SPENT FUEL REPATRIATION FROM THE REPUBLIC OF SERBIA

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Abstract

During the RA research reactor's nearly 25 years of operation, more than 2.5 tons of irradiated fuel elements were generated and temporarily stored in the spent fuel storage pond within the reactor building. Because the storage lacked adequate conditions for long-term storing, a number of fuel elements lost their tightness, which led to fission products release into water at the storage pools. Specific design of the fuel elements and the fact that a number of them were in poor condition, necessitated repackaging of these elements into new canisters, designed specifically for transportation in the TUK-19 and SKODA VPVR/M transport casks. At the beginning of 2002, the Government of the Republic of Serbia issued a directive to permanently shut down the RA research reactor at the "Vinča" Institute of Nuclear Sciences in Belgrade, and decided to repatriate all fresh high enriched uranium fuel elements and all spent low and high enriched uranium fuel elements used during entire exploitation of this reactor. After four years of negotiations and planning, in September 2006, a contract for the repatriation of the RA reactor's spent fuel was signed. The parties involved included consortium of Russian companies led by the R&D Sosny Company, the "Vinča" Institute of Nuclear Sciences and the Technical Cooperation Department of the International Atomic Energy Agency. Efficient planning and otganization, including extremely good cooperatioon with many international organizations and institutions, followed up with substantial financial help provided by several countries, enabled successful completion of this task. Nearly four years later, at the end of 2010, the spent fuel elements left Serbia, bound for the Russian Federation.

1. INTRODUCTION

1.1. Fuel repatriation background

Following the lead of an American nuclear fuel return programme, the Russian Federation, the United States and the International Atomic Energy Agency (IAEA) launched the so-called Russian Research Reactors Fuel Return Programme (RRRFR) in 1999. One year later, the Director General of the IAEA sent a letter to countries in possession of the Russian-origin research reactor fuel to examine interest in returning highly enriched uranium (HEU) fuel to the Russian Federation. Former Federal Republic of Yugoslavia (now the Republic of Serbia) expressed strong willingness in participating in this programme.

At the beginning of 2002, the Yugoslav government issued a directive to repatriate all fresh HEU fuel elements and also all spent low enriched uranium (LEU) and HEU fuel elements used during entire exploitation of the RA research reactor at the "Vinča" Institute of Nuclear Sciences (the Vinča Institute).

1.2. RA reactor facility

The RA reactor is a Russian-design, tank-type research reactor, using heavy water as a primary coolant and a moderator. It is located at the Public Company "Nuclear Facilities of Serbia", nearby the River Danube (nuclear facilities at the Vinča Institute were separated into new organization in 2009). Its nominal power was 6.5 MW. The reactor went critical in December 1959 and was temporarily shut down in August 1984 (*the RA reactor block is shown in FIG.1*). During this period of operation, reactor has been successfully used for scientific research, but also for commercial purposes. From its first commissioning in 1960 until 1975, the reactor was using Russian-origin low enriched uranium fuel (2% of ^{235}U). In

1976, the original fuel was gradually replaced by a highly enriched uranium fuel (80% of ^{235}U), developed and qualified in the former Soviet Union in the meantime.

After temporary shutdown in 1984, it was decided to make a series of reconstructions of facility's systems in order to enable safe and continuous operation of the reactor for the next 20 to 25 years. However, planned reconstructions had never been finished and reactor has never been put into operation again. In 2002, the Government of the Federal Republic of Yugoslavia made a decision to shut down the RA reactor permanently.

FIG. 1. RA reactor block.

1.3. Fuel type and inventory

During exploitation, only the so-called TVR-S fuel elements of the LEU and HEU type, manufactured in the former Soviet Union, were used in the RA research reactor (*see FIG.2*). Both types of fuel elements have the same geometry, but the mass of ^{235}U is slightly different (7.25 g in LEU and 7.7 g in HEU fuel element). TVR-S fuel element is an empty cylinder with the outer diameter of 37.2 mm having tubular fuel section 2 mm thick and 100 mm long. This section, coated with 1 mm aluminium cladding, is made of metal uranium in LEU and uranium dioxide mixed in aluminium matrix in HEU fuel element. Total length of the fuel element is 113 mm.

