Transactions

RRFM 2009

Vienna, Austria
22 -25 March 2009

IAEA
International Atomic Energy Agency

ATOMINSTITUT
TU WIEN

European Nuclear Society
Rue Belliard 65
1040 Brussels, Belgium
Phone + 32 2 505 30 54
Fax +32 2 502 39 02
E-mail ens@euronuclear.org
Internet www.euronuclear.org

ISBN 978-92-95064-07-2

These transactions contain all contributions submitted by 20 March 2009.

Session III

Back-end

LESSONS LEARNED FROM THE SPENT FUEL SHIPMENT BUDAPEST – MAYAK

JOHN DEWES
Washington Savannah River Company,
Aiken South Carolina, 29808 USA

SÁNDOR TŐZSÉR , ISTVÁN VIDOVSZKY
Hungarian Academy of Sciences KFKI Atomic Energy Research Institute
Konkoly Thege M út 29-33, Budapest 1121, Hungary

ABSTRACT

The largest shipment yet of Russian-origin spent nuclear fuel (about 130 kgs HEU and 100 kgs LEU) arrived to the Mayak facility on October 22, 2008. All 16 available Skoda VPVR/M type casks were used, in 8 20 feet ISO containers. The containers were transported on trucks, on rail and on sea. The nuclear fuel was used in the Budapest Research Reactor between 1959 and 2005. The preparations of the shipment started in 2004. Technical works progressed well all the time, the administrative part caused much more difficulties. The paper gives an overview of the activities and tries to find the points where more attention could be necessary. Future shipments can be prepared and performed easiear based on the lessons learned. The paper is illustrated by pictures, the authors have taken during the events.

Background

The Budapest Research Reactor, the first nuclear facility of Hungary was put into operation in March 1959, consequently it celebrates its fifty years anniversary these days. The power of the reactor was originally 2 MW, 10% enriched fuel (EK-10) was used in this period. The reactor was firts upgraded in 1966. As part of the upgrading the fuel was changed to the 36% enriched VVR-SM type. Spent fuel was stored in the site of the reactor using two facilities an AR and an AFR pool. Due to the excellent water chemistry no traces of corrosion could be seen on the surface of the spent fuel, however in the late nineties the semi-dry storage method was introduced (1) as reported on a previous RRFM meeting in 2002. The semi-dry storage was performed in Aluminum capsules in the same AFR facility were the simultaneous wet storge continued. The capsules did not fit into the selected transport container, so they had to be opened before the shipment.

Technical preparations onsite

After the selection of the transport cask (VPVR/M Skoda) it was obvious, that a transfer hall with a bridge crane of at least 14 ton lifting capacity is necesssary. The design and construction of this hall was the greatest part of the technical preparations. Two special problems had to be solved. The first problem was to manipulate the heavy transport casks without dangering the spent fuel in the pool. The second problem was to open the Aluminum capsules underwater to load the SNF assemblies into the transport casks. Both problems were solved by constructing special equipment.

Fig.1. The transfer hall (left in construction, right ready)

To avoid the lifting of heavy load above the storage pool a trolley was constracted. The trolley can safely move on rail above the pool. The bridge crane was used only to load and reload the trucks and to handle the transport casks. In the procedure of loading the transport casks, the casks were put by the crane to the trolley in a position near to the pool, then the trolley moved the cask to the loading position above the pool (see Fig.2).

Fig.2. View of the transfer hall from the crane

To open the Aluminum capsules of the semi-dry storage a cutting device was constructed, which can be moved by the bridge crane. Construction works stared in June 2007, the building and the equipment was ready by September 2007. The shipment started in September 2008.

Intergovernmental agreements, licences and permits

The first step was to establish intergovernmental agreements between the countries concerned. In the first approximation three intergovernmental agreements were necessary, one between the United States and Hungary, one between the Russian Federation and Hungary, both on the transport and one on the transit between three countries, Russian Federation, Ukraine and Hungary. The first two agreements are obviously necessary, however the third one depends on the route of transport. The shortest and simplest way between the site of the BRR and the Mayak facility in central Russia is crossing Ukraine, so it was a natural approach to plan the transport on this route. Making intergovernmental agreements is always a long process. The reason for the long time is mainly, that even the authorized persons can only sign such agreements, if they consult with all organizations of the country, which might be involved in the subject of the agreement. The procedure of agreeing in all three above cases took much longer time than expected. The schedule of the shipment was made based on the progress of the necessary technical preparations. As the global threat reduction program concerns a number of countries, the delay of a shipment could cause major difficulties in the entire program. It became clear early 2008, that the greatest difficulty is the delay in signing the intergovernmental agreements. The two transport agreements could be signed in the last minute, but the trilateral agreement should have taken longer time. To solve this problem the project management decided to choose a longer and more complicated way, involving Slovenia and the sea. As between Slovenia and Hungary no intergovernmental agreement is necessary this solved the problem and the shipment could be completed in time.

The second step was to get the necessary permits for the transportation of dangerous goods in Hungary, Slovenia and in the Russian Federation. This step took also rather long time, but we were prepared for that. The VPVR/M transport cask was already licensed for the Czech Republic and for the Russian Federation, so it seemed to be an easy task. It wasn't. The first difficulty was to get the proper documentation, the second was caused by the complicated nature of the Hungarian licensing. There was no Hungarian truck company licensed for this type of dangerous goods, so the vehicles and the drivers had to get their permits in the framework of our shipment. This took long time and caused some extra costs as well. The Czech company involved in the shipment needed a special permission to do this work in Hungary according to EU rules, but they needed some extra permit even to enter Budapest, due to the new rules of the capital. The necessary permits for the rail-transport were provided by the railway company. The licensing for Slovenia was only problematic because the decision, that the shipment will go through Slovenia was made rather late. Anyhow the three necessary permits (transit, environmental and health) were provided in time. The set of permits and licenses for the Russian Federation were provided via Russian companies. The professionalism of the companies (Sosny and FCNRS) helped to avoid the difficulties.

