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SEVEN SNF AIR SHIPMENTS IN TYPE B PACKAGES – SUMMARY AND LESSONS LEARNED

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ABSTRACT

Four highly enriched uranium (HEU) spent nuclear fuel (SNF) air shipments from Romania, Libya and Uzbekistan were realized in the framework of the Russian Research Reactor Fuel Return (RRRFR) Program and three additional low enriched uranium (LEU) SNF air shipments from Romania were realized under the Russian-Romanian governmental agreement.

Each project had its technical, geographical, political, licensing and implementation peculiarities. Each time all the difficulties were solved in time and the type B package SNF air shipment proved to be the most efficient solution.

This paper realizes an analysis of all seven research reactor (RR) SNF air shipments performed in type B packages, pointing out the technical differences and similarities between them, the obstacles and benefits met, and lessons learned from the implementation of such projects, from the point of view of the shipment coordinating organization and the air carrier.

INTRODUCTION

The nuclear power and civil aviation industries have in common a lot of approaches and aspects with due regard to safety: common safety culture approaches, similar quality assurance systems, same safety goals of operation without any incidents harmful to the population. For example, in the nuclear world, according to Nuclear Energy Agency (NEA), the limits or objectives defined by the regulators, licensers, designers etc. for the Large (Early) Release Frequency vary within the interval 10^{-5} to 10^{-7} / yr [1], while in the civil aviation world, the International Civil Aviation Organization (ICAO) 2010 official global accident rate was of $4x10^{-6}$ (4 accidents per million departures) [2].

However, none of the established safety limits or objectives can sustain the public myth of absolute safety. Accidents can happen anyway, and this fact was proven by the previous unfortunate experiences in both nuclear power and civil aviation industries, from which we can remember the most recent nuclear accident at Fukushima (March, 2011) and the biggest aviation accident in New York (September, 2001). Media coverage showed us that the two industries have the same very high sensibility and degree of public resonance. Each time, the main nuclear power and civil aviation actors generated industry-wide responses which concretized in new approaches to safety, accident mitigation measures, safety systems, and quality and security improvements. For example after the Chernobyl accident International Atomic Energy Agency (IAEA) defined the safety culture concept and a new era of safety improvements began, after the Fukushima accident stress-tests were undertaken to most of operating nuclear power plants, some of which resulted in expensive safety improvements to be implemented by the world-wide industry. Starting with 2000 the air industry made considerable progress in assuring the safety of transportations by air resulting in drastically reduction (by more than 50 %) of the number of serious accidents by developing new aircraft safety and control systems and the Universal Safety Oversight Audit Programme. After September 2001 a lot of efforts were made and huge progress was achieved in assuring the security of air transportations by developing new standards, systems improvements and the Universal Security Audit Programme.

On this background, many previously non-nuclear countries are preparing to start peaceful nuclear programs but only a few countries own technologies for nuclear fuel enrichment and for spent nuclear fuel reprocessing. Also, many aged nuclear power or research reactors will be decommissioned. Centralized storage facilities or final repositories for high level radioactive waste and spent nuclear fuel are being developed, and maybe one center for several countries. So the number and complexity of transports of radioactive materials will, therefore, rapidly grow and their security and schedules will be harder and harder to control.

A series of nuclear transports were realized in the framework of the RRRFR Program. The DOE funded program has the goal to eliminate HEU stockpiles and encourage eligible countries to convert their research reactors from HEU to LEU fuel. So far, fresh and spent nuclear fuel has been returned to the Russian Federation in the period 2003-2013 in more than 50 operations.

HEU spent fuel was shipped from thirteen countries: Belarus, Bulgaria, Czech Republic, Hungary, Kazakhstan, Latvia, Libya, Poland, Romania, Serbia, Ukraine, Uzbekistan and Vietnam.

All the HEU spent fuel was shipped for reprocessing to only one facility in Russia – Federal State Unitary Enterprise (FSUE) Production Association (PA) Mayak, using two sets of type B casks: 20 Russian TUK-19 casks and 16 Czech Skoda VPVR/M casks. The TUK-19 cask was certified for air shipments, complying with the requirements for Type B casks with limit on activity content of up to 3000 A_2 [3].