FIG. 2. TVR-S fuel elements.

There were 8030 TVR-S fuel elements of both types being irradiated until August 1984. All of them were stored in reactor building in four basins (filled with tap water) in spent fuel storage next to the reactor room (basins are interconnected by the channel, which ends up inside reactor block). Fuel elements were positioned in aluminium tubes inserted either in stainless steel containers, or in aluminium barrels. Majority consisted of LEU fuel elements (6656) placed in aluminium barrels and stainless steel containers, while HEU fuel elements (1374) have been put into stainless steel containers only.

The fresh fuel elements were transported to the Russian Federation in August 2002. Packed in special containers, 5046 HEU fuel elements were transported by truck from the Vinča Institute to the Belgrade Airport and then sent by commercial cargo aircraft to its final destination in the Russian Federation.

2. LEGAL FRAMEWORK

2.1. Agreements and contracts

The Agreement between the governments of the United States and the Russian Federation, which has been signed in May 2004 in Bratislava, provided legal authority for the realization of the RRRFR Programme. Four months later, the Ministry of Science and

Technology of the Republic of Serbia engaged the Vinča Institute to prepare input data relevant for the spent fuel shipment to the Russian Federation. In the meantime, close cooperation with the IAEA had been established.

Upon the invitation of the IAEA, in May 2005, an international consultancy meeting was held at the Vinča Institute with participation of several invited international enterprises. The main goal of the meeting was to draft the outlines of an international bid for the preparation and transportation technologies of the RA reactor's spent nuclear fuel. In September 2006, following an international tender, a tripartite contract for repatriating RA reactor's spent nuclear fuel was signed. The parties involved included consortium of the Russian companies ("Sosny", "Tenex" and "Mayak"), the Vinča Institute and the IAEA. Work obligations for the Russian companies and for the Vinča Institute were fully determined and distributed among participants. Spent fuel repackaging and loading technology, comprising design and manufacture of special equipment had to be developed and worked out by the Sosny Company, while required facility preparations including repackaging and loading activities had to be carried out by the Vinča Institute. Transportation of all the spent nuclear fuel from the reactor facility, as stated in the contract, had to be completed until the end of 2010 and in one shipment only.

2.2. Import of spent fuel to the Russian Federation

To import spent nuclear fuel into the Russian Federation, a series of extensive preparatory activities was required. Among those, two basic documents had to be elaborated and signed. The first one is the so-called "Government-to-Government Agreement" determining general conditions of the spent fuel import. Such an agreement between the governments of the Russian Federation and of the Republic of Serbia was signed in June 2009. According to this agreement, waste generated by the reprocessing of the RA reactor's spent fuel will be permanently stored in the Russian Federation. The second one, the so-called "Foreign Trade Contract", determines all mutual obligations referring to spent fuel transport including the scope of services to be provided by the Russian Federation. In September 2009, such a contract was signed between the Public Company "Nuclear Facilities of Serbia" (the Public Company) and the "Federal Centre of Nuclear and Radiation Safety" from the Russian Federation.

3. FEASIBILITY CONSIDERATIONS

3.1. Characterization of the fuel

Average burn-up of LEU fuel elements for all the time of reactor exploitation was approximately 6.9 MWd/kgU, while the maximum burn-up did not exceed 17 MWd/kgU. For HEU fuel elements, average burn-up was about 134 MWd/kgU and the maximum burn-up reached up to 400 MWd/kgU. Total activity of all spent fuel elements did not exceed 4000 TBq. At the beginning of 2002, maximum decay heat was approximately 150 mW for LEU fuel element and 90 mW for HEU fuel element.

