Transportation Risk Assessment of VVER-1000 Spent Nuclear Fuel in the Territory of the Hashemite Kingdom of Jordan

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Abstract. In the work introduced, risk assessment was performed in the accident-free case during transportation of spent nuclear fuel from the Qasr Amra area in the middle of Jordan to the Aqaba sea port. The fuel container was the Russian made TUK – 13 containing VVER-1000 spent nuclear fuel. Program used is Intertran 2 which is based on the RADTRAN program.

1. Introduction
Risk assessment calculations are considered a crucial part of the operations related to the spent nuclear fuel cycle. Risks can be produced during transportation as well as any other side of operations, yet risks due to transportation are very important since nuclear materials gets closer to public and this raises a large amount of concerns. To provide a safe and secure environment for both people and shipment is not an easy task, thus since the 80s of the last century, studies were conducted by the US and the Russian Federation, in addition to European countries such as France, Germany and Spain [1].

For the Jordanian case, a nuclear reactor of the type VVER-1000 was supposed to be built in the central region of the country, which of course raises the question of how to transport the spent nuclear fuel from the middle of Jordan down through the south up to the sea port in Aqaba (assuming that spent fuel is moved for disposal/reprocessing in Russia). Studying the American and the Russian cases for actual and hypothetical cases of transporting different types of spent fuels using different types of transportation methods, we were able to highlight the results for the Jordanian transportation case. Assumptions and methodology are to be described in the coming sections.

In order to develop the methodology for the work completion, reports from the US department of energy and published works by Russian officials and companies were studied, different cases of transportation methods and containers were involved in the studies.

2. Methodology
It is necessary to follow the general approach that takes place in the risk assessment studies related to spent fuel such as the DOE and the NRC report NUREG-2125 published in 2014 [2], and the report published by the Sosny R&D company for transporting spent nuclear fuel from Bilibinskaya nuclear power plant [3]. The software was obtained from the developers in Sweden, which was developed in partnership with the IAEA.

Input data was obtained according to availability, some of the input data was used as the default input set for the software, the study could be enhanced by performing specific studies to specific countries.
such as Jordan. Studies related to population and traffic situation could improve the quality of the results. The conservativity of the data used as input was always the main guiding prospect.

3. Input Data
Input of the program is significantly large, specific information about the choice of the route through Jordan will be described.

Table 1. General input values.

| Entry                             | Value       |
|-----------------------------------|-------------|
| Route length                      | 402 km      |
| Route segments                    | 7           |
| Cities                            | 4           |
| Transport mode                    | Highway     |
| Container                         | TUK-13      |
| Number of fuel assemblies         | 6           |
| Transport index                   | 10\(^a\)    |

\(^a\)The value was taken from a study completed in MEPhI in 2017 in the department of nuclear reactors physics.

Table 2. Areas and public density \(^a\).

|                          | Amman  | Zarqa  | Maan   | Aqaba  |
|--------------------------|--------|--------|--------|--------|
| **Total area (km\(^2\))**| 7579   | 4761   | 32832  | 6905   |
| **Rural area (km\(^2\))/population** | 7015/117900 | 4423/52400 | 32812/69800 | 6876/29500 |
| **Urban area (km\(^2\))/population** | 564/4108800 | 338/1387100 | 20/82200 | 29/169000 |
| **Total population**      | 4226700| 1439500| 152000 | 198500 |
| **Rural population density (person/km\(^2\))** | 16.8 | 11.8 | 2.1 | 4.3 |
| **Urban population density (person/km\(^2\))** | 7285 | 4104 | 4110 | 5827.6 |

\(^a\) According to the Jordanian department of statistics data published in 2017 [4].

Table 3. Routes.

|                          | Total length (km) | Rural segment (km) | Urban segment (km) | Speed (rural) (km/h) | Speed (urban) (km/h) |
|--------------------------|-------------------|--------------------|--------------------|----------------------|-----------------------|
| **Amman 1**              | 6.3               | 6.3                | 0                  | 88.6                 | 24                    |
| **Zarqa**                | 43.4              | 43.4               | 0                  | 88.6                 | 24                    |
| **Amman 2**              | 47.1              | 47.1               | 0                  | 88.6                 | 24                    |
| **Maan**                 | 227.51            | 221                | 6.51               | 88.6                 | 24                    |
| **Aqaba**                | 78.3              | 67                 | 11.3               | 88.6                 | 24                    |

\(^ab\)Values were taken from the software Intertran 2 default input [5].

