SIMULATION OF CONSEQUENCES OF SEVERE ACCIDENTS FOR TRIGA MARK II REACTOR IN VIENNA WITH RODOS

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ABSTRACT

The TRIGA reactor at the Atominstitut Vienna (ATI) operated until 2012 with three different types of fuel elements including HEU fuel. In 2008, the Austrian Regulatory Authority responsible to supervise the safety of nuclear facilities, requested to estimate the impact of a major reactor accident using nuclear- and meteorological parameters available at that time. These calculations were performed using the PC COSYMA code.
In 2012 the TRIGA core was converted to a uniform LEU core, a meteorological station was installed at the reactor site and the RODOS simulation tool was implemented. Using these new features realistic scenarios for four types of major TRIGA accidents were calculated and are presented in this paper.
The outcome of these simulations can easily be adapted for other TRIGA reactors to document the safety of this type of research reactor.

1. Introduction

The TRIGA Mark-II reactor (Training, Research, Isotope Production, General Atomic) in Vienna was built by General Atomic [GA] and went critical for the first time on March 7th 1962. It is a swimming pool type research reactor that operates in average 220 days per year for training and research. The maximum power output under continuous conditions amounts 250 kW_{th}. The power output is very low, thus the burn-up of the fuel is small.
The fuel consists of a uniform mixture of 8 wt% uranium, 1 wt% hydrogen and 91 wt% zirconium, whereas the zirconium-hydride acts as a main moderator. The special property of this moderator is a reduced moderation at high temperatures, which permits a pulsed operation of the reactor.
The safety report [1] of the reactor includes four accident scenarios and their deterministic dose consequences to the environment. Those were calculated for the old core inventory including HEU fuel. Since 2012 the reactor operates with a uniform LEU core. Therefore it was now necessary to evaluate those accident scenarios again with the current core inventory. The simulations were carried out with RODOS, a dispersion simulation tool.

2. The simulation tool RODOS

After the Chernobyl accident the emergency tools, regarding the calculation of accident scenarios and the risk for general public in Europe needed to be improved. Therefore the European Commission supported the development of RODOS (Real-time On-line DecisiOn Support) to increase the knowledge and risk perception after possible accidents, and to improve communication with the public.
RODOS is a strong tool to provide decision support on 4 levels [2]:

- **Level 0**: acquisition and checking of radiological data and their presentation, directly or with minimal analysis, to decision makers, along with geographical and demographic information.
- **Level 1**: analysis and prediction of the current and future radiological situation (i.e., the distribution over space and time in the absence of countermeasures) based

upon information on the source term, monitoring data, meteorological data and models.

- **Level 2**: simulation of potential countermeasures (e.g., sheltering, evacuation, issue of iodine tablets, relocation, decontamination and food-bans), in particular, determination of their feasibility and quantification of their benefits and disadvantages.
- **Level 3**: evaluation and ranking of alternative countermeasure strategies by balancing their respective benefits and disadvantages (e.g., costs, averted dose, stress reduction, social and political acceptability) taking account of societal preferences as perceived by decision makers.

2.1 The dispersion model DIPCOT [3]

RODOS offers the possibility to use several dispersion models. DIPCOT (DIsPersion over COmplex Terrain) offers the possibility to simulate the dispersion over complex terrain. The model has the ability to simulate atmospheric dispersion in both homogeneous and inhomogeneous conditions based on a Lagrangian particle model scheme. The mass of the pollutants is distributed to a certain number of fictitious puffs or particles that are displaced in the computational domain according to the wind velocity. A random component is added to the wind velocity to account for turbulent diffusion. The knowledge of the spatial and temporal distribution of the particles allows the calculation of the pollutants air concentration at specified locations and times. It can calculate dry and wet deposition, which was one of the reasons to choose DIPCOT as model chain for the following scenarios. DIPCOT is also able to simulate gamma radiation dose rates.
As DIPCOT needs a clear topographical information to perform its calculations, RODOS Meteorological Pre-Processor provides such.
DIPCOT uses 3-dimensional fields for the wind velocity, temperature, and pressure and 2-dimensional fields for topography, ground roughness, mixing layer height, friction velocity, convective velocity, category of atmospheric stability, precipitation intensity and Monin-Obukhov length.
The particle trajectories are calculated according to the following equation:

$$x_i^{n+1} = x_i^n + (\overline{u_\iota} + u_i') * \Delta\, t$$

with n as time-step index, i the Cartesian direction index, $\overline{(u_\iota)}$ the mean wind velocity, and $u_i{}'$ the turbulent velocity fluctuations.

