Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Disclaimer:

This work was prepared under an agreement with and funded by the U.S. Government. Neither the U. S. Government or its employees, nor any of its contractors, subcontractors or their employees, makes any express or implied:

1) warranty or assumes any legal liability for the accuracy, completeness, or for the use or results of such use of any information, product, or process disclosed; or
2) representation that such use or results of such use would not infringe privately owned rights; or
3) endorsement or recommendation of any specifically identified commercial product, process, or service.

Any views and opinions of authors expressed in this work do not necessarily state or reflect those of the United States Government, or its contractors, or subcontractors.

OPTIMIZING APPROACHES TO SPENT NUCLEAR FUEL TRANSPORT

J.N. DEWES
Savannah River National Laboratory
Aiken South Carolina 29808 - USA

I. BOLSHINSKY
Idaho National Laboratory
Idaho Falls, Idaho - USA

S. M. TOZSER
International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna - Austria

ABSTRACT

The security risk associated with transport of HEU spent nuclear fuel is, among other factors, proportional to the duration of the transport process. Many other factors such as distance, access to airports, railheads, and docks also impact options available for transport. Economic also play al large role in the selection of transport mode. For the past ten years the approach for spent nuclear fuel transport in Europe and Asia has been modified based upon changes in technology and careful exploration of options. This paper will summarize the historical evolution of transport mechanisms utilized for the Russian Research Reactor Fuel Return Program. It will also explore the factors utilized in determining the appropriate approach to fuel transport for particular situations and provide a basis for comparison in support of future transport projects.

I. Introduction

The Atoms for Peace program was initiated in 1953 by then U.S. President Eisenhower as a means of developing peaceful uses for the atom. The aim of the program was to establish the infrastructure necessary for development of nuclear power in foreign countries allied with the United States. One key aspect of the program was the provision of research reactors and low enriched uranium (LEU) fuel. These reactors could be utilized to foster research in nuclear technology as well as for production of isotopes for medical and industrial purposes. In addition, they could support the education and training of personnel needed to support the nuclear industry. The Soviet Union established a similar program in the same time period.

Over time, the original LEU fuel was limiting the performance of the reactors, and high enriched uranium (HEU) fuel was developed as a means of increasing the neutron flux and thus increasing the efficacy of the reactor facilities in countries all around the world. In subsequent years, the threat associated with utilization of HEU fuel became evident, and substitution of HEU fuel was initiated by both governments in 1978 under programs such as the US Reduced Enrichment for Research and Test Reactors program. Progress was slow, however, due to funding constraints and economic difficulties.

II. History of the Russian Research Reactor Fuel Return Program

In 1999 the IAEA, the United States, and the Russian Federation established an agreement in concept to repatriate Soviet origin fuel to the Russian Federation with the assistance of the United States and the IAEA. In October 2000, the Director General of the IAEA sent a letter regarding the management of research reactors of Soviet-/Russian-origin to the relevant Ministers in various countries, offering participation in a program to repatriate HEU fuel back to the Russian Federation. Over the next few years the Russian Federation developed legislation necessary to support the program.

Following the events of September 11, 2001, efforts to convert reactors and repatriate HEU became a priority. Concern over 80% enriched uranium fuel at the Vinca facility in Serbia led to the three parties to launch a recovery effort for the HEU in 2002. This was a critical breakthrough in cooperation on repatriation of Russian origin fuel. A formal agreement between the U.S.A. and the Russian Federation establishing the Russian Research Reactor Fuel Return (RRRFR) program was signed in 2004. The two countries established a Joint Coordinating Committee to manage the effort.

Since 2004, the RRRFR program has successfully returned more than 2000kg of fresh and spent HEU to the Russian Federation. After the first urgent HEU removal operations from Serbia and Romania (in 2003), several more shipments of fresh HEU fuel were repatriated over the next three years. In 2006 the first shipment of spent nuclear fuel was completed from Uzbekistan. Since then over 60 shipments of fresh and spent HEU have been completed from 15 countries.

