

CONSIDERATIONS ON THE SAFETY OF TRANSPORT OF NUCLEAR FUEL ON DANUBE RIVER

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ABSTRACT

Romania as a Member State of the International Atomic Energy Agency has implemented national regulations for a safe transport of radioactive materials (RAM) in accordance with the Agency's recommendations as well as other international specialized organizations. These regulations are based on the IAEA's Safety Standard-TS-R-1 (ST-1), and were adopted under the title: "Fundamentals Regulations for a Safe Transport of the Radioactive Materials, in Romania".

The transport of Spent Nuclear Fuel (SNF) from Nuclear Power Station (NPP) Kozloduy (Bulgaria) to the Russian Federation, on the Danube River, is a very important problem taking into consideration its potential risks and radiological consequences for human being and the environment.

The paper will describe the potential severe accidents in the deep waters of the Danube River scenarios that have to be taken into consideration. Also, as a consequence of September 11 2001 events, possible terrorist attacks or sabotage of the SNF shipments should also be considered.

INTRODUCTION

Romanian Nuclear Regulatory Body-CNCAN, is very much concerned about the transport of Spent Nuclear Fuel (SNF) from Nuclear Power Station (NPP) Kozloduy (Bulgaria) to the Russian Federation. Potential severe accidents in the deep waters of the Danube River, such as: mechanical impact (collision) during transportation, fire, or submersion in deep water, has to be taken into consideration.

Since the primary objective for the safety of radioactive materials transport is to protect human health and the environment, the problem of the spent fuel transport through the Danube River was presented at the 7th Meeting of the IAEA Transport Safety Standard Committee-(TRANSSC) meeting, held in Vienna at the IAEA Headquarters on March 4-8, 2002, in Information Paper (IP) 39. IP39 stated that the risk and safety of SNF transport through the Danube River should be assessed, with the technical and financial support of the IAEA in co-operation with the USA nuclear research laboratories - Sandia National Laboratories and Oak Ridge National Laboratory.

ACCIDENT RISKS DURING RIVER TRANSPORTATION

Doses to the public and to emergency workers, following an event or accident that could release radioactive materials to the environment, may be calculated by considering the following[1,2]:

The severity of the accident. The universe of accidents may be divided into any number of accidents of varying severity. Six such "severity categories" will be considered in this analysis.

The conditional probability that an accident will belong to a particular severity category [3].

Release fractions (RF), which will vary according to the shipping cask and the physical form of the radioactive materials released from the cask, e.g. particulate, volatile, solid, gas, etc [1,2,3,4].

In the case of SNF, some solids, gases and volatile materials could be released in the event that spent fuel rods fail and the cask seal is breached in a severe accident. Some of the radioactive gases that are generated in the fuel pellets and that had diffused and collected in the helium gas plenum of each spent fuel rod would be released to the cask cavity from each fuel rod that is ruptured in a possible accident. A seal that failed in the accident would be the most likely cause of a breach in a shipping cask. This opening would result in a small leak path from the cask cavity to the environment.

The accident consequences for each severity category and risks will be calculated using severity levels and release fractions [5] using a risk analysis computer code such as RADTRAN 5.

Accident Scenarios

The risks are associated with the exposure of human beings to the radiation doses analyzed in similar accidents [6,7,8]. Doses could be hundred of times larger after very long periods of exposure.

Exposures could result from the following hypothetical accidents:

- Mechanical impacts (collision);
- Fire;
- Submersion in deep waters;
- Terrorist or sabotage attacks.

Mechanical Impacts

The barge carrying SNF shipment from NPP Kozloduy (Bulgaria) to Russia may be struck by a vessel traveling along the Danube River at 20 Km/hr or more, e. g., a barge or a string of barges carrying raw materials, a ship carrying passengers, a military guard fluvial vessel. Even if the striking vessel were to penetrate the cargo shipment area, it is unlikely that it would compromise the safety of the spent fuel cask.

However, the NEA (OECD) estimate that the probability that the ship could lose its cargo as a result of such an accident will be between 0.12% and 0.16% per year, a small but not negligible value.