Activity measurements of water samples taken from aluminium barrels and stainless steel containers in the early 2000s showed that several hundreds of fuel elements may have had breached cladding. On the other hand, formation of significant corrosion deposits on the cladding of numerous fuel elements, which occurred mainly during the last years of reactor operation, made it very difficult to take them out from aluminium tubes.

3.2. Fuel removal assessment

Taking into account the structure of fuel elements and the containers where they have been placed, it was clear that all fuel elements had to be repackaged into new containers that would be suitable for transportation. However, pulling out fuel elements from aluminium tubes would have been an impossible or very risky action that could damage their cladding being already weakened by corrosion processes. This demanded an appropriate repackaging technique be developed.

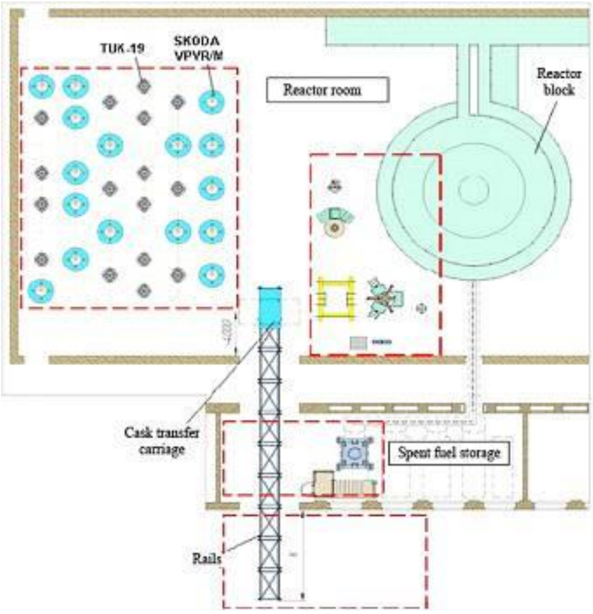

FIG. 3. Layout of the working area.

Performed calculations have pointed out that upon opening of aluminum barrels, some 10^{13} Bq of ^{137}Cs activity might be released into water at the spent fuel pond, and that the same amount may be released in one-year time afterwards. Therefore, an efficient system for absorbing radionuclide ^{137}Cs in the storage basins was mandatory if any fuel handling were to be carried out there.

Looking for the most suitable place where repackaging of TVR-S spent fuel elements into new containers and then loading them into transport casks could be performed, the ground floor area inside reactor building was chosen (*see FIG.3*). Although rather small, the spent fuel storage room, where all the spent fuel elements were stored, enabled mounting of the fuel repackaging and interim storage equipment, including baskets loading equipment, as well. On the other hand, reactor room with a large free space and direct connection with the spent fuel storage room, enabled storing of all transport casks and their preparation for transportation. Both rooms were equipped with cranes and special ventilation systems. However, a lot of adaptations and modifications, including purchase of transfer equipment, had yet to be realized.

3.3. Transport cask selection

While developing technical solutions for transporting spent nuclear fuel from the Vinča Institute to the Mayak Reprocessing Plant in the Russian Federation, the possibilities to use SKODA VPVR/M, TUK-128, TUK-19, NAC-LWT and Castor MTR-2 casks were considered. Taking into account technological and economic aspects, combined with a request to transport all TVR-S spent fuel elements at once, SKODA and TUK-19 casks had been chosen. Both types of casks were certified, acceptable for the Mayak Reprocessing Plant and available by the end of 2010.

In order to realize the one-time shipment of all RA reactor's spent fuel elements, 32 casks in total were needed.

4. PREPARATIONS

4.1. Engineering design

Once the transport casks have been chosen, major fuel handling procedures and equipment design, including facility modifications, were directed by the features of these casks. For positioning of the TVR-S fuel elements into transport casks, special canisters were designed, as well as the corresponding baskets (*see FIGs.4,5*). Numerous failed fuel elements and technical difficulties to separate them from the others, as well as long time of storing canisters with such elements in the storage pond (up to one year), demanded non-hermetic canister design. One canister for the TUK-19 cask could have been loaded with 132 TVR-S fuel elements and the one for the SKODA cask with 72 such elements. Capacity of the casks was: one canister in the TUK-19 and 6 canisters in the SKODA cask. Consequently 16 TUK-19 casks and 16 SKODA casks were needed to load all RA reactor's spent fuel.