The shipment

Fig.3. ISO containers on trucks

The shipment included all the SNF from the Budapest Research Reactor, used before September 2005. The data characterizing the shipment are given in Table 1. Fig.3. shows the ISO containers on trucks leaving the site of the Budapest Research Reactor.

	LEU	HEU	Total
Number of assemblies	82	716	798
U mass[kg]	102.27	130.26	232.53
Pu mass [kg]	0.25	1.29	1.54
^{235}U mass [kg]	7.86	26.50	34.36
Heat [W]	28.28	657.91	686.19
Activity [TBq]	266	6390	6656
Total mass [kg]	288.44	1407.19	1695.63

Table 1. SNF data

The selection of the transport route was a complex problem as well. As the site of the Budapest Research Reactor is not connected to the railway network, the first part of the route was on road to a railway terminal. To make this part of the transport in one run was a big advantage from the point of view of the physical protection, however in this way eight vehicles were needed. The only Hungarian company licensed for such transports had only four vehicles, so we had to involve a Czech company, having the other four trucks. The second part of the route was on rail, this part did not cause any special difficulty.

Fig.4. Loading the ship with the ISO containers

The third part of the route was on sea. It was not an easy job to find the appropriate ship and company. Unfortunately one of the biggest storms of the last few decades coincided with the shipment, but without any consequences due to the properly selected ship and personnel. The fourth and last part of the route was again on rail and again without difficulties.

The entire shipment lasted for about 25 days, the preparations took more than four years, the number of companies and government offices involved is 24, the number of persons involved is more than 100 even if the persons of the physical protection are not counted. The project was a complicated and huge one, so the above measures can be accepted.

Lessons learned

If one analyzes what activities took four years, the picture is less attractive. The technical preparations were done rather quickly, the main part of these preparations was the construction of the transport hall, that took less than half a year. The longest part of the project was the administrative part. The preparations of the intergovernmental agreements were very time consuming as mentioned above. Some licenses and permits were given in a very long procedure, due to complicated regulation. The best example for this is the transport cask licensing in Hungary. The license is given by the regulator, i.e. the Hungarian Atomic Energy Authority, but before the application the client has to get the opinion of the Cask Committee. The Cask Committee is not a government office, and so no binding deadline is applied. Hungarian Law prescribes acceptable deadlines for government offices. The lesson learned from this is, that one has to plan enough time for the administrative works

Another lesson learned can be, that one has to be prepared for necessary changes in the project, therefore at least one back-up plan is necessary. (Ukraine replaced by Slovenia).

The last lesson learned could be that one has to be prepared for unsuspected events. E.g. a permit can be withdrawn in any moment.

Acknowledgement

The entire project was supported by US DOE, giving a decisive part of the finincing and of the organizing as well. Personally Dr. Igor Bolshinsky, project manager of the Repatriation Program of Russian Origin SNF contributed very much to the success of this project. Without Igor the shipment could not have been realized in 2008.

References

1 T. Hargitai, I. Vidovszky: New Storage Mode for Spent Fuel at the Budapest Research Reactor, **ENS RRFM 2002 Transactions**, 6th International Topical Meeting on Research Reactor Fuel Management, Ghent, Belgium, March 17-20, 2002, p109

FRESH AND SPENT NUCLEAR FUEL REPATRIATION FROM THE IRT-2000 RESEARCH REACTOR FACILITY, SOFIA, BULGARIA[1]

T. G. APOSTOLOV, I. S. DIMITROV
Bulgarian Academy of Sciences - Institute for Nuclear Research and Nuclear Energy
72 Tzarigradsko Chaussee, Blvd., 1784 Sofia – Bulgaria

K. J. ALLEN
Idaho National Laboratory
P.O. Box 1625, Idaho Falls, Idaho 83415-3740 – USA

ABSTRACT

The IRT-2000 research reactor, operated by the Bulgarian Institute for Nuclear Research and Nuclear Energy (INRNE), safely shipped all of their Russian-origin nuclear fuel from the Republic of Bulgaria to the Russian Federation beginning in 2003 and completing in 2008. These fresh and spent fuel shipments removed all highly enriched uranium (HEU) from Bulgaria. The fresh fuel was shipped by air in December 2003 using trucks and a commercial cargo aircraft. One combined spent fuel shipment of HEU and low enriched uranium (LEU) was completed in July 2008 using high capacity VPVR/M casks transported by truck, barge, and rail. The HEU shipments were assisted by the Russian Research Reactor Fuel Return Program (RRRFR) and the LEU spent fuel shipment was funded by Bulgaria. This report describes the work, approvals, organizations, equipment, and agreements required to complete these shipments and concludes with several major lessons learned.

1. Introduction

1.1 Reactor Description

The IRT–2000 research reactor is situated in the Nuclear Scientific Experimental and Education Centre (NSEEC), which is part of the Institute for Nuclear Research and Nuclear Energy's (INRNE), Bulgarian Academy of Sciences, located on the east side of Sofia, Republic of Bulgaria. IRT-2000 was constructed in 1959 by the Kurchatov Institute of Moscow, Russia and is operated by INRNE. The reactor went critical in 1961 with a nominal power of 1.0 MW, increased power to 1.5 MW in 1965, and increased again in 1970 to 2.0 MW. The reactor was temporarily shut down in 1989 and is now being reconstructed into a 200 kW reactor to meet increased safety requirements.