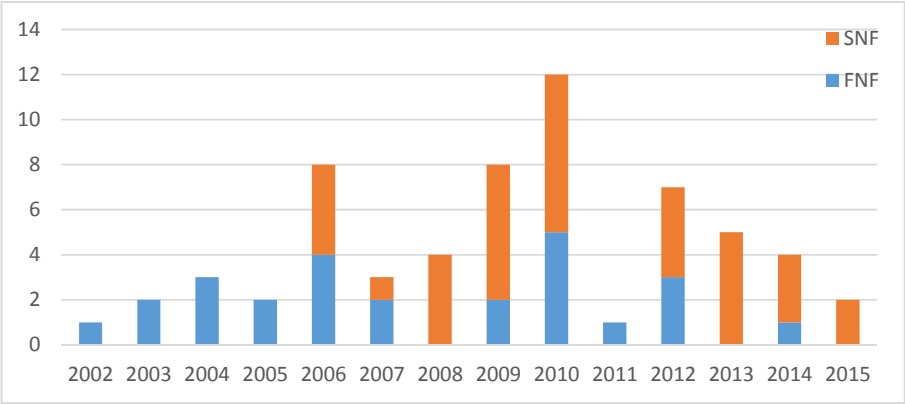

FIGURE 1. RRRFR SHIPMENTS

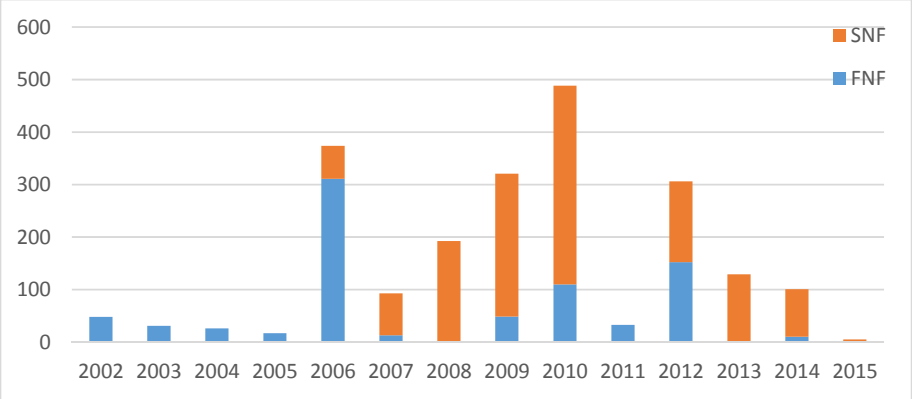

FIGURE 2. HEU MASS SHIPPED

As can be seen from Figure 1 and 2, shipments were limited to fresh HEU during the initial phases of the program. This was largely due to difficulties in developing the legislation and process for licensing of spent fuel shipments. This was overcome by 2005 and the first spent fuel shipment licensed under these new regulations occurred in 2006.

III. Security of Spent Nuclear Fuel Shipments

The threat of HEU is the ease with which it can be used to build a nuclear device. Given sufficient fissile materials, application of simple machining technology along with rudimentary experience with explosives can produce a device with significant explosive power. The design and methods for construction of such a nuclear device, although currently kept out of the public eye by most governments, has been disseminated to a fair extent in the past. Construction of a crude nuclear device can be accomplished by a competent team of scientists without significant prior experience. Terrorists seeking to fabricate a nuclear device are therefore largely limited by the availability of fissile materials.

Sources of fissile materials for non-State actors are extremely limited, as measures to secure existing stockpiles are substantially complete and scrutiny of possible black market transactions is intense. Assuming that a terrorist organization seeks to steal materials, factors in target selection would include the quantity of material, the form of the material, and the security of the facility in question. HEU fuel in research reactors have sufficient material in a form easily portable, and historically did not have security measures as rigorous as other facilities containing fissile materials. Although security measures have been greatly improved over the years, no security posture is completely effective at preventing theft.

Given the improved security posture at research reactors and the intention to repatriate the HEU materials to the country of fuel origin as the publicized ultimate solution, theft during shipment has now become a much more significant risk. With the material removed from the reactor and packaged in a suitable shipping container, diversion of a shipment becomes a strictly force-on-force effort requiring far less time to accomplish than theft from a facility. It is for this reason that the NNSA has sought to minimize the number of transport modes, the duration each mode of transport, and the number of mode transfers, which eventually results in minimization of the transit time for HEU fuel shipments.

Another significant factor in the risk of transport is the number of shipments. Although the reactor fuels in Soviet-designed research reactors came in different shapes and sizes, the bulk of the fuel to be shipped were VV-R or IRT type assemblies, which are “sticks” of roughly 0.8 m in length. For fresh fuel, sufficient casks of Soviet design such as the TUK-14/16 have been available as to avoid multiple shipments.

Most Soviet research reactor facilities were designed to utilize the TUK-19 shipping cask system for shipment of spent nuclear fuel. The TUK-19 weighs 5 tons, which is the capability of the cranes in most facilities, and rail cars specifically designed for transport of these casks were also developed. The capacity of the TUK-19 is 4 assemblies. With 20 TUK-19 casks in existence, and roughly 15,000 assemblies to ship under the RRRFR program, the number of shipments approached 200. As a result, reducing the number of shipments was also made an NNSA priority.

