# MODELING OF DOSE RATES IN CASE OF A RADIOLOGICAL INCIDENT AT THE IFIN-HH INTERMEDIARY GRAPHITE STORAGE

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**Abstract.** *The low and intermediate level activity wastes resulted from decommissioning of the VVR-S nuclear research reactor belonging to the "Horia Hulubei" National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), are kept in an intermediary storage facility. The storage is located on the premises of the Institute near Bucharest, Romania and includes activated graphite from the reactor thermal column. In case of a very low probability hypothetical atmospheric radiological dispersal incident such as an unexpected fire, despite all the implemented safety measures, there is a certain radiological risk for the workers and general public due to potential ingestion or inhalation or contact with the radioactive aerosols released on a certain range from the storage building. For estimating the total gamma dose intake and adequate countermeasures for workers and public members, the JRODOS (Real-time On-line Decision Support) code system for off-site emergency management after nuclear accidents was used in the paper.*

**Keywords:** Radiological incident; Atmospheric dispersal; Aerosol dose intake; Nuclear decommissioning; Radioactive waste, Graphite

## 1. Introduction

The VVR-S nuclear research reactor with thermal neutrons was located within the IFIN-HH premises. The reactor was operated from July 1957 to December 1997 with a power of 2 MW and a maximum neutron flow of $2x10^{13}$ $n/cm^2s$, producing 9.59 MWd of thermal energy. It used distilled water as a cooling agent and moderator as reflector. Initially, low-enriched nuclear fission fuel was used in isotope U-235 (10%) – type EK-10. Since 1984 it has been progressively replaced with nuclear fission fuel type S-36, highly enriched in isotope U-235 (36%). The installation has been used for research activities in the field of physics, biophysics, biochemistry and radiochemistry as well as for research and analysis on the composition of materials by irradiating them in the internal column with thermal high flux neutrons.

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The main activity consisted of production of radioisotopes in the thermal column of the reactor with applications in industry and medicine. The nuclear reactor has also been used for teaching purposes, in the initiation and training of personnel. The reactor has been designed to operate for 40 years due to the security reasons. In 1997 the plant was shut down and entered the conservation phase until 2010. The Romanian government decided by HG 18/2002 to permanently decommission the reactor.

## 2. Intermediary storage building

The Spent Nuclear Fuel Storage (DCNU) was located next to the reactor building. Currently the DCNU is authorized by the regulatory body for nuclear activities - CNCAN - for Stage 1 decommissioning. It should be noted that since December 2012 there is no longer any spent nuclear fuel in the storage building, it was transferred to the Russian Federation. Storage water was also discharged and transferred to the Radioactive Waste Management Department for treatment. The building is currently used for intermediate dry storage (inside the 4 former wet storage tanks) of the activated graphite discs of the reactor thermal column. Graphite discs are stored here until their final geological disposal will be possible or until the conditioning technology for final safe storage is approved at DNDR Băița-Bihor [1].

**Fig. 1.** Overview of the thermal column and its composing discs [1]

The mobile thermal column of