Figure 1: Cask Loading

IRT-2000 is a pool type, light water cooled and moderated reactor that operated with Russian-origin type EK-10 (10% enrichment) and type C-36 (36% enrichment) fuel assemblies, all of which were shipped to the Russian Federation (RF) in July 2008 as spent nuclear fuel (SNF). Twenty eight (28) type IRT-2M fuel assemblies (36% enrichment) were returned to Russia in December 2003 as fresh (unirradiated) fuel. The spent fuel storage pool, which connects to both the reactor pool and the hot cell laboratories, contained seventy three (73) SNF assemblies until shipped in 2008.

---

[1] Work supported by the U.S. Department of Energy Office of National Nuclear Security Administration under DOE Idaho Operations Office Contract DE-AC07-05ID14517.

1.2 Fuel Shipment Background

In September 2000, Mr. Mohamed ElBaradei, Director General of the International Atomic Energy Agency (IAEA), invited the governments of 16 countries to participate in a new program to transfer Russian/Soviet-origin highly enriched uranium (HEU) research reactor fuel to the Russian Federation to reduce potential proliferation risks associated with HEU in research reactors. The United States (US) Department of Energy (DOE) agreed to fund this program and Russia agreed to accept and process HEU nuclear fuel from these countries into low enriched uranium (LEU). Bulgaria agreed to participate in this program and, as the result of one fresh fuel shipment and one spent fuel shipment, all HEU has been removed from Bulgaria. The Russian Research Reactor Fuel Return Program (RRRFR) was created by the DOE National Nuclear Security Administration (NNSA) to assist participating countries with this transfer of HEU. RRRFR is one of multiple nuclear nonproliferation programs administered by the NNSA Global Threat Reduction Initiative (GTRI) and works in close cooperation with the IAEA and the RF Rosatom State Corporation.

1.3 Fuel Quantities Shipped

INRNE successfully and safely shipped the following nuclear fuel to Russia:

Fresh Fuel – December 23, 2003
- HEU: 16.91 kg, 28 type IRT-2M fuel assemblies (36% enrichment)

Spent Fuel – July 5-17, 2008
- HEU: 6.44 kg, 16 type C-36 fuel assemblies (36% enrichment)
- LEU: 72.48 kg, 58 type EK-10 fuel assemblies (10% enrichment)

Total HEU: 23.35 kg

2. Fresh Fuel Shipment

Per contract between INRNE and IAEA, and with cooperation of the US and Russia, Bulgaria shipped 16.91 kg of HEU fresh fuel by air to Russia on 23 December 2003. Twenty eight (28) unirradiated IRT-2M fuel assemblies were loaded into Russian transportation casks, sealed by IAEA inspectors, transported by truck to the Gorna Oryahovitsa airport, then air shipped in a Russian commercial aircraft to Dimitrovgrad, Russia, where the HEU was down-blended into LEU. This shipment took about 4 months to plan and execute.

Figure 2: Loading IRT-2M HEU into Casks

3. Spent Fuel Removal

Spent fuel shipment planning began in October 2004 and the shipment was completed in July 2008, requiring about 45 months of activities. This length of time was required by local and international requirements to conduct the shipment safely and securely and by the availability of the casks selected for the spent fuel shipment. The activities can be summarized into the headings categories that are discussed below.

3.1 Shipment Planning and Management

When shipment planning began, the Bulgaria project lifecycle was defined to include all activities expected to complete the shipment. However, at that time no RRRFR shipments of spent fuel had been completed and Russia was developing new procedures to import spent fuel, so some activities were defined as work progressed. As other RRRFR spent fuel shipments were planned or completed, the Bulgarian tasks were refined to use lessons learned from those shipments. The final project ended up with 17 major tasks and 37 subtasks. The tasks fit into general categories of planning and management, facility modifications, spent fuel inspections, shipping licenses, cask loading, and transportation. Each task and subtask required deliverable documents to prove completion of the required activities. Table 1 shows the times required for each task activity, including task approval, performance, and acceptance of the final deliverables.

General Task Activity	2004	2005	2006	2007	2008
Planning & Management	▨	▨	▨	▨	▨
Facility Modifications			▨	▨	▨
Spent Fuel Inspections		▨	▨	▨	▨
Shipping Licenses				▨	▨
Cask Loading					▨
Transportation				▨	▨

Table 1: General Task Activity Schedule

INRNE provided a Project Manager to plan and manage all activities. A large number INRNE operators, technicians, and administrative personnel were required to support the multitude of complex arrangements and activities. Both Bulgarian and international contracts were required to complete some tasks.

3.2 Cask Selection and Loading

Several potential shipping casks were considered and the Škoda VPVR/M high capacity cask was selected for Bulgaria. This top and bottom loading cask allowed fuel assemblies to be loaded into the cask basket at the bottom of the reactor pool, minimizing radiation exposure during loading, and allowed the baskets to be remotely unloaded from the top when received at the Production Association Mayak facility using their standard equipment. Three (3) VPVR/M casks were used: one (1) cask contained 15 HEU assemblies and two (2) casks contained a total of 58 LEU assemblies. Six (6) LEU fuel pins were loaded into an approved by Mayak canister, welded closed, and inserted into the basket as though it were a normal fuel assembly.