IV. Evolution of Transport Modes

Development of the Škoda VPVR/M Cask

After assessment of available spent fuel shipping casks, it was determined early on that a higher capacity cask was needed to reduce the number of shipments required to complete the program, as well as expansion of transport modes available. The IAEA conducted a

procurement to design and build a high capacity cask, which was awarded to the Škoda company. The Škoda VPVR/M cask[1] holds 9 times as much fuel as the TUK-19, holding 36 assemblies, and was certified for vehicle, rail, and sea transport. Sixteen casks were manufactured, ten of which were procured by the IAEA and six of which were procured by the Nuclear Research Institute (NRI) in Řež, Czech Republic[2].

Although the higher capacity Škoda VPVR/M cask seemed the logical choice to use, the program took an "all of the above" approach to shipments and assessed the best method of shipment for each facility. Cask selection for a particular facility has been a function of the quantity of fuel to be shipped, the time frame during which fuel is ready to be shipped, modes of transportation available, facility infrastructure, and the proximity of the facility to its destination.

Most facilities undergoing conversion of their reactors had at least two shipments, with the fuel available for shipment taken out as soon as possible, and the remainder shipped following conversion to LEU fuel and sufficient cooling time. For this reason, the higher capacity Škoda VPVR/M cask was not required in some cases. In other situations, involving large quantities of fuel to be shipped, a combination of all Škoda VPVR/M casks and all TUK-19 casks were utilized.

The original design of the Škoda VPVR/M cask included a companion ISO sea land container specifically modified to hold either one or two Škoda VPVR/M casks, allowing easy inter-modal transfers during shipment. This allowed for an expansion in the modes of transport from the vehicle or rail shipment modes allowed for the TUK-19 cask by allowing sea transport. In order to utilize the TUK-19 cask in modes other than by truck and rail, a similar ISO container was developed[3], opening the door to sea shipment of the TUK-19[4].

Where suitable for other reasons, utilization of the Škoda VPVR/M cask required the additional task of modifying the facility to accommodate the greater weight of the cask (13T vs 5T). In some of these cases, facilities were extensively modified by constructing a new structure with a higher capacity crane around the existing fuel storage facilities. The cost of construction of these facilities was a small fraction of the cost of a typical shipment, and therefore cost effective. Where modification of the facility was not feasible or desired, special transfer casks were developed to load fuel from the facility spent fuel pool into the Škoda VPVR/M cask.

The development of the Škoda VPVR/M cask dropped the number of shipments required substantially, allowing transport of all stored SNF in a single shipment for most facilities. Overall, utilization of the Škoda VPVR/M cask was the greatest single factor in reducing the security risk of spent HEU fuel shipments.

Program Acceleration

Following the Bratislava meeting between the United States and the Russian Federation, as well as the subsequent Nuclear Security Summits, acceleration of the RRRFR program became a priority. Assessment of the factors limiting the pace of shipments resulted in the conclusion that other means of transport needed to be developed. This included development of a means to ship HEU spent nuclear fuel by air. Packaging for shipment of spent nuclear fuel by air did not exist at that time. Shipments of spent fuel by air had been done under emergency situations in the past, utilizing Type (B) packaging, but it was apparent that development of suitable Type (C) packaging was necessary.

SOSNY corporation was awarded a contract to develop Type (C) packaging. Rather than starting from scratch, the SOSNY approach was to develop an over pack for the existing Škoda cask. The simple design of the TUK-145C package[5] utilized an over pack that surrounds the Škoda cask with hollow titanium spheres that absorb the momentum of the cask by crushing upon impact. Trailers were also developed to transport the TUK-145C,

allowing for a complete transportation system. Following quarter scale testing of the TUK-145C, it was certified by the Russian Federation for land, sea, and air shipment. Two TUK-145C over packs were constructed, allowing for shipment of up to 72 assemblies by air.

Only two over packs were constructed based on the weight of the TUK-145C system, which is 47 tons. Simultaneous shipment of both over packs approaches the cargo capacity limit of commercial airplanes. The Antonov-124 cargo plane, with a capacity of 150 tons, has been utilized for all shipments of the TUK-145C to date. Since the weight of aircraft fuel is also a factor, long shipments of both over packs can involve multiple refueling stops.

Another significant factor in the time required for shipment of spent nuclear fuel was the requirement in the safety analysis of the Škoda VPVR/M cask for multi-year cooling of spent fuel removed from the reactor prior to shipment. Time frames ranging from 36 months to 20 years were imposed[6], restricting how soon fuel could be shipped. The cask analysis included three limits on the contents of the cask; thermal power, radioactivity, and weight. The thermal power and radioactivity are calculated using standard industry codes that assume a certain set of radioisotopes. The cooling limitations allowed for simplification of the analysis by neglecting many short-lived radioisotopes associated with fission products. Re-evaluation of the limits allowed for elimination of the spent fuel cooling time limit, allowing for assessment against only the thermal and radioactive limits[7]. Elimination of the fuel storage time limit therefore reduced the time to shipment by two years in most cases.