The spent nuclear fuel was assumed to be held in the spent fuel pool for 6 years, burn up is 60 Mwt.day/TU, assuming an initial enrichment of 4.95%.

Routes were divided into seven segments depending on the categories of the areas, either rural or urban, depending on the population density living in that area [6]. The choice of the most suitable route
took into account the population density in cities. Figure 1 shows the route chosen away from the capital city of Jordan, Amman, which goes through 4 cities. Specific data was kept as the developers of Intertran 2 set it to be as they kept an eye on conservativity of the input values, such as shielding factors in cities and number of vehicles sharing the route with the container.

![Map showing the route from Qasr Amra area to Port Aqaba](image)

**Figure 1.** Route in Jordan from Qasr Amra area to Port Aqaba.

4. **Results and Discussion**
Results of the risk assessment calculations were showed in the collective dose unit (person-Sv), this would give the ability to compare the results with the studies completed by the Russian officials and the department of energy in the United States, in addition to that, a comparison with the limitations set by the IAEA for individual effective doses in order to keep control on the radiation doses that the public is being exposed to.

As represented in figure 2, the doses by the software used were collected for 4 categories, for public living around the route, for people sharing the route with the container, for people involving or sharing the place while the truck is refueling in a gas station, and finally for workers involved with all steps and procedures from the point the container goes on the route until it gets to its final destination, including conveyers and security conveyance.

In addition to safety concerns and doses, nuclear security aspects must be taken into account, this is added through further security related studies and deeply analyzed research regarding the situation surrounding Jordan, which adds further efforts in order to complete the work in a comprehensive way that guarantees that all procedures run smoothly without interruptions.
Figure 2. Results obtained by Intertran 2 for collective doses.

As seen in figure 2, all the dose values are low except for on specific category, which is the dose to public during a refueling stop in segment 4 of the route, this kind of results was obtained due to the settings of the software, which assumes (by default) a stopping time of 0.011 h.km\(^{-1}\) [5]. This high value could be significantly reduced by managing the number of stops that the shipment should (and could) do during a 402 km trip in Jordan. According to the Russian Federation, officials has set a definition of risk that could be indicated regarding the maximum individual effective dose. Values calculated for Jordan are described in table 4.

Table 4. Risks as calculated according to the NRB-99/2009 document in Jordan.

| Route Segments | Collective dose (Sv) | Risk \(^{a}\) | Maximum individual eff. Dose (Sv) |
|----------------|----------------------|--------------|----------------------------------|
| Jordan         | Public               | 4.36 \times 10^{-4} | 1.205 \times 10^{-9} | 2.41 \times 10^{-8} |
|                | Workers              | 8.07 \times 10^{-4} | 1.7 \times 10^{-5} | 3.35 \times 10^{-4} |

\(^{a}\) Risk was calculated according to the equation given by the Russian documents NRB-99/2009 and NP-053-04 [7].

In table 4, values for the risk are the values of the maximum individual effective doses multiplied by the factor 0.05 Sv\(^{-1}\) [7], this factor is set by the Russian Federation in order to control the risks values...
and be able to measure it. The limits for workers and the public are $10^{-3}$ and $10^{-5}$, respectively [7]. As seen in the results above we still did not pass the safe limits of the risk.

Another aspect of the transportation issue, which is of a high significance, is the nature of roads and links in Jordan, going towards southern Jordan is not an easy task, since it contains a fair amount of mountains and hills, add to that a road quality, that needs to be reconsidered in the upcoming plans of development in order to withstand such a huge shipment.

Nuclear terrorism is a matter that should be treated very professionally, since the terrorist groups have been still continuing to spread threats and explicitly threatening Jordan. The matter of protecting a shipment of spent nuclear fuel must be highly secured [8]. The route should be studied from a security prospect, studying all the threats and involve them in the plan in order to increase the security level and reduce the risks [9].

5. Conclusion
To conclude, this study focused on the accident-free case of transporting a spent nuclear fuel shipment from the Qasr Amra area in the middle of Jordan to the sea port of Aqaba. The study was involving the Russian container TUK-13 on the highway, containing 6 spent nuclear fuel assemblies of VVER-1000 reactor. Results using the Intertran 2 software showed that the values of the collective doses (risks) are below the limits set by the Russian officials and the IAEA, thorough a 402 km trip on the highway.

This study requires more enhanced research in order to complete another side of the risk assessment which is related to the accident analysis [10]. More work is required in order to form the event and fault trees to perform the severity analysis.

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