Figure 3: Loading Cask into ISO Container

Prior to cask loading, the Nuclear Research Institute (NRI), Rez, Czech Republic, and representatives of Škoda provided cask handling training to INRNE and cask loading began one week after this training was completed. All cask loading was witnessed by IAEA and Euratom safeguards inspectors who applied tamper indicating seals on each cask. The loaded and sealed casks were stored inside the secure reactor hall until all final transportation approvals were obtained.

3.3 Facility Modifications

Facility modifications were performed to allow use of the VPVR/M casks in the IRT-2000 reactor hall. Structural analyses of the reactor shielding and reactor hall floor were performed and core samples of the reactor access pavement were analyzed to assure the loaded casks and transport trucks would not cause structural problems. The facility modifications included:

- Replacement of the reactor hall crane with a new 12.5-ton capacity bridge crane;
- Fabrication of a VPVR/M support platform above the reactor pool;
- Fabrication of weight distribution frames to support the cask and truck weights in the reactor hall and avoid structural modifications to the building:
- Replacement of the reactor building access pavement;

- Installation of an underwater camera and lights;
- Upgrade of the reactor hall electrical power supply; and
- Modification of the ventilation air-ducts above the reactor pool.

3.4 Spent Fuel Assembly Inspections

Accurate spent fuel assembly data was required to obtain shipping licenses from Bulgaria, Russia, and the transit countries of Romania and Ukraine. The fresh fuel supply data, irradiation data, and physical conditions were determined and recorded on a passport for each assembly. To assure compliance with Russian requirements, the spent fuel inspection and irradiation calculation procedures were reviewed and accepted by Mayak. No failed fuel was found. The final spent fuel data was reviewed by Mayak and accepted for delivery prior to shipment.

3.5 Cask and Shipping Licenses

Approved cask and shipping licenses were required from Russia, Ukraine, Romania, and Bulgaria, in sequential order from destination to origination. The VPVR/M cask had been previously licensed in Russia for the Czech Republic RRRFR spent fuel shipment and the license was still valid for the Bulgaria shipment. The Competent Authority in each country reviewed the Russian cask certificate, accepted it in accordance with their rules, and issued a cask license for Bulgaria. Russia issued a combined cask and shipping license.

Figure 4: Casks on Barge

The Russian shipping license required the completion of technical activities, an environmental assessment, public education, and expert reviews, collectively called the Unified Project task, and required a long time to complete. The Romania and Ukraine license approvals were assisted by the Kozloduy Nuclear Power Plant (NPP), which periodically ships its commercial spent fuel through these countries to Russia. The Kozloduy NPP prior experience expedited procedural, transportation, and security arrangements for license approvals from Bulgaria, Romania, and Ukraine.

3.6 Legal Framework

The legal basis for the RRRFR program is a government-to-government agreement between Russia and the United States, signed in May 2004, allowing the US to assist third countries with the repatriation of Russian-origin HEU research reactor fuel. Bulgaria signed agreements with the US to assist with the transport and with Russia to import the spent fuel. No new agreement was required to transit Romania. Ukraine transit complied with an existing agreement between Bulgaria, Ukraine, and the Russian Federation used for Kozloduy NPP shipments but a transport conditions document specific for the IRT-2000 research reactor spent fuel was provided and approved.

3.7 Shipment Logistics

The Bulgarian SNF was transported by truck, barge, and rail. After all shipment authorizations were obtained, the VPVR/M casks were loaded into ISO containers and placed on nuclear shipment licensed trucks. On 5 July 2008, the truck convoy left IRT-2000 and travelled by public roads to the Kozloduy NPP, located on the Danube River, where the casks were transferred into a licensed barge owned by the Kozloduy NPP. After clearing a Romanian final check and Bulgarian Customs, the barge departed down the Danube River.

The shipment cleared Romanian Customs a few days later at Calarasi and finished the river transport at Izmail, Ukraine. After clearing Ukrainian Customs, the ISO containers were transferred from the barge onto Russian railcars and transported to the Ukraine-Russian border. At the border, title to the SNF was transferred from INRNE to Mayak. The shipment continued by rail to Mayak where it was received and accepted on 17 July 2008. Armed security personnel accompanied the shipment from the time it left IRT-2000 until it was accepted at Mayak and no security or other incidents were encountered. To meet a constrained schedule for the Hungarian RRRFR SNF shipment, the emptied casks were shipped by air in a commercial Russian cargo aircraft from Chelyabinsk, Russia, to Budapest, Hungary.

4. Conclusion and Lessons Learned

With RRRFR assistance, Bulgaria planned and safely shipped fresh and spent HEU and LEU fuel from the IRT-2000 research reactor to Russia in 2003 and 2008. These fresh and spent fuel shipments removed all HEU from the Republic of Bulgaria, a significant global nuclear non-proliferation accomplishment. Key lessons learned are:

Figure 5: Transferring SNF Title at Russian Border

- Use a carrier with experience shipping nuclear materials to Russia to expedite the process and avoid problems;
- Sign carrier and security contracts in advance to minimize last-minute delays;
- Draft and review shipping papers in advance with the help of experienced carriers (Kozloduy NPP) and Mayak to avoid last-minute delays;
- Have all permits and licenses in place as far in advance as possible;
- Procure nuclear liability, cargo, and personnel insurance in advance of the shipment;
- Provide a senior technical person to accompany the shipment with the authority to resolve issues enroute;
- Pre-arrange a method for 24-hour monitoring and reporting during shipment to provide “Need-to-Know” information to obtain immediate technical support, if needed;
- Develop a coded location tracking system in advance to send shipment monitoring reports to DOE without compromising security;
- Provide the senior technical person accompanying the shipment with communications equipment, a laptop computer and a printer;
- Establish good cooperation with the nuclear regulator and safety authorities early in the project to help with planning and implementation;
- Establish good cooperation with other important partners, such as the carrier, security forces, and emergency response organizations, to help plan and provide support during the shipment; and
- Assure that main points of contact personnel in all involved organizations have a sufficient security level for the shipment details.