Two Type B HEU spent fuel air shipments to Russia from Romania and Libya were performed in 2009 and 2 more from Uzbekistan were performed in 2012. Also in 2012 3 LEU spent fuel air shipments from Romania to Russia were performed outside the RRRFR Program.

Further on in this paper the safety aspects of Type B cask spent nuclear fuel air shipments and lessons learned will be discussed.

OVERVIEW OF AIR SHIPMENTS SAFETY

A Flight Safety Foundation (FSF) analysis of global accident rates for over the past 20 years demonstrated that the average figure for the 2000-2009 decade shows a marked improvement compared with the average for the 1990s.

The FSF's rate, which includes serious accidents involving Western-built jets, is as follows:

- 1990-1994: 1.32 serious accidents per million departures.
- 1995-1999: 1.06.
- 2000-2004: 0.58.
- 2005-2009: 0.55.

In 2010, the hull-loss accident rate for International Air Transport Association (IATA) carriers flying Western-built jets dropped to an all-time low of 0.28 hull losses per million flights (see Figure 1), whereas the world average situated at 0.66 [4].

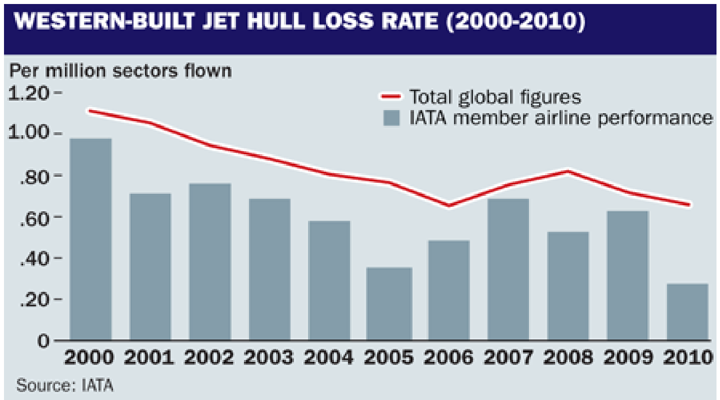

Fig. 1. Air Accident Statistics

The FSF's director of technical standards, Jim Burin, said that a good safety culture in an airline is the key to safety performance improvement. In case of RRRFR shipments of spent nuclear fuel by air, the requirements to the safety culture of air carriers were heightened. RR SNF shipments from Romania, Libya and Uzbekistan were performed by Russian company "Volga-Dnepr Airlines" that has Rostechnadzor license to transport radioactive materials. Additionally Volga-Dnepr Airlines documents and references in the field of quality assurance and safety culture were reviewed on the request of the regulating (Rostechnadzor) and competent (Sate Atomic Energy Corporation "Rosatom") authorities during the preparation of the first air shipment to the Russian Federation (RF). Tables 1 and 2 present statistics of the incidents during air shipment by Volga-Dnepr Airlines in comparison with absolute numbers for the RF civil aviation.

Table 1. Absolute number of air events (2007)

Type of event	RF Civil Aviation (aircraft of 1-3 classes)	Volga-Dnepr Airlines
Air accidents	2	0
Incidents	803	6
Damage of aircrafts on the ground	81	1

Table 2. Comparative characteristics of the level of flight safety for 2006-2007

Characteristic	RF Civil Aviation	Volga-Dnepr Airlines
Number of air events, 2006	888	18
Number of air events, 2007	931	6
Number of take-offs, 2006	2 000 000	41 540
Number of take-offs, 2007	2 413 793	28 111
Safety indicator, 2006	44,40	43,30
Safety indicator, 2007	38,57	21,30

OVERVIEW OF SAFETY MEASURES FOR SNF AIR SHIPMENTS

To transport the spent fuel assemblies (SFA) from Romania, Libya and Uzbekistan the TUK-19 cask was selected as most appropriate. In order to ensure that the transport can be performed by various modes of transport (air, automobile, rail and sea) a dedicated overpack was developed on the basis of the specialized heavy-duty 20-foot ISO cargo container, accommodating three TUK-19 casks (fig. 2). The TUK-19 casks were to be secured inside the ISO container by a system of buckles, capable to withstand the accelerations and vibrations characteristic of all these types of transport. The ISO container was certified by the Russian Registrar of Shipping for compliance with the requirements of applicable standards in 2008 and after that successfully used in various multimodal shipments from Romania, Libya and Uzbekistan (air, road), Poland (road, rail, sea), Serbia (road, rail, sea) and other countries.