Nevertheless, there could be few accident scenarios in which the SNF shipment could be impacted i.e: a head-on collision with a faster naval vessel that has a rigid prow, impact with a support column for a bridge over the Danube, impact with a fluvial icebreaker, if the shipment is to be carried out during winter when the river is frozen.

Considering the thickness of the metal shells of the cask and of the canister, it is very unlikely that such a collision will produce a puncture, serious enough to penetrate the cask shell and to lead to a possible release from its containment [9,10,11].

Fire

If the barge carrying SNF shipment through the Danube River is struck by a string of barges carrying flammable cargo, and the flammable storage tanks are punctured so the liquid was spilled onto the surface of the river, the barge carrying SNF shipment might be fully engulfed by fire. A potential strong wind and a hot temperature (over 38°C) may contribute to the dispersal of the spilled burning liquid onto the

surface of water. It is estimated that the duration of the fire could exceed 3 to 4 hours. In this case the inner wall of the cask could reach a temperature of about 350°C. At this temperature, degradation of the cask's elastomeric seal could cause the cask seal to begin to leak^(11,12), with a leak path that has a cross-sectional area of about 1mm². In addition, if the temperature exceeds 450°C, decomposition of the elastomeric seal may be so extensive that the effective leak path has a cross-sectional area equal to the product of the closure circumference and the roughness height of the lid and the lid well where they contact inside of closure.

Taking into consideration the relative low speed of the barge, the water currents and the relative small distance to the river banks, the duration of the fire might be limited, in which case such an event would not be likely to produce serious damage to the cask or release of its content⁽¹³⁾.

Submersion in Deep Waters

Following the initial collision with a string of barges or other vessels traveling on the Danube, the shipping cask could fall into the waters of the river. The average depth of waters is about 17m. In a collision with an icebreaker, a military vessel or a column supporting a bridge over Danube, the barge carrying the SNF shipment could be sunk. The sunken cask could be salvaged within few hours or few days, depending on the recovery tools available when sinking occurs. These impacts could stress the package beyond the failure point. Water could also leak into the package [2,10].

However, because the impact forces from such a collision are less than the forces on the cask generated during a regulatory drop test, cask failure is not expected. In more violent collisions the impact forces could be greater and regulatory conditions could be exceeded [10,16,17].

Terrorist Attacks or Sabotage Attacks

For the competent authority (CNCAN), physical protection during transportation of SNF shipment through the Danube River has been an ongoing concern. Possible radiological impact of a breach following a shaped charge attack on a SNF cask is of particular interest.

SNF casks have very strongly constructed walls and lids (large wall thickness, typically 35 cm for a monolithic steel cask), and a high degree of shielding is needed to reduce penetrating radiation from radioactive decay, as well as a very high mechanical stability to effectively protect the spent fuel and to avoid any significant release of radioactive material in possible accidents during transport and storage [6]. At the same time, these characteristics of the cask also give a very high degree of physical protection of the spent fuel against many conceivable malevolent actions. However, some anti-tank weapons which are available in the military domain, such as high energy density devices (HEDD), could locally breach the wall of a spent fuel cask and lead to the destruction of short sections of some spent fuel elements and result in a release of radioactive matter through the penetration hole.

On this basis potential airborne releases of radioactive material can be estimated for the real cask and resulting radiation exposures for the population can be calculated.

In order to estimate potential radiological consequences of such sabotage or terrorist attacks and to judge to what extent protective measures are required, it is important to have quantitative data on possible releases in such circumstances.

Experimental results presented by (GRS) Germany concerning the uranium mass released by HEDD attacks show that the release of particulate matter from the breached cask is predominantly a short-term release, and the particle size distribution has been measured for the size range below 12.5 µm [6]. Less

than 1% of the total release of fine ($< 12 \mu\text{m}$) particles was measured after 30 s. A sub-atmospheric pressure of 0.8bar inside the cask had a noticeable effect on the amount of released particulate matter.

The SNL study on experimental data and calculations to define the potential hazard from a hostile attack on a metal spent fuel cask, by using a HEDD, produced penetration holes and resulted in fine fracturing of the fuel material in the path of the hole and in its immediate vicinity.