TRIGA LEU AND HEU FUEL SHIELDING ANALYSIS DURING SPENT FUEL TRANSPORT

C.A. MARGEANU, S. MARGEANU, C. IORGULIS
Institute for Nuclear Research Pitesti
No. 1 Campului Street, 115400 Mioveni, Arges County, Romania

ABSTRACT

The paper goal is a comparative study on the effects of TRIGA LEU and HEU fuel for the shielding analysis during spent fuel transport. All geometrical and material data for the shipping cask were considered according to NAC-LWT Cask approved model. The shielding analysis estimates the radiation doses to the shipping cask wall, and in air at 1 m and 2 m, respectively, from the cask, by means of 3D Monte Carlo MORSE-SGC code. Before loading into the shipping cask, TRIGA spent fuel source terms and spent fuel parameters have been obtained by means of ORIGEN-S code. Both codes are included in ORNL's SCALE 5 programs package. ^{60}Co radioactivity is important for HEU spent fuel; actinides contribution to total fuel radioactivity is low. For LEU spent fuel ^{60}Co radioactivity is insignificant; actinides contribution to total fuel radioactivity is high. Comparison of TRIGA fuels gamma source terms shows that the LEU source terms are higher then the HEU ones. LEU spent fuel photon dose rates are greater than the HEU ones. Dose rates for both HEU and LEU fuel contents are below regulatory limits.

1. Introduction

The TRIGA dual–core research reactor located in Pitesti, Romania, was provided by General Atomic Company and is operated by the Institute for Nuclear Research (INR). The dual-core concept involves the operation of a 14 MW TRIGA Steady State research and materials testing reactor at one end of a large pool, and the independent operation of an annular-core pulsing reactor (TRIGA-ACPR) at the other end of the pool [1].

The TRIGA-SSR is equipped with two beam tubes, one radial and one tangential, and an underwater thermal column used for research purposes. Radioisotopes are also produced both for medical and industrial applications. TRIGA reactor operation was mostly oriented towards long-term irradiation and testing of fuel components followed by post-irradiation.

The 14 MW TRIGA steady state reactor (SSR) located in Pitesti, Romania, first went critical in 1979. Until 1992 the core configuration for full power operation used HEU fuel (93 wt% ^{235}U), with 29 fuel clusters. Back in 1978 US and, later on, IAEA recommended an international program related to the decrease of uranium enrichment in research reactors by converting the nuclear fuel containing highly enriched uranium (HEU) into fuel with low uranium enrichment (LEU). Between 1992 and 2006, the core configuration contained both HEU and LEU (20 wt% ^{235}U) fuel, up to a core configuration with 35 fuel clusters. In May 2006, a new core configuration, fully converted, containing only LEU fuel, 29 fuel clusters, was established. The HEU fuel repatriation effectively started in 1999, the final stage being achieved in summer of 2008. The 14 MW TRIGA SSR is now available for research and irradiation products and services activities.

For spent fuel transport was used a shipping cask approved model. The NAC-LWT spent fuel shipping cask has been developed by NAC International Inc. as a safe means of transporting pressurized water reactor fuel, boiling water reactor fuel, material test reactor fuel elements, and metallic fuel [2]. The cask assembly is composed of a package providing a containment barrier, to prevent radioactive material release. The shield materials are selected and arranged to minimize cask weight while maintaining overall shield effectiveness. Lead and steel are chosen as effective gamma radiation shields, and a water tank on outside of the cask is provided to efficiently moderate and absorb neutron radiation.

2. Theoretical model set-up

The TRIGA fuel clusters consists of 25 fuel rods each, with 1.29 cm active diameter and 55.88 cm active height, arranged in a square 5 x 5 array (see Fig 1). The cylindrical Uranium-Zirconium hydride-Erbium fuel/moderator pellets are tightly enclosed within Incoloy 800 tubes having a 0.041 cm wall thickness. The control rods are square annular assemblies containing sintered B_4C compacts and an aluminum follower rod. Unclad Beryllium reflector blocks, some containing a central irradiation hole (experimental), make up the radial reflector [1].

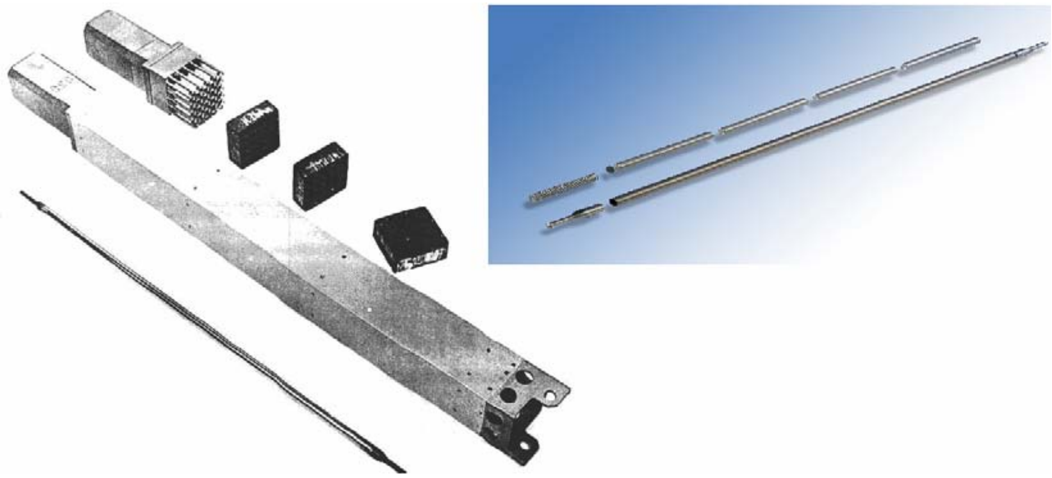

Fig 1. TRIGA fuel cluster and rod [1]