Reducing the time required for conversion of a reactor core from HEU to LEU was also a factor that warranted consideration. During operation, research reactor operators periodically substitute a small portion of the most highly irradiated fuel with fresh fuel, and then re-distribute the remaining fuel so as to evenly distribute the neutron flux within the core. This allows for optimum utilization of the fissile content of the fuel. Conversion of a reactor historically involved introduction of LEU fuel as part of this normal refueling cycle, a process that resulted in a three-year conversion timeframe.

In order to accelerate this process, some reactors developed an approach that discharged the entire HEU core and substituted an LEU core. This involved a reduction in capacity for a period of time, however, as it required startup with a smaller core, allowing for addition of fresh fuel as the core expanded.

V. Cost Impacts of Transport Modes

Over the history of the RRRFR Program, shipping modes have evolved from land to sea to air. This has, in most cases, involved higher costs for the actual transport vehicles associated with each mode. The total impact of the cost for shipment by various modes is not, however, dependent upon the actual transport vehicle cost. Several other factors can impact the overall cost, such as licensing, security, and support costs.

At the time preparations began for the second Hungarian SNF shipment, and prior to the initial use of air transport, an analysis of relative costs associated with various transport routes were compared in some depth[8]. The results of the cost comparison were somewhat surprising, as the costs associated with utilizing multiple modes and transiting multiple countries were significant factors.

Table 1 is a simplified table illustrating the costs of each option studied. Given the significant reduction in time-at-risk for the shipment, the incremental costs of air transport were funds well spent. It should also be noted that the cost of licensing the initial air shipment was higher than that in subsequent shipments.

One factor that should be noted is how the political situation can impact selection of routes, costs, and security. Note that the Land option in Table 1 is by far the most cost effective

option, and given the physical distance between the country of shipment and its destination, an expedient rail shipment might seem the logical choice. This option was not feasible, however, due to a lack of current agreements on transport of such materials between the governments involved.

TABLE 1. COST COMPARISON FOR MULTIPLE ROUTES

COST	INITIAL SHIPMENT	PORT A	PORT B	LAND	AIR
LICENSING	$800,000	$800,000	$700,000	$470,000	$1,100,000
INSURANCE	$22,000	$86,000	$86,000	$86,000	$86,000
TRUCK TRANSPORT	$240,000	$925,000	$750,000	$240,000	$140,000
RUSSIAN TRANSPORT	$900,000	$900,000	$900,000	$800,000	$400,000
RAIL TRANSPORT	$200,000	$480,000	$200,000	$200,000	
SECURITY	$67,907	$200,000	$200,000	$100,000	$100,000
SEA TRANSPORT	$1,500,000	$560,000	$860,000		
AIR TRANSPORT					$3,000,000
TOTAL	$3,729,907	$3,951,000	$3,696,000	$1,896,000	$4,826,000

VI. Future Transport Approaches

Over the course of the RRRFR program, transit times, and the commensurate risk of transport, have been significantly reduced. The average air shipment requires no more than 3 days, with the only vulnerable portion being between the facility and the airport. In comparison, some shipments have taken as much as a month to complete.

Every mode of transport has positive and negative aspects. Proximity to rail heads, airports of sufficient length, availability of suitable trucks, and the political situation between governments involved will always be factors to consider. Future shipments will be assessed on a case-by-case basis to determine the most cost effective and secure solution.

VII. References

1. M. Tayack et al: *Development of new transportation/storage cask system for use by DOE Russian Research Reactor Fuel Return Program*. PATRAM 2007, 21-26 Oct, 2007 Miami, Florida, USA.
2. F. Sviták: *Experience Gained from Skoda VPVR/M Cask Use for RRRFR programme*. Regional Workshop on RRRFR Program Lessons Learned. 7-10 June 2011, Jackson Hole, Wyoming US.
3. O.P.Barinkov, B.A.Kanashov, K.V.Golubkin, V.M.Ipatov, *Transport Overpack for TUK-19 Packages*, Nuclear & Environmental Safety, №1, 2009.
4. S. V. Komarov et al: *Serbian SNF Repatriation Operation: Issues, Solving, Lessons Learned*. PATRAM 2013, 18-23 Aug, 2013, San Francisco, CA USA

5. M.E. Budu, D.V. Derganov, O.A. Savina, S.V. Komarov, S.D. Moses, *Developing a Spent Fuel Cask For Air Transport*, Nuclear Engineering International magazine, February 2014 Edition.
6. Czech Republic State Office for Nuclear Safety, *Decision 6943/2005*, CZ/048/B(U)F–96, March 23, 2005.
7. Czech Republic State Office for Nuclear Safety, *Decision 2827/2007*, CZ/048/B(U)F–96, February 16, 2007.
8. J. Dewes, I. Vidovszky: *Task 1 Shipment Initiation, Subtask 1.2 Project Authorization and Transport Concept*, RRRFR Internal Report, Budapest 2012.