FIG. 4. Canister for the TVR-S fuel elements.

Technical preparation of RA reactor's spent fuel for transportation was divided into several stages: repackaging of fuel elements into new canisters; loading of the canisters into baskets; loading of the baskets into transport casks and preparation of these casks for shipment. A great number of sophisticated tools, devices and auxiliary equipment had to be designed and constructed to enable these operations - especially the repackaging ones. Rather limited space in the spent fuel storage pond demanded compact and versatile equipment design, in order to execute underwater repackaging and loading operations (*see FIGs.6,7*). When dealing with long-length reactor channel tubes (app. 6 m long), the first cutting of the aluminium tube had to be performed in a small compartment inside reactor block. For temporary storing of the canisters, after being loaded with fuel elements, special underwater shelves were placed at the bottom of the storage basins (*see FIG.6*). The entire process of repackaging and loading operations was surveyed and controlled by an underwater video system.

FIG. 5. SKODA basket.

All the procedures for repackaging TVR-S fuel elements and loading canisters into transport casks were thoroughly evaluated primarily from the viewpoint of sub-criticality and radiation safety. Safety of loaded casks has also been analyzed for normal and accidental conditions. Obtained results have shown that chosen technology approach and designed equipment satisfied all the requirements of nuclear and radiation safety and were in compliance with relevant spent fuel transport regulations, too.

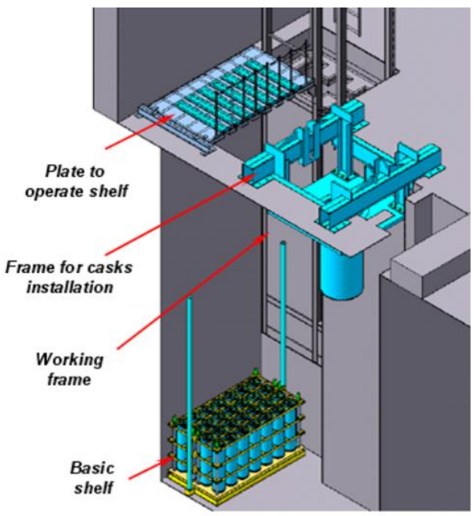

FIG. 6. Working platform with the basic shelf.

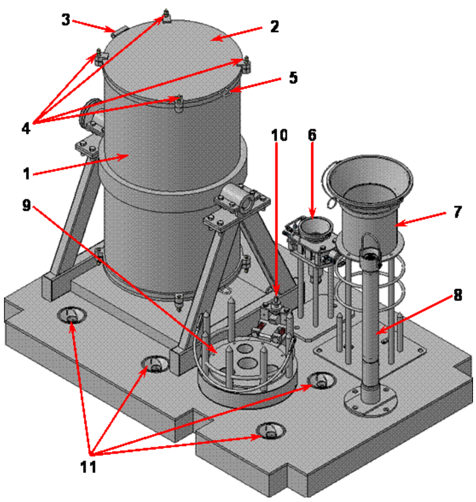

FIG. 7. Underwater section of the working platform.

4.2. Facility preparations

A lot of facility modifications and activities, including new equipment provision, were carried out to enable repackaging and loading activities in the reactor building. Among them, the substantial ones were:

— Underwater metal structures removal (from the spent fuel storage pond);
— Bridge crane replacement in spent fuel storage;
— Bridge crane upgrade in reactor room;
— Special ventilation system reconstruction (*see FIG.8*);
— Electric power supply system adjustment;
— Adaptation of the control room in spent fuel storage;
— Adaptation of access roads to the reactor building;
— Purchase of the 16-ton capacity forklift;
— Purchase of the casks rail-transfer system (*see FIG.9*);
— Purchase of the ^{137}Cs removal system (*see FIG.10*);
— Purchase of additional radiation monitoring systems.