The dry deposition flux F_d is calculated by the following equation:

$$F_d(x, y) = V_{dc}(x, y, z = 1m)$$

where V_d is the dry deposition velocity, which is a function of land cover and species and c is the particle concentration at a point. The wet deposition F_w is slightly more complicated and is calculated for each puff *p* with coordinates(x_p, y_p), load Q_p (e.g. mass or radioactivity for a particle) and U the horizontal wind velocity from the relation:

$$F_w(x, y) = \frac{\Lambda\, Q_p}{2\pi U \sigma_{xp}\sigma_{yp}} \{\exp[-\frac{1}{2}\frac{(x_p - x)^2}{\sigma_{xp}^2} - \frac{1}{2}\frac{(y_p - y)^2}{\sigma_{yp}^2}]\}$$

where $\Lambda\ (1/s)$ is a wet deposition coefficient calculated as a function of the precipitation intensity ($\Lambda = \alpha\, I^\beta$) RODOS provides the coefficients α and β.

3. Scenarios for Simulation

The current safety report of the TRIGA Mark II reactor uses 4 different accident scenarios, which need a dispersion calculation:

- Exposure of 1 fuel elements - fuel element 10197 was taken, as it had the highest activity content
- Exposure of all fuel elements- the activity content of all fuel elements was taken corrected by the factors of GA (see below)
- Crash of a small airplane - the activity of all fuel elements corrected by the factors of GA (see below)
- Crash of a large airplane - the activity of all fuel elements corrected by the factors of GA (see below)

As the calculation of a source term of each of the scenarios would be difficult, GA has experimentally found weighting factors [5] which can be used to work with the source terms. With the help of MCNP the current activity of the fuel elements was calculated (approx. 2 year burnup at the end of 2014).The source term was calculated for a continuous run of the reactor of 1719 hours. For comparisons the source term was also calculated for a run until 2025. The relevant nuclides for the simulation where found to be volatile noble gasses (Kr and Xe) and halogens (I). Those nuclides were also taken into consideration to be consistent with previous calculations [4].

In Table 2 the different source terms are shown, in Table 1 the weighting factors of GA are shown, which were multiplied with the activity of the nuclides. The fraction for the organic halogens was 92% to 8% of other halogens, hence the iodine activities where fractured into 92:8.

Factor GE	**Nobel Gases**	**Organic Halogens**	**Other Halogens**
Small Airplane Crash			
e_i	1,50E-05	1,50E-05	1,50E-05
f_i	1	0,5	0,5
g_i	1	0,1	0,9
w_i	1,50E-05	7,50E-07	6,75E-06
Large Airplane Crash			
e_i	1,00	1,50E-05	1,50E-05
f_i	1	1	1
g_i	1	0,1	0,9
w_i	1	1,50E-06	1,35E-05
Fuel Element Damage			
e_i	1,50E-05	1,50E-05	1,50E-05
f_i	1,00E+00	0,5	0,5
g_i	1,00E+00	0,1	0,009
w_i	1,50E-05	7,50E-07	6,75E-08

Table 1 : GA calculated factors for all accident scenarios, e_i defines the leakage from the fuel element into the gap, f_i from the gap into the water and g_i from the water into the atmosphere. g_i is the product of all the above factors.

Nuclides	**All fuel Elements**	**Small Airplane Crash**	**Large Airplane Crash**	**1 Fuel Element**
	[Bq]	[Bq]	[Bq]	[Bq]
Kr 83 m	6,13E+08	6,13E+08	4,08E+13	1,24E+07
Kr 85 m	1,44E+09	1,44E+09	9,58E+13	2,92E+07
Kr 85	7,16E+06	7,16E+06	4,77E+11	1,23E+05
I130	6,13E+04	1,08E+05	2,17E+05	1,47E+03

I131	1,53E+08	2,70E+08	5,41E+08	3,10E+06
I132	2,28E+08	4,03E+08	8,06E+08	4,62E+06
I134	3,99E+08	7,06E+08	1,41E+09	8,10E+06
I135	3,29E+08	5,82E+08	1,16E+09	6,67E+06
Xe131m	3,54E+07	3,54E+07	2,36E+12	6,66E+05
Xe133m	2,25E+08	2,25E+08	1,50E+13	4,56E+06
Xe133	7,68E+09	7,68E+09	5,12E+14	1,56E+08
Xe135m	1,25E+09	1,25E+09	8,36E+13	2,55E+07
Xe135	5,84E+09	5,84E+09	3,90E+14	1,08E+08
Xe138	5,51E+09	5,51E+09	3,67E+14	1,12E+08