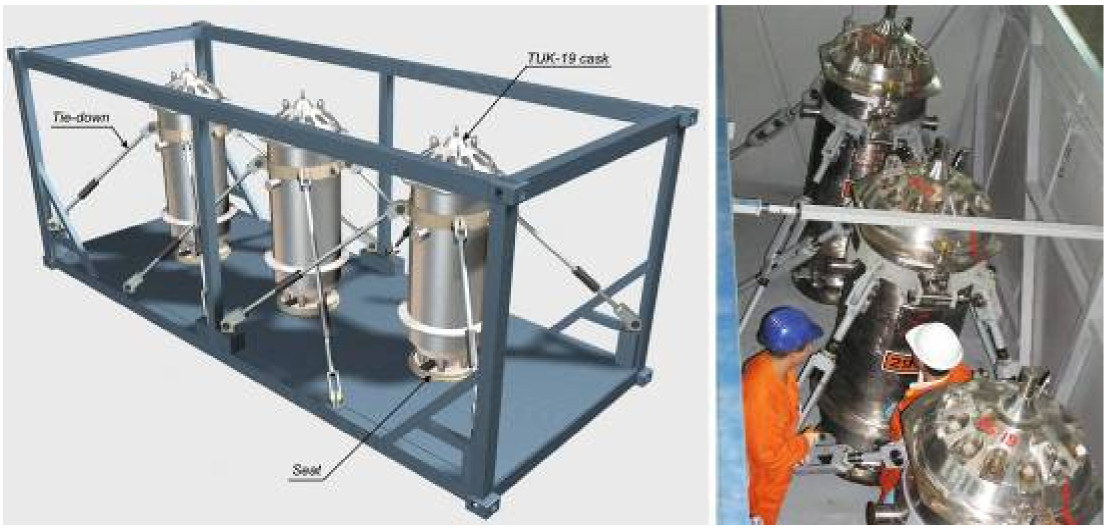

Fig. 2. Cargo container and buckles for TUK-19 shipments by any conveyance

Since the potential consequences of an air transport accident are far more severe than on land or sea transport, the 1996 edition of the IAEA TS-R-1 regulation was amended to include stricter requirements applicable to packages that are intended for transport of fissile materials by air. In particular, new requirements regarding the limitation of radioactive content in the package and the subcriticality of a single package after a series of extended tests were introduced. The later, 2005, 2009 and 2012 editions confirmed the validity of those provisions.

Under these regulations, the licensing process not under 'special conditions' (as in the past case of the RR SNF shipment from Iraq) of first SNF air shipments to Russia (from Romania, 2009, shortly followed by Libya) brought up many questions about package and shipment safety from the licensing experts' side and so the scope of analyses exceeded the requirements of IAEA.

Except the Type B package subcriticality during impact test onto a target at the velocity not less than 90 m/s for a single package, the safety was additionally proved by calculations for a group of packages (Figure 3). It was shown [5] that in the case of an air accident (at the velocity not less than 90 m/s) the nuclear material will remain inside the transport package with high probability level.

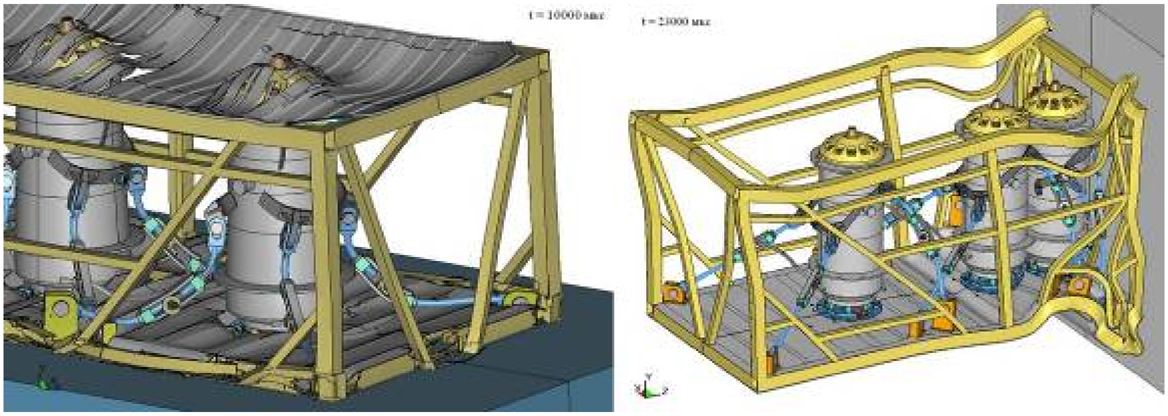

Fig. 3. Additional dynamic deformation analysis of a group of TUK-19 packages during impact onto a target at the velocity 90 m/s

