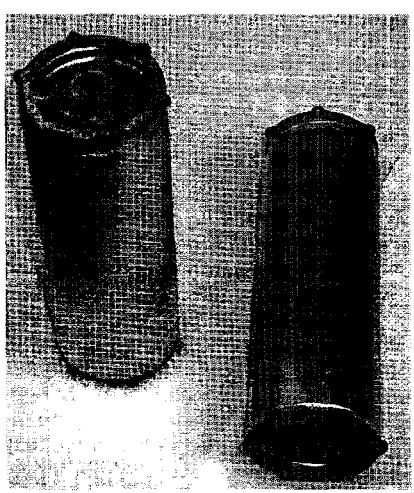

Figure 1. TVR-S fuel element.

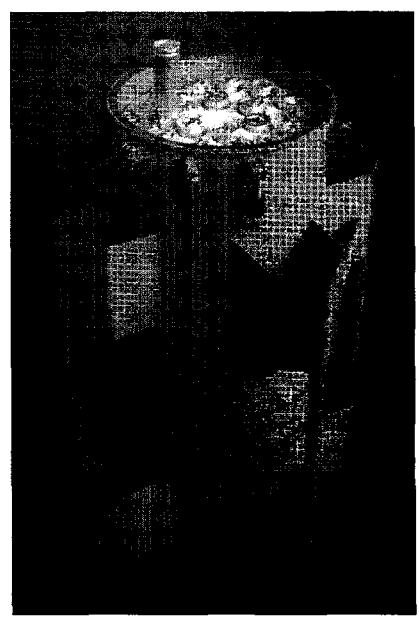

Figure 2. SU/086/B(U)F transport container for TVR-S fuel elements designed in Russia in the 1970s.

assemblies (FA) for the operation of MR, MIR, i.e., IRT-2M, IRT-3M and IVV-10 types of Russian research reactors, respectively.

New packaging procedures were proposed by the STNM Institute according to the available packaging space within TK-S15 and TK-S16 containers, and according to the safety requirements with respect to the criticality safety index (CSI) and to the transportation index (TI). The Russian certificates, licensed on 1 July 2002, authorised these containers and packaging procedures for the transport of the TVR-S type HEU fuel elements. Criticality calculations[8], according to the requirements given in STI[7], were carried out independently in the State Scientific Centre of the Russian Federation 'Fizichesko Energheticheskiy Institut–FEI', Obninsk, Russia and in the Centre for Nuclear Technologies and Research 'NTI' of the Vinča Institute of Nuclear Sciences, Yugoslavia. Results of the calculations showed that an unlimited number of the TK-S15 and TK-S16 packages filled with the proposed number of 80% HEU fuel slugs of the TVR-S type could be used in transport by truck or by aircraft, i.e., that CSI = TI = 0 even in the case of the worst assumed accident.

The TK-S15 packaging assembly includes a container, the inner equipment and accessories. The container consists of a welded steel case, two covers, heat insulation and a wrapper. The inner equipment is a welded construction of seven aluminium tubes that can accommodate seven FAs. The mass of TK-S15 is 240 kg. The dimensions of the TK-S15 package are length 1650 mm, width 400 mm and height 420 mm.

TK-S16 packaging assembly also includes a container, inner equipment and accessories. The container case is a welded construction in the form of a barrel with double walls. The gap between the walls is filled with heat-insulating material. The inner equipment is a welded construction of seven aluminium tubes that can also accommodate seven FAs. The mass of TK-S16 is 160 kg. The dimensions of the TK-S15 package are diameter 655 mm, maximum width 740 mm and height 1200 mm.

In each aluminium tube of TK-S15 packaging, 13 pairs of TVR-S slugs (a total of 26 slugs, tied together by adhesive tape such as Scotch® tape) can be stored. In this way, a total of $7 \times 26 = 182$ TVR-S slugs may be stored in a single TK-S15 package. The total mass of ^{235}U per TK-S15 package is 1401.4 g. A total of 20 TK-S15 packages were delivered to the Vinča Institute for the transport (17 were used, while three were spare).

In each tube of the TK-S16 packaging eight bundles of four TVR-S slugs (a total of 32 slugs, tied together by Scotch® tape) were placed one above the other. In this way, $7 \times 32 = 224$ TVR-S slugs may be stored in a single TK-S16 package. The total mass of ^{235}U per TK-S16 container is 1724.8 g. Ten TK-S16 packages were delivered to the Vinča Institute for the transport.