FIG. 8. New ventilation pipeline.

FIG. 9. Cask rail-transfer system.

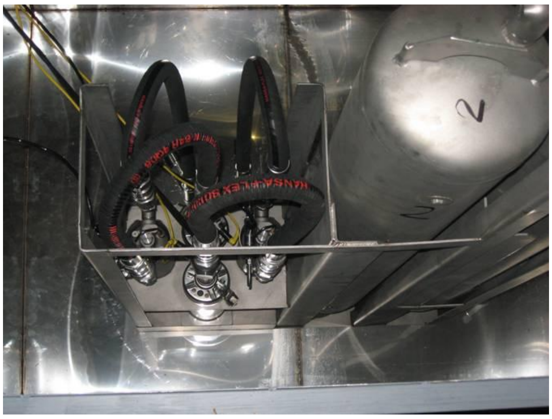

FIG. 10. Caesium removal system.

To assure safety in executing such a complex and delicate operations, a series of safety analysis reports on spent fuel repackaging and loading techniques had to be elaborated and approved. Written by the Sosny Company and the Vinča Institute, several international institutions had been engaged in reviewing these reports (Rostechnadzor, Slovenian Nuclear Safety Administration and Research Reactor Safety Section from the IAEA). Final approval was issued by the Serbian Regulatory Agency for Radiation and Nuclear Protection. Sosny Company also worked out sequential set of instructions to be used in spent fuel repackaging and loading operations. These instructions have been incorporated into all-inclusive operational procedures prepared by the Public Company and approved together with safety analysis reports.

Reactor staff received extensive training for handling tools and devices both for repackaging activities and for loading ones. Specialists from the Sosny Company have conducted training of reactor staff for repackaging activities, while specialists from the Mayak Reprocessing Plant and the Nuclear Research Institute in Řež (NRI Řež, Czech Republic) joined them in conducting training for loading activities. Special training was organized for persons from supporting organizations being engaged in the spent fuel transportation (several practical exercises have been performed, too).

Upon delivery to the reactor facility, special equipment, including all necessary devices and tools, was installed, tested and adjusted prior to executing repackaging and loading operations. Existing containers with spent fuel elements have been prepared for repackaging and relocated in the storage basins according to the pre-defined repackaging sequence.

Safeguards Division of the IAEA was informed from the very beginning about the spent fuel shipment, so they have been prepared to control the transfer of nuclear material in all phases of repackaging and loading operations.

5. FUEL HANDLING OPERATIONS

5.1. Fuel repackaging

FIG. 11. Working platform.

Dismantling of aluminium barrels was performed at the working platform installed in Basin 4 in the spent fuel storage pond (*see FIG.11*). Fuel elements were taken out from the barrel and positioned in the new canister. The whole operation had been carried out underwater, using long tools and an electric cutting device. Actions performed by operating personnel were monitored in the spent fuel storage control room (*see FIG.12*). When repackaging fuel elements from stainless steel tubes, alumunium tubes that were holding the elements, were cut in a small compartment in the reactor block, firstly. Fragment with fuel elements was brought to the working platform in the spent fuel storage, where further cutting of the fragment tube with manual cutting device enabled transferring fuel elements into new canisters.

Repackaging of RA reactor's spent fuel began on December 2nd 2009 when the first aluminium barrel was opened. Working in 3 shifts per day (total of 5 shifts were engaged), spent fuel elements from all 30 barrels were repackaged by the end of February 2010. Four weeks later, repackaging of spent fuel elements from the stainless steel tubes began. In the meantime, part of the repackaging equipment had been removed and additional loading equipment was installed, adjusted and tested. Fuel elements from the last of 297 steel tubes, were repacked on May 24th 2010.

When repackaging operation was finished, 110 canisters loaded with 8030 fuel elements were temporarily stored in underwater shelves mounted at the bottom of all four basins in the storage pond.