Table 2 Source Terms for different scenarios after GA factor correction

3.1 Weather Scenarios

To show that the weather has a strong impact on the dispersion in case of an accident, seven different weather scenarios were taken into consideration. The reactor has its own weather station, which continuously measured the wind speed, wind direction, the rain rate and the temperature over three years. Those measurements were taken to define the seven scenarios:

- spring day - this scenario describes an average spring day
- summer day - this scenario describes an average summer day
- autumn day - this scenario describes an average autumn day
- winter day - this scenario describes an average winter day
- thunderstorm day - this scenario describes a thunderstorm day (except for large airplane crash)
- foggy day - this scenario describes a foggy day (except for large airplane crash)
- hot day - this scenario describes a hot summer day (except for large airplane crash)

For this paper, all simulations were carried out with RODOS in automated mode, Emergency Lite and marked as Exercise. All data were included manually.
All simulations were carried out for a 1 hour release, with a 24 hour monitoring of the dispersion.

4. Results

In Table 3 the dose results are shown for the average weather scenarios of a spring day, a summer day, an autumn day and a winter day of the 4 above describe source terms. The results show the maximum dose received after 1 year of exposure, including all exposure paths (inhalation and ingestion).

Scenario	All Fuel Elements	Large Airplane crash	Small Airplane crash	1 fuel Element
	[mSv]	[mSv]	[mSv]	[mSv]
Spring	1,66E-04	2,7	2,62E-04	3,35E-06
summer	2,01E-04	3,18	3,19E-04	4,07E-06
Autumn	1,85E-04	3,2	2,91E-04	3,74E-06
Winter	7,39E-03	1,83	1,10E-04	1,50E-06

Table 3: Maximum dose after potential accident scenarios after 1 year for average weather scenarios

In Table 4 the maximum dose received after 1 year of exposure, including all exposure paths (inhalation and ingestion) is shown for specific weather scenarios (thunderstorm, fog and hot day) and the source terms of all fuel elements exposure, 1 fuel element exposure and a small airplane crash.

Scenario	All Fuel Elements	Small Airplane crash	1 fuel Element
	[mSv]	[mSv]	[mSv]
Hot Day	1,21E-04	1,84E-04	2,45E-06
Foggy Day	1,18E-03	1,92E-03	2,38E-05
Thunderstorm Day	6,40E-04	9,97E-04	1,29E-05

Table 4: Maximum dose after potential accident scenarios after 1 year for specific weather scenarios

The simulations were also carried out with the calculated activities of the reactor core at the end of its designated life time in 2025. The results did show negligible deviations to the above calculated results.

5. Discussion

The results in Table 3 and 4 show that the maximum dose received for the average weather scenarios are all around (Large Airplane Crash) or well below 1 mSv in the first year. This is the maximum allowed additional annual dose for general public in Austria. Taking a closer look at the outcome for the Large Airplane Crash, we find that the dose maximum is localized in the vicinity of the reactor. In Figure 1 the outcome for the Large Airplane Crash with the winter scenario is shown. The inner grid size is 25 m. It shows clearly that the dose is lower than 1 mSv in 75 m distance, indicated by the red arrow. This lies within the property boundaries of the Atominstitut.