The risk assessment established that there are no credible events ($P>1\times10^{-7}$) that would fall into the 'accident' category according to the INES scale (Figure 4). The most probable events would be characterized as 'incidents' according to that scale, while the events with the most severe consequences (accidents) turned out to have a low probability. Several studied events were both low-probability and without any severe consequences (incident) [6].

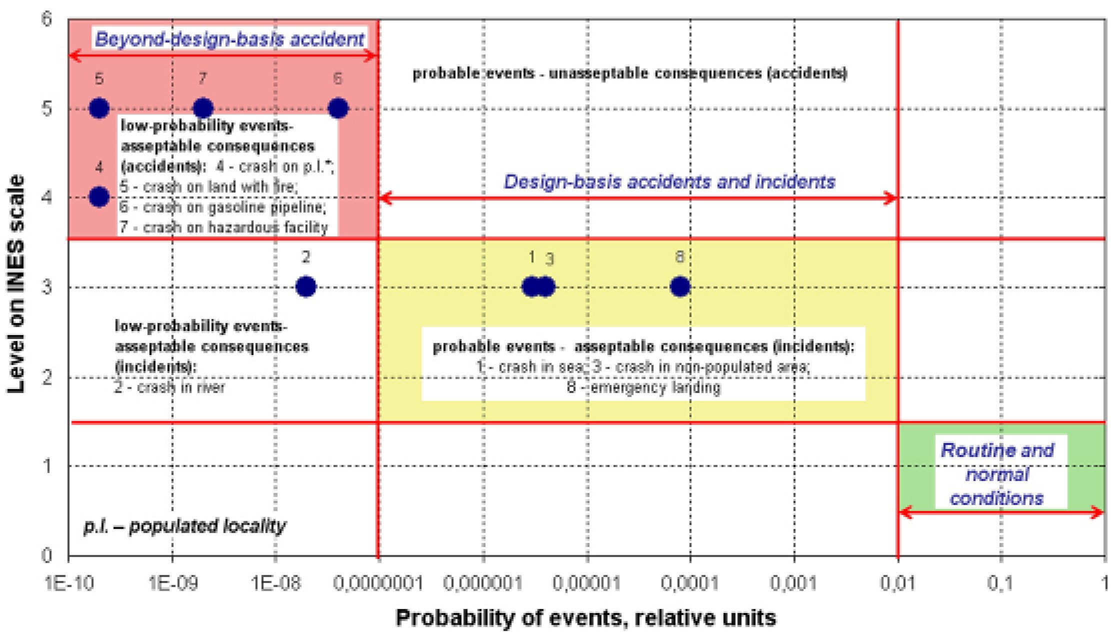

Fig. 4. The risk assessment of the air shipment from Romania

In 2009 the work on development of Type C package on the base of SKODA VPVR/M cask for air shipment of research reactor spent nuclear fuel was started under the U.S./Russia Research Reactor Fuel Return (RRRFR) program by the order of the U.S. Department of Energy. The Type C package has no activity limits and was used for the first time for the RR SNF shipment from Vietnam in July 2013. The development of the Type C package is aimed to enhance safety of air shipments of radioactive material.

The most severe consequences of air accidents during RR SNF transportation can occur in densely populated areas. In this connection the routes are specially located above the sea and bypassing large cities above the land or, sometimes, even transit countries (Figure 5) [7].

Fig. 5. The routes of the SNF air shipments from Romania and Libya, 2009

For the first two SNF air shipments to Russia from Romania and Libya special Emergency Cards for primary response operations with radioactive consignment in case of an accident during an air shipment of freight containers with TUK-19 packages containing SFAs were issued due to the extended efforts of the Technical Emergency Center of Rosatom (Sankt Petersburg). In 2011 the development of a new unified Emergency Card no. 701 intended for primary response actions in case of emergency during road, railway, air and water transport of radioactive material (RM) cargoes for all types of packages was completed. Emergency Card no. 701 was approved by Rosatom order, marking the SNF air shipments to Russia as regulated activity.