5.2. Fuel loading

Canisters with fuel elements were loaded into corresponding baskets placed on an underwater stand mounted in Basin 4 in the storage pond. Special tool was used to carry out this operation. Above the stand (out of water), a platform for SKODA casks was mounted, enabling direct insertion of baskets into them (*see FIG.13*). However, in TUK-19 casks, the basket can be inserted only from above. To avoid performing such an operation in the air, technology procedure carried out in Romania one year ago was applied. Special transfer cask was constructed enabling loading the basket into this cask from below while standing on the same platform equipped with an adaptation plate. Being loaded, transfer cask was brought into reactor room, placed upon the TUK-19 cask, its bottom part opened and the basket was moved down into the TUK-19 cask (*see FIG.14*).

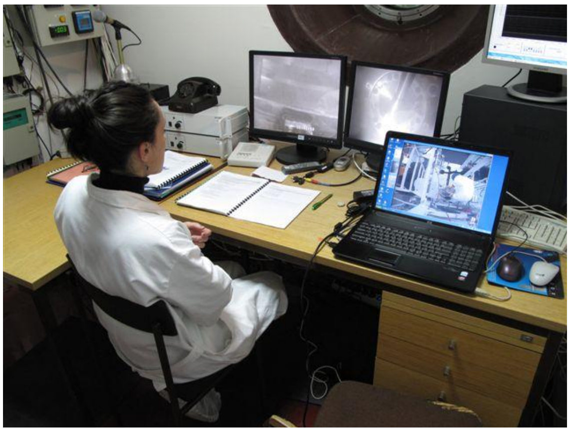

FIG. 12. Control room.

FIG. 13. Loading a basket into SKODA cask.

Small working area and low-capacity crane in the spent fuel storage room required specific way of transferring casks from reactor room to the platform for casks loading. Special mobile rail-transfer system was installed connecting the two rooms (reactor room and the spent fuel storage) with the outside area. This system was used to transfer casks from the outside area into reactor building and backwards (*see FIGs.3,9*). For transferring SKODA casks and transfer cask from rail-transfer vehicle to the platform for casks loading (and back) inside the spent fuel storage, a forklift of 16-ton capacity was used.

Due to casks availability and delivery schedule, loading them with canisters was carried out at three different times. In the second half of August, the first 12 SKODA casks were loaded with 72 canisters; and in the first half of November, the last 4 SKODA casks were loaded with 22 canisters. In the meantime, in the second half of October, all 16 TUK-19 casks were loaded with 16 canisters.

FIG. 14. Loading a basket into TUK-19 cask.

5.3. Casks preparation for shipment

When transporting spent nuclear fuel, transport casks have to be prepared according to standard procedures determined for each type of casks. Criteria for dryness, inside pressure and tightness had to be met for each cask before shipment. Special equipment, the so called SDGL equipment, designed and constructed at the NRI Řež was used for the SKODA casks and slightly modified version was used for the TUK-19 casks (*see FIG.15*).

Each transport cask, after being loaded with spent fuel, was drained at first and then blown out with hot air. After that a cyclic vacuum-drying of transport casks was applied until the inside pressure of 3 mbar was reached. Filling the gas (mixture of He and CO_2 was used) into transport casks was the next step in their preparation for shipment. Absolute pressure of 0.7 bar for SKODA casks and 1 bar for TUK-19 casks had to be reached. (The TUK-19 casks had been exposed to the vacuum for the first time and the results were quite satisfactory).

At the end, helium leak tests were performed and the IAEA seals have been put onto each cask.

FIG. 15. Drying and vacuuming of TUK-19 casks.

6. LICENSING AND AUTHORIZATIONS

Considerable effort was required to provide necessary permits and licenses for spent fuel shipment to the Russian Federation. To import spent nuclear fuel into the Russian Federation, a series of documents had to be worked out and then approved by competent Russian authorities. The initial document was certificate for the RA reactor's spent fuel package design for both TUK-19 and SKODA casks. This certificate, issued by Rosatom, enabled elaboration of the so-called Unified Project documents. This project is basically an overall assessment of the radiation, economic, social and environmental impact to the country, especially for the Chelyabinsk region (Mayak Reprocessing Plant is located there). When positive assessment issued by the State Ecological Expertise Committee has been submitted to Rosatom, import of spent nuclear fuel was granted and the "Foreign Trade Contract" was signed.