The source of radiation: TRIGA HEU and LEU spent fuel cluster, discharged from the reactor core after 5 years of burnup (970 kW specific power) and cooled down up to 2 years before loading into the shipping cask, was considered for source term calculations and spent fuel characterization. The two SSR TRIGA fuels pin loadings, before alloy formation and subsequent hydration, are presented in Tab 1.

Element/Isotope	HEU cluster [wt%]	LEU cluster [wt%]
U total	10.0	45.0
^{234}U	1.00	0.15
^{235}U	93.09	19.79
^{236}U	0.43	0.25
^{238}U	5.48	79.81
Er total	2.8	1.1
^{162}Er	0.14	0.14
^{164}Er	1.58	1.58
^{166}Er	33.33	33.33
^{167}Er	22.90	22.90
^{168}Er	26.91	26.91
^{170}Er	15.14	15.14
Zr	87.2	53.9

Tab 1: SSR TRIGA fuel pin loadings [1]

A period of 1825 days residence time inside the reactor core was considered. After the discharge from the reactor, before loading into the shipping cask, the spent fuel have been stored up to 2 years in aluminium racks inside the reactor pool. For the shielding analysis, a shipping cask loading of 6 TRIGA spent fuel clusters (150 fuel rods) was considered.

The shipping cask: The NAC-LWT cask is evaluated for transport of up to 140 TRIGA fuel elements or up to 560 TRIGA fuel cluster rods arranged in 5 SS304 basket modules in vertical superposed position (one base and one top module, 3 intermediate interchangeable modules) with 2 possible configurations (poisoned and non-poisoned, where the poisoned basket configuration utilizes borated steel plates for additional criticality control) [2]. The NAC-LWT cask utilizes a concentric cylindrical arrangement of steel, lead, steel and water to provide gamma shielding for the design basis fuel. The cask body is fabricated from stainless steel, SS 304 and SS XM-19 types, with about 500 cm overall length and 112 cm maximum outside diameter. The water-glycol solution in the neutron shield tank, surrounding the SS outer shell, also provides neutron shielding and is designed to axially blanket the active fuel length of the more common LWR fuels. The water contains 1 wt% Boron, which absorbs neutrons without producing significant secondary gamma radiation. The inner shell, end forgings, and the closure lid establish a cask cavity of about 450 cm long and 35 cm in diameter [2]. Fig 2 presents the radial model geometry used for the shipping cask and spent fuel shipping cask assembly.

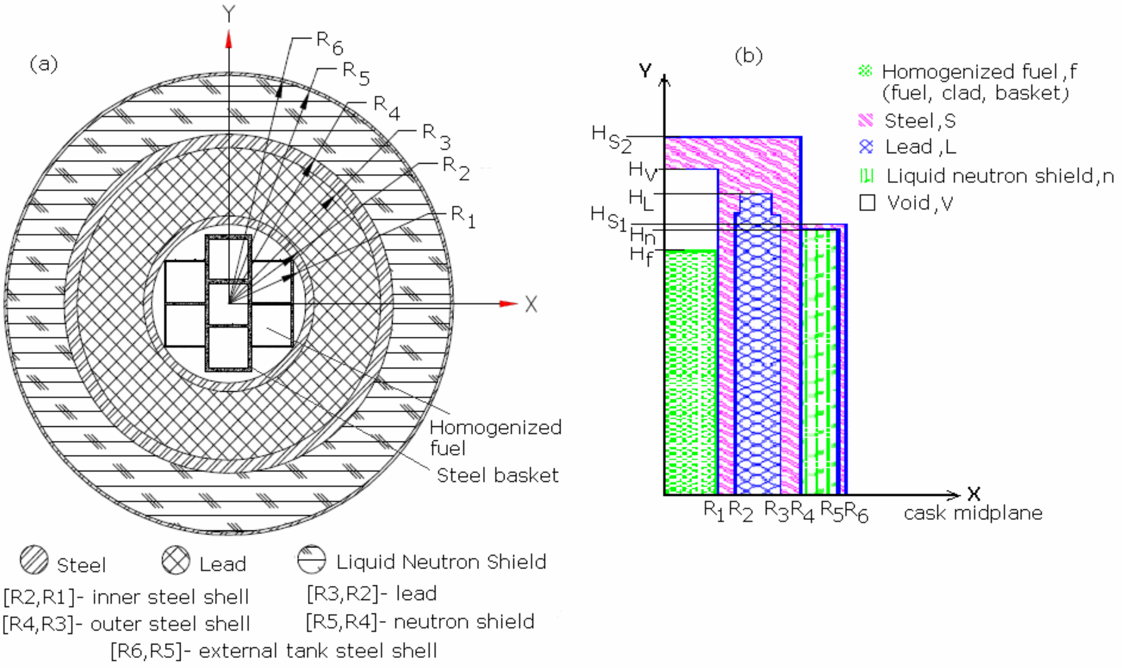

Fig 2. 2D geometrical model for: a) shipping cask; b) spent fuel – shipping cask assembly

The shielding calculations: Source term assessment and spent fuel characteristic parameters estimation were done by means of ORIGEN-S code. ORIGEN-S code solves a set of coupled differential equations which describe the generation and transformation of all radioisotopes and provide the spent fuel final isotopic characterization.