These test results and calculations demonstrate, with a reasonable confidence level, that an individual at the site boundary (how many meters away?) would receive a dose below the limits for “accidental” releases as a result of an explosive sabotage attack on a fuel storage cask. Furthermore, it assumes an attack with a HEDD of the general size and penetrating power as the one used in those experiments.

Note: Scenarios not included are: a) breaching of the VHLW package as a result of excessive stress (the IAEA cites “the good history of performance of elastomer seals, as demonstrated by a series of elevated-temperature tests done by SANDIA NATIONAL LABORATORY, which found very few failures”); b) corrosion of the river water (sweet) of Danube of the stainless steel VHLW canisters; c) theft of the SNF shipment following a terrorist (pirate) attack; d) sinking of the barge due to a strong storm and high waves; e) explosion on board at the towboat following by sinking of the barge; f) human errors during handling of the cask;

Generation of the input data for the accident risks and radiological consequences evaluation

In order to analyze the consequences and the risks of SNF shipment radioactive materials transportation (RAM), through the Danube River, the following computer codes can be used: RADTRAN 5, INTERTRAN 2 and RISKIND.

RADTRAN 5 and INTERTRAN 2 can be used for the estimation of risks associated with incident free transportation of RAM and with accidents that might be occur during transportation.

Note: incident-free (normal) transportation is defined as: transportation during which no accident, packaging or handling abnormality, or malevolent attack occurs; The RISKIND code can be used for calculation of the individual doses. RADTRAN 5 models yield conservative estimates of integrated population dose and other metrics in a way that can be supported by readily available data [7,8]. RADTRAN 5 permits route-specific analysis to be performed in such a way that the route of the barge transporting SNF on the Danube can be subdivided into segments with independent, analyst-assigned values for population density and other route specific parameters (RADTRAN 5 User Guide). Features include: a) an expansion of the number of parameters that can be made segment-specific; b) the capability to treat individual stops separately; c) the capability to treat each cask handling separately. The RADTRAN 5 internal’s library contains data on 60 of the most commonly transported radionuclides. Radionuclides may be added to this list as needed.

Almost all RADTRAN 5 parameters are user definable. An array of standard or recommended values for many parameters is available. The user may employ all, some or none of these values as the needs of the analysis require. RADTRAN 5 permits direct estimation of (1) individual accident dose by a method that parallels the population-dose consequence calculation, (2) population ingestion dose using values of ingestion-dose per activity unit per square meter that have been pre-calculated for most radio-nuclides and are stored in an the internal library, (3) expected numbers of fatalities from mechanical effects of traffic accidents, and (4) sensitivity of the incident-free dose vs. variation of the input parameters. Both risks and consequences, to both individuals and populations, may be calculated using RADTRAN 5 [7,8].

CONCLUSION

The safety for the SNF shipments during transportation through the Danube River, from Kozloduy to Russia is of maximum importance particularly for the Romanian Competent Authorities. The main objective of this assessment is to protect the public against unreasonable risks from the transport of radioactive materials (NUREG/CR-6672).

For the spent fuel shipments that occur without accidents (incident-free transport), radiation doses have to be estimated for two population groups: a) shipment workers (e.g., the barge crew, cask handlers, and persons who inspect the cask or barge); b) members of the general public who would be exposed to low levels of radiation, because they live near the shipment route or came near the cask while traveling on the route. For transportation accidents, release of radioactive material from spent fuel to the environment, the probability of these releases and the population doses and radiation-induced latent cancer fatalities that such release might cause have to be estimated also.

The risks associated with the transport of spent nuclear fuel from NPP Kozloduy (Bulgaria) to Russian Federation, through the Danube River, by barge using RADTRAN 5 computer code, will be estimated as follows:

- For incident –free transport;
- For transportation accidents so severe that they result in the release of radioactive materials from the cask to the environment;
- For less severe accidents that cause the cask shielding to be degraded but result in no release of radioactive materials (loss of shielding accidents).

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