Authorities in the Republic of Serbia validated certificates for the spent fuel package design and then issued approvals and permits for radiation protection procedures, emergency preparedness plans, physical protection procedures and reactor facility operation programmes and procedures. After the Take-back Guarantee and Civil Liability Insurance documents have been provided, Serbian export license for spent nuclear fuel was issued by the Serbian Regulatory Agency for Radiation and Nuclear Protection.

To provide for transport license in transit countries (Hungary and Slovenia), Regulatory bodies in these countries had to validate spent fuel package design, firstly. After all aspects of spent fuel transit have been discussed and coordinated with Serbian institutions, authorities in these countries issued the so-called Trans-boundary Shipment Authorization and then provided transit approvals.

7. TRANSPORTATION LOGISTICS

7.1. Route determination

Finding the proper route for transporting spent nuclear fuel is not at all as simple as it may look like at first. A lot of aspects including political, economic and safety had to be taken into account. However, the final decision depends solely on the goodwill of the transit countries.

FIG. 16. Transportation route.

In our case, it was assumed that transportation of the RA reactor's spent nuclear fuel would be realized through Hungary and Ukraine. However, negotiations with Ukraine had failed (the same situation happened two years ago when Hungary tried to ship their spent fuel from the research reactor at KFKI, Budapest). So, instead of using the shortest route from Belgrade to Ozersk in the Chelyabinsk region, we had to transport the spent fuel all around the European continent (*see FIG.16*).

7.2. Transportation

FIG. 17. Loading SKODA casks into ISO-containers.

Each of three groups of casks, being loaded with canisters, were immediately transferred into ISO-containers placed on the plateau in front of the reactor building (*see FIG.17*). All ISO-containers were properly marked and sealed by the Public Company and the Serbian customs. On November 14th 2010, eight ISO-containers loaded with 16 SKODA casks, six ISO-containers loaded with 16 TUK-19 casks and one ISO-container loaded with casks handling equipment, were all ready for transport.

Loading of ISO-containers onto trucks was carried out on November 18th and the convoy consisting of 15 trucks loaded with 32 transport casks and auxiliary equipment left the Public Company the next day. Transportation route was determined almost one year ago, but the timetable was fixed only a few days before transportation. Near the Hungarian border, ISO-containers were reloaded onto railway flatbed cars and transported through Hungary and Slovenia to the Koper harbor. The train arrived to Koper on November 21st. Immediately upon arrival, ISO-containers were reloaded again - from the railway cars onto the ship (*see FIG.18*). A few hours later, the ship left Koper towards Murmansk. It took more than three weeks until the ship reached Murmansk, where ISO-containers were reloaded onto railway cars again and on December 22nd RA reactor's spent nuclear fuel arrived to Mayak.

FIG. 18. Loading ISO-containers on a ship in Koper harbor.

During loading of ISO-containers at the RA reactor facility and along the entire route to the Koper harbor, significant police forces were engaged to provide physical protection of the cargo. At the same time, continuous radiation control had been provided, too.

8. SUMMARY

As a first step in decommissioning the RA research reactor facility, repatriation of its spent nuclear fuel was a complex and challenging task. Unique fuel elements, bad storing conditions and poor fuel handling capabilities on one hand, combined with requirement to repackage all fuel elements on the other, demanded development of sophisticated operational methods and proper equipment design. Good planning and organization from the very beginning and extremely good cooperation with many international organizations and institutions, followed up with substantial financial help given by several countries, enabled successful completion of this task.

After repatriations of fresh and spent nuclear fuel, carried out in 2002 and 2010 respectively, the Republic of Serbia lined up alongside other countries in having no highly enriched uranium anymore.