The photon dose rates calculations have been performed by means of Monte Carlo MORSE-SGC code. The code treats the particle transport by means of Boltzmann transport equation from which a complete set of forward and adjoint integral transport equations in energy-group notation were derived and related to used Monte Carlo procedures. Both codes are included in ORNL's SCALE 5 programs package [3]. The (27n-18g) coupled nuclear data library (27 neutron and 18 gamma energy groups) was used. As regarding the Monte Carlo simulation, 1000 bunches of 2000 particles each, have been generated.

3. Shielding analysis results

Radionuclide inventory and irradiated fuel characteristics have been obtained by taking into account for all relevant isotopes generation and depletion during both the irradiation and cooling phases of the fuel history. Fig 3 presents some long lived nuclides radioactivity evolution during the wet storage cooling period, characterizing HEU and LEU fuels.

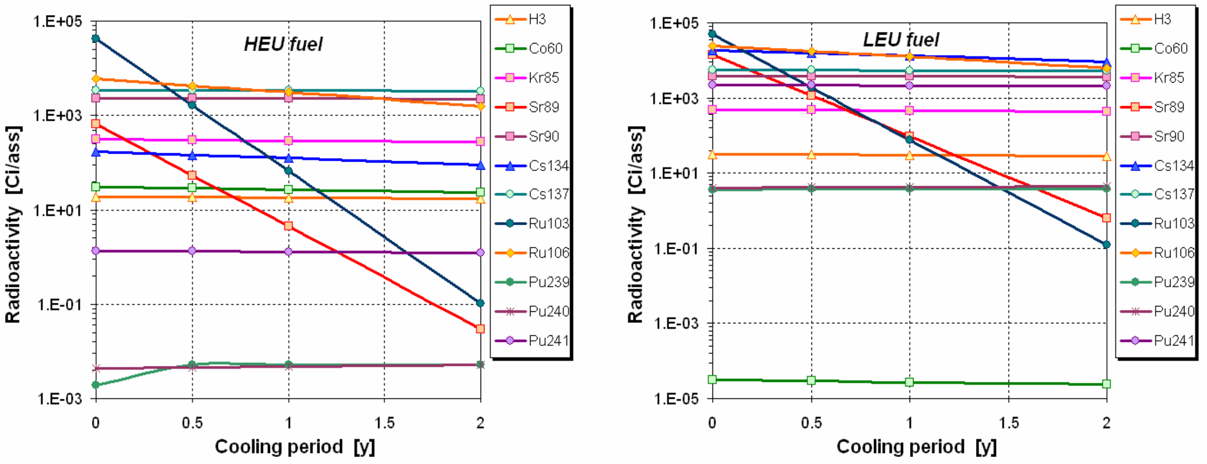

Fig 3. Long lived nuclides radioactivity evolution during the cooling period

Spent fuel was characterized by radioactivity, thermal power and gamma energy values in cladding, actinides and fission products. In Fig 4 a), b) and c), the above mentioned parameters evolution during the cooling period, both for HEU and LEU fuels, is presented.