PREPARATORY ACTIVITIES

All preparatory activities related to packaging procedures were carried out at the Vinča Institute during July and the beginning of August 2002, in close cooperation with safety inspectors of the IAEA and experts from the STNM Institute. These activities included:

(1) Establishment of a management structure and executive transport programme team.
(2) Elaboration of repackaging procedures, preparation of repackaging area, organisation of necessary logistics support and personnel training.
(3) Provision of increased physical protection at the Institute and police escort during the transport of fresh fuel elements from the Institute to the airport in Belgrade.
(4) After all decisions had been made by the governments of the Federal Republics of Yugoslavia and the Republic of Serbia, and the steering board of the Vinča Institute, all documents, required permissions and certificates issued in Yugoslavia were provided.
(5) The STNM Institute provided all permissions and certificates issued in Russia and all transport equipment, logistics support and hired a cargo aircraft of the Russian transport company Volga-Dnepr.
(6) Provision of appropriate transport vehicles and close cooperation with the customs at the airport in Belgrade.
(7) Presentation of the task and training of members of various supporting teams (e.g., health physics department, medical protection department, fire department) for the regular and possible incidental situations that could happen while carrying out these activities.
(8) Preparation of necessary equipment for packaging, radiation protection measurements, marking and sealing of packages.

The whole task was kept a secret, according to recommendations given in Chapter 8 of the INFCIRC 225[9], in order to reduce the possibility of a terrorist attack or of any conflicts with members of Greenpeace during the transport.

As the first step, all 985 HEU fresh fuel elements used at the RB critical assembly were unloaded from the core in July 2002. They were returned to the storage containers placed at the RB reactor room. These containers were verified for the fuel type and number by RB staff. The IAEA safety inspectors verified the contents of the containers. The containers were also closed and sealed by safety inspectors from the IAEA. At the same time, in the presence of the IAEA safety inspectors, the storage containers with fresh HEU fuel elements at the RA reactor storage site were unsealed and opened, one by one. In this way, a total of about 4000 fuel slugs were released from their original protection packaging (paper and plastic foils) and

returned to their positions in the containers. The reason for this preparatory activity was the fact that, according to the proposed procedures, only 'naked' fuel elements could be inserted inside tubes of the TK-S15 and TK-S16 containers. Each container was closed and sealed using the E-cup seals by the safety inspectors of the IAEA, as soon as the procedures mentioned above were completed.

The repackaging area, i.e., the TK-S15 and TK-S16 loading area, was prepared within the RA reactor room. Three additional areas (so called 'arrays') were also marked for the location of 51 existing storage containers, and for 20 TK-S15 and 10 TK-S16 new transport packages. Two working (packaging) lines (labelled 'A' and 'B') were set, including all necessary tools and supporting material needed for repackaging. A place was designated for control measurements of fuel element samples by the IAEA safety inspectors, along with a place for gamma ray dose rate measuring, sealing and marking of loaded containers. Record forms for all procedures were also prepared. The requested radiation control included contamination monitoring of the area, used equipment and new transport packages and gamma-ray dose rate measurements. For all personnel engaged in the work within the RA reactor room, appropriate protective clothes, gloves, overshoes and thermoluminescence dosemeters were provided, although the gamma ray dose rate from the fresh fuel elements was very low. A special metal detector gate was set at the only allowed exit/entrance of the RA reactor room in order to prevent any deliberate removal of fuel slugs from the room. Only personnel wearing special badges, approved and allowed by the managers of the transport programme team, were permitted to enter the reactor room. With a few exceptions, the use of mobile phones and cameras was not allowed inside the RA reactor room during repackaging activities.

All existing storage containers loaded with fresh HEU fuel elements were transferred from their regular storage places, at the RA and RB reactors, to the RA reactor room, 1 day before the Il'yushin-76 cargo aircraft with TK-S15 and TK-S16 transport packages arrived from STNM Institute, Dimitrovgrad, Russia, at Belgrade airport.

PACKAGING ACTIVITIES AND TRANSPORT

The aircraft was unloaded at the airport immediately after landing and all TK-S15 and TK-S16 packages were loaded into the transport vehicle in a few hours, including radiation and contamination control and customs procedures. Police cars escorted the transport vehicle during its passage from the airport to the Vinča Institute. After the arrival of the vehicle at the parking place in front of the RA reactor building, the TK-S15 and TK-S16 packages were unloaded, one by one, using a forklift truck, and transported to the transport entrance of the RA reactor room. There, the packages were reloaded onto the transport cart and carried to marked positions in the reactor room. The existing crane in the RA reactor room was used to unload the cart and locate each package at the desired position within the marked array area. This activity took about 3 h.