An important factor that can be ranked as a safety measure for the SNF air shipments to Russia is the use of the AN-124-100 (Ruslan) aircraft. An-124 is the world's second largest serially manufactured cargo airplane. The An-124 has been used to carry locomotives, yachts, aircraft fuselages, and a variety of other oversized cargoes. The aircraft is able to kneel to allow easier front loading. The back loading is supported by a an on-board overhead crane capable of lifting up to 20 tons of cargo, and items up to 120 tons can be winched on board. On May 1987, an An-124 set a world record, covering the distance of 20,151 km (10,881 nmi) without refueling. The flight took 25 hours and 30 minutes; the takeoff weight was 455,000 kg [8].

An-124 fulfills missions for the U.S. Department of Defense, BP, Shell, Boeing, Halliburton, Lockheed Martin, General Electric, Loral Space Systems, NATO, AMC, Ministries of Defense of Germany and UK (Figure 6) [9]. An-124 of Volga-Dnepr Airlines was used in April 2011 to airlift a large concrete pump from Germany to Japan to help cool reactors damaged in the Fukushima nuclear accident [8].

Fig. 6. An-124 missions

SNF AIR SHIPMENTS TO RUSSIA

Until now, 7 SNF air shipments to Russia in type B casks have been successfully achieved: from Romania in 2009 and 2012 (4 shipments), from Libya in 2009 and from Uzbekistan in 2012 (2 shipments). The common characteristics of these shipments are:

- research reactor SNF is being shipped, so the quantities and the dimensions of the SFAs allow the use of transport containers that can be easily loaded in ISO containers and airplane (Figure 7);
- the ISO containers are good for transportation by any means of transport (including aircrafts);
- the activity for a single package is limited to no more than 3000 A_2 as required by IAEA TS-R-1; so, a Type B package is used;
- each ISO container accommodates 3 TUK-19 casks reaching a total weight of less than 20 t, making the back loading in an AN-124-100 easy by using only the on-board overhead crane, so that supplementary lifting equipment is not necessary in airports.

Fig. 7. Past SNF air shipment operations for Type B packages - TUK-19 casks

The main technological difference for Type C cask from shipment operations using Type B package is that the larger and heavier TUK-145/C package can be front loaded in the An-124 using a special rolling system or fixed with the tie-down system on a special frame of a trailer and loaded by the truck (Figure 8).

Fig. 8. TUK-145/C packaging loading into An-124

It should be mentioned that in 2012 the RR SNF air shipments from Romania were organized outside the RRRFR Program, consisting exclusively in LEU SNF and they were entirely financed by Romania. For this particular project Rosatom State Corporation and other Russian authorities provided full support and a new route for class 7 radioactive materials was opened at the Black Sea through port Kavkaz for the empty casks delivery to Romania by sea, using a ferry boat (Figure 9). The number of requests for RR LEU SNF back end management addressed to the country of origin for the fuel production grew in the past time, mostly due to the conversion of research reactors from HEU to LEU fuel or their decommissioning. Completing the Romanian LEU RR SNF shipments in 2012, Russian authorities proved their cooperation in the back-end management of this type of fuel of Russian origin.

Fig. 9 Empty cask delivery on the Black Sea

CONCLUSIONS

The sustained efforts of the Russian organizations and the strict supervision of the Russian and foreign authorities made it possible to achieve great progress in shipments of nuclear fuel by air. At the same time this increased safety, security and schedule efficiency of such operations.

However, in the future there may be many other perspectives for the just-begun work: transports of contaminated big-size equipment resulted from the decommissioning of nuclear installations to processing centers for volume reducing and recovery of the reusable materials, transports of high-level radioactive waste from processing plants to centralized final repositories, transports of damaged power reactor spent fuel assemblies to research centers for analysis, transports of new small modular-type fresh or spent reactor cores. The air shipment may help reaching difficult access places, improve the shipments schedule in big programs or when a limited fleet of transport packages can be used, can assure better security in the cases of long routes, avoid dangerous goods transiting in the close proximity of communities or environmental protected zones etc.

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