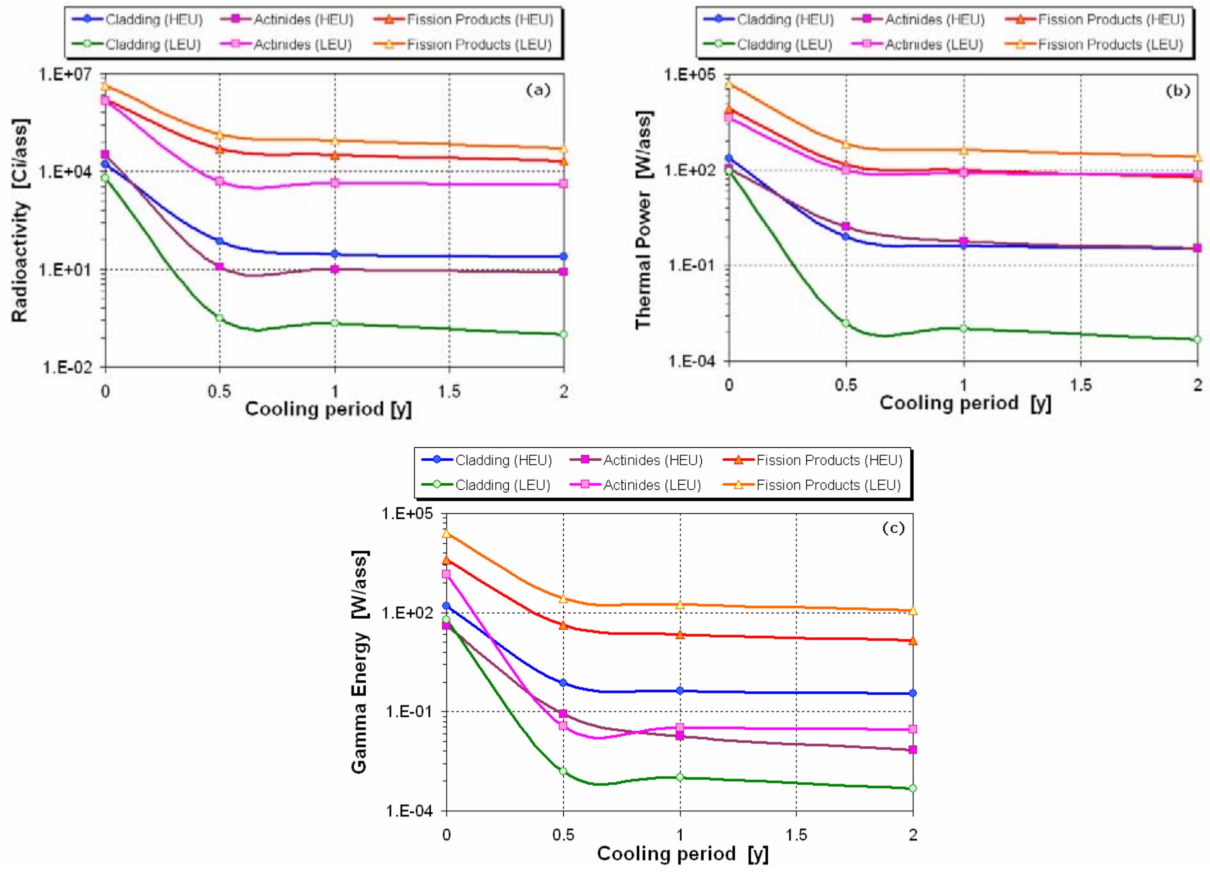

Fig 4. Spent fuel parameters evolution during the cooling period

By using the Monte Carlo MORSE-SGC code, the radiation dose rates for spent fuel clusters have been estimated. Only the fuel cluster rods shipment was analyzed here; no other activated components of the TRIGA cluster assembly are considered for shipment in this analysis. Dose points for normal operation conditions are placed at the fuel midplane on the neutron shield jacket surface and at 1 m and 2 m, respectively, from the cask surface, according to spent fuel transport regulations [4-6]. Fig 5 shows photon dose rates evolution in the considered measuring points for spent TRIGA HEU and LEU loadings with different cooling times (180 days, 360 days and 730 days, respectively).

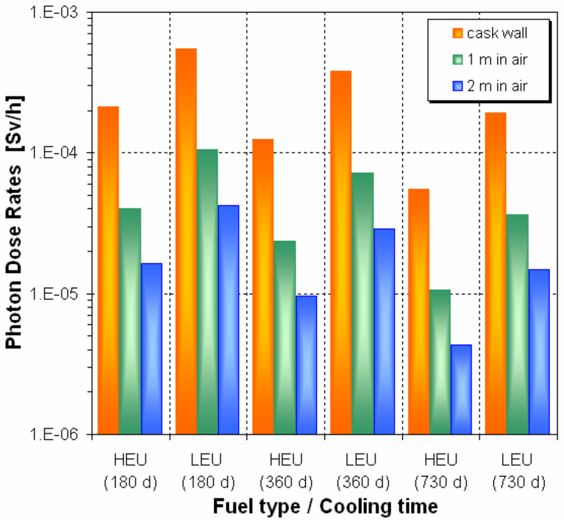

Fig 5. Photon Dose Rates [Sv/h] evolution in the considered measuring points

4. Conclusions

For a defined residence period inside the TRIGA SSR reactor core, at a 970 KW specific power, LEU fuel (20% wt ^{235}U) produces a larger and more radioactive amount of spent fuel than the HEU fuel (93 wt% ^{235}U). LEU-HEU comparison leads to the following relative differences in spent fuel characteristic parameters: 43% in actinides and 33% in fission products mass, 70% in radioactivity, 82% in thermal power and 86% in gamma energy.

^{60}Co radioactivity is important in HEU spent fuel; actinides contribution to the total fuel radioactivity is low (from 2% at discharge moment to 0.04% after 2 years of cooling), fission products contribution keeping a slowly increasing trend, from about 97% at discharge moment to 99.8% after considered cooling.

For LEU spent fuel ^{60}Co radioactivity is insignificant; actinides contribution to the total fuel radioactivity is high (25% at discharge moment, decrease to 4% after 180 days of cooling and reaches 7% after 2 years of cooling, following a slowly increasing trend), fission products contribution being about 75% at discharge moment, increase to 96% after 180 days of cooling and reaches 93% after 2 years of cooling, on a slowly decreasing trend.

The photon dose rates for both HEU and LEU spent fuel contents are below regulatory limits [4-6]. LEU spent fuel dose rates are greater than the HEU fuel ones, the relative differences being, as follow: 62% after 180 days of cooling, 67% after 1 year of cooling and 71% after 2 years of cooling, respectively.

5. References

[1] “Design and safety evaluation of INR 14-MW TRIGA Research Reactor”, Gulf General Atomic Report, 1974

[2] NAC-LWT Cask Safety Analysis Report, Rev. 27, June, 1999, Docket No. 9225, T-8804

[3] “SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations”, ORNL/TM-2005/39, Version 5, Vols. I–III, April 2005. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-725

[4] “Containment Analysis for type B Packages used for Transport various Contents”, NUREG/CR-6487, 1996

[5] Regulations for the Safe Transport of Radioactive Material - 1996 Edition (Revised) // TS-R-1 (SF-1, Revised) / IAEA Safety Standard Series, 2000

[6] Fundamental Regulations for the Safe Transport of Radioactive Material // NTR-01 / National Commission for Nuclear Activities Control – CNCAN, 2001 - Order no 373

European Nuclear Society

Rue Belliard 65
1040 Brussels
Belgium
Telephone +32 2 505 30 54
Fax + 32 2 502 39 02

rrfm2009@euronuclear.org

www.euronuclear.org

IAEA
International Atomic Energy Agency

ATOMINSTITUT
TU
WIEN