The next day, all ten TK-S16 packages were fully loaded, closed, sealed by IAEA seals, measured for contamination and the transport index, labelled with yellow II and fissile diamond labels and moved back to their position in the reactor room. The HEU fuel slugs were prepared according to the proposed procedure — four in each bundle, and eight bundles connected in a row, using strong nylon string that was pulled through central axial holes of every two slugs in each bundle by means of a specially prepared needle. The nylon string was used for moving the whole row of eight bundles from the repackaging table to the aluminium tubes in the TK-S16 package. The nylon string also enabled unloading of fuel elements from the containers at the receiving site in Russia.

During the next 2 days, all seventeen TK-S15 packages were fully loaded, closed, sealed by IAEA seals, measured for contamination and the transport index, labelled with yellow II and fissile diamond labels and moved back to their position in the reactor room. The HEU fuel slugs were prepared according to a proposed procedure — two in a bundle, and 13 bundles connected in a row, using strong nylon string that was passed through the central axial holes of both slugs of each bundle by means of a prepared needle. The nylon string and a plastic supporter designed as a long semi-tube was used for moving the whole row of 13 bundles from the repackaging table to the aluminium tubes in the TK-S16 package. The nylon string also enabled unloading of the fuel elements from the containers.

Figures 3 and 4 show the top view of TK-S15 and

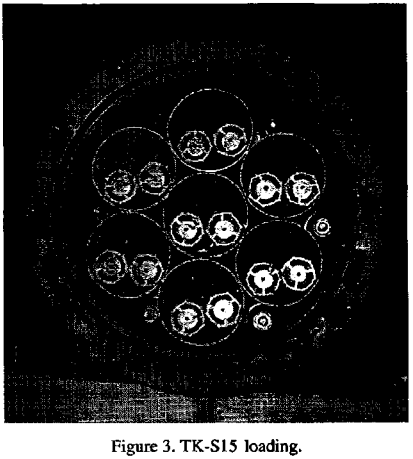

Figure 3. TK-S15 loading.

TK-S16 opened packages completely filled with TVR-S fuel elements, before closing by the top cover.

The IAEA safety inspectors monitored repackaging activities in the reactor room and carried out the MMCN measurements of randomly selected HEU fuel slugs according to procedures prepared in advance. A NaI crystal scintillation detector with the multichannel analyser MCA-166 was used for the non-destructive analysis (NDA) measurements in the predefined geometry. A calibration check was made by using the control slugs. About 1% of all HEU fuel slugs were verified without any remark or objection by the safety inspectors. The results were within the expected uncertainty for all the slugs measured.

Due to well-trained staff and using some additional supporting tools for packaging, fuel element reloading activities in the RA reactor room were completed in about half the time anticipated in the plan.

The repackaging activity was monitored completely by two transport experts from the STNM Institute, and by two representatives of the DOE ORNL, one being a non-proliferation specialist and the other a transport expert. Because various US agencies were interested in, and contractually supporting, this non-proliferation endeavour, the ORNL representatives provided additional observation of the repackaging and transport operations. They also generated additional summary inventory reports that were used by the follow-up Russian site and DOE teams in validating subsequent receipt of the material.

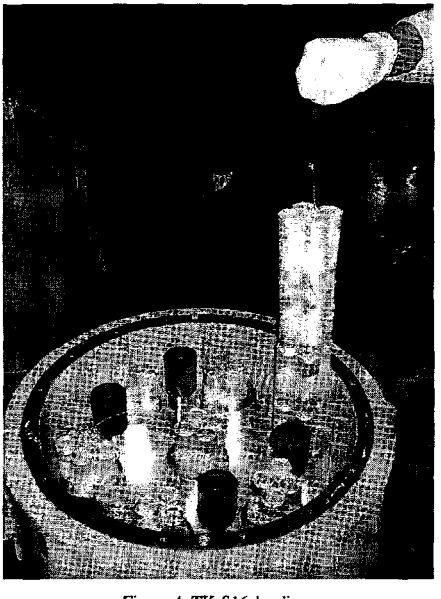

Figure 4. TK-S16 loading.

Yugoslav customs officers also inspected the activity in the RA reactor room and put their seals on the containers. The Minister of Science, Technologies and Development for the Republic of Serbia visited the repackaging area in the reactor room and the departure area at Belgrade airport during loading of the transport packages with the fresh nuclear fuel into the cargo aircraft, emphasising the importance of the whole event to the Government of the Republic of Serbia. A representative of the Federal Ministry of Economy and Internal Trade, responsible for nuclear safety and safeguarding nuclear material, also monitored the repackaging activities carried out at the Vinča Institute.

The TK-S15 and TK-S16 packages filled with HEU fuel slugs, including the three spare empty ones, were moved from the reactor room to the entrance by using the crane in the reactor room and the cart. The forklift truck picked up the packages there and loaded them into the transport truck. This activity took about 2.5 h, including measuring the transport index of the packages loaded on the vehicle.