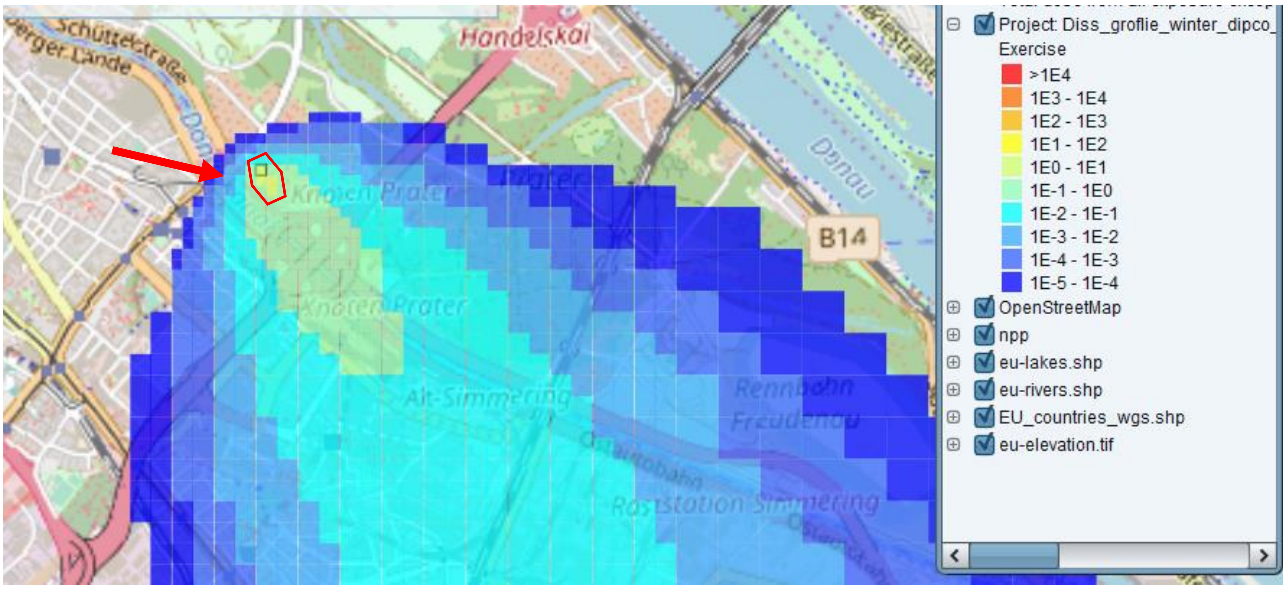

Figure 1: Dose distribution after a large airplane crash on a winter day after 1 year of exposure

As mentioned in [6] the specific weather scenarios need an additional analysis. Looking at the foggy day scenario with a Small Airplane Crash Scenario (Figure 2), it can be seen that the wind does not follow its main wind direction. The lower wind velocity also explains the higher maximum dose compared to the average weather scenarios. Figure 2 also shows that the dose is concentrated around the reactor (inner grid size 25 m), and drops quickly at maximum 75 m distance to the reactor.

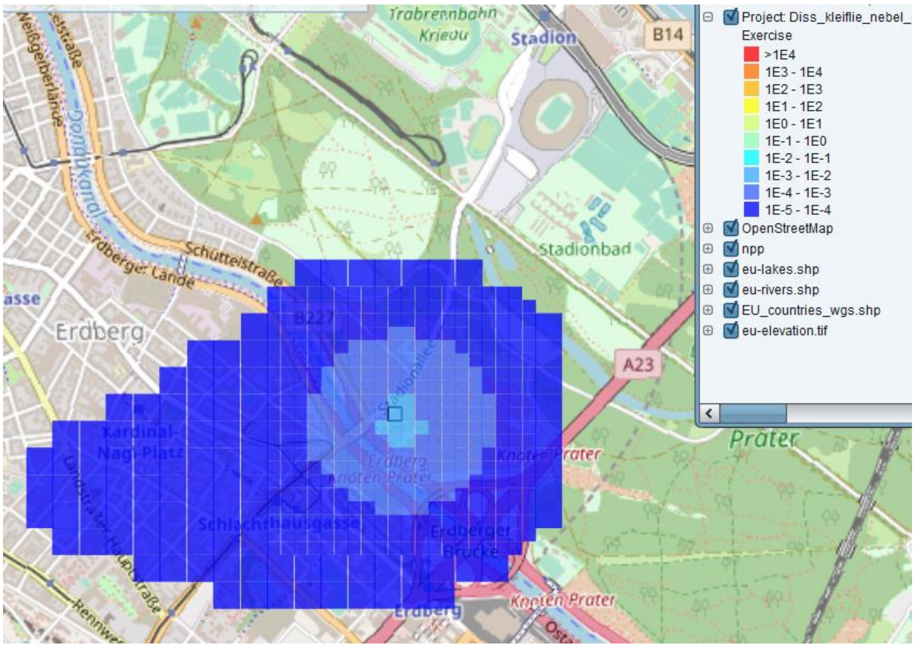

Figure 2: Dose distribution after a small airplane crash on a foggy day scenario after 1 year of exposure

With the reception of a new core inventory in 2012 it was necessary to recalculate the dispersion in case of an accident. As found out in [6] different weather scenarios needed to be taken into account.
The simulations carried out for this paper and described above, show that even in case of an accident scenario, the maximum dose for an average weather scenario is 3,18 mSv in the first year (see Table 3). As shown in Figure 1 and Figure 2 the dose drops quickly and falls below the max. 1 mSv additional dose allowed for public in Austria.

6. References

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