The core of the transport programme team consisted of about 30 members of the operations staff of the RA and RB reactors, while the whole activity at the Vinča site engaged about 50 persons including two IAEA safety experts, two STNM Institute experts and two ORNL DOE monitoring experts. About 1200 policemen, including members of the Special Anti-terrorist Unit (SAJ), were also engaged during loading of the packages on to the vehicle at the Vinča Institute, transport of the fuel elements from the Vinča Institute to Belgrade airport and during loading of the aircraft at the airport.

The transport to Belgrade airport itself took place after midnight, when police forces closed traffic lanes in both directions along the whole route and blocked all intersections en route from the Vinča Institute to Belgrade airport. The transport convoy included two transport vehicles (one loaded with the nuclear fuel and the other, the so-called 'dummy'), various police escort units, radiation protection, medical protection and fire protection units and the vehicles carrying experts. The transport convoy (Figure 5), escorted also by a police helicopter, moved smoothly along the route from the Vinča Institute to Belgrade airport without any incidents in less than 50 mins. The transport activities, due to closed roads, helicopter escort and heavy police presence, attracted the attention and curiosity of Belgrade citizens and the media. The cargo aircraft was loaded in about 3 h including fixing packages in their locations in the aircraft, measuring the transport index in the aircraft, customs procedures and preparation of the final export documents. The aircraft departed from Belgrade airport the same morning, on August 22 at 08:05, escorted by two Yugoslav air-force fighters to Yugoslav border. The transport aircraft landed at Ul'yanovsk airport near Dimitrovgrad after about a 4 h flight. Russian experts who escorted the consignment immediately

reported the successful landing of the aircraft with the fuel cargo. This was transported by Russian trucks designed for special shipment of nuclear material, and escorted by proper security forces, to the Russian Institute of Atomic Reactors (RIAR), Dimitrovgrad, Russia. The material remained in the shipping packages and was stored in the RIAR central storage facility. This latter receipt check included verification and removal of all IAEA seals, counting and inspection of all fuel slugs, and random sampling of the slugs for measurement by weighing and gamma non-destructive examination.

On the same day as the transport of this material, at 12:15 in Belgrade, the Minister of Science, Technologies and Development of the Republic of Serbia and the Director General of the Vinča Institute held a press conference concerning these activities and the success of the whole operation.

CONCLUSION

In order to carry out the whole operation for the transport of fresh HEU fuel at the Vinča Institute, about 50 people were engaged, including the safety inspectors from the IAEA, STNM Institute experts and monitoring experts from ORNL, DOE. The executive team consisted of 30 experts from the operational staff members of the RA and RB research reactors. In order to provide adequate security measures during the transport operation, about 1200 policemen, including special task forces, helicopter and two military air-force fighters were engaged.

This operation was a very useful experience for various government and non-governmental institutions and management personnel in all the three countries involved, the first, planned and achieved, transport of fresh HEU fuel of Russian origin from one research reactor back to Russia for uranium reprocessing. This paper shows the experiences during organisation, planning and undertaking such a task. It is hoped that these shared experiences can provide a model for potential transfers from other similar reactor research facilities where such material is no longer needed. For the Yugoslav party, the successful conduct of the operation is considered as a test for performing the much more complex task that awaits it in the future — the transport of spent nuclear fuel from the RA research reactor back to Russia for reprocessing.

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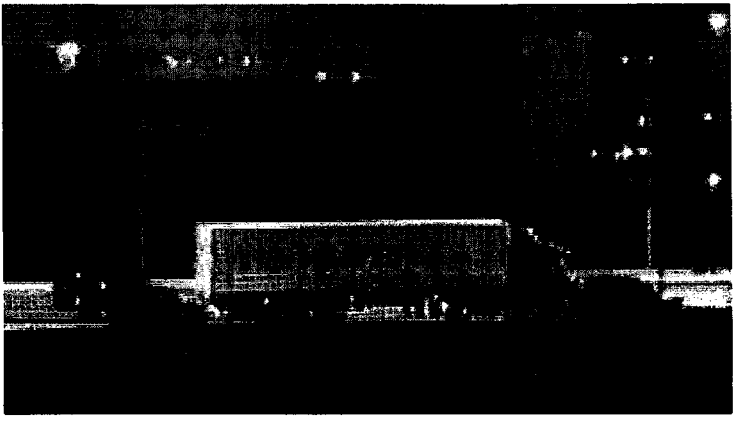

Figure 5. Transport convoy escorted by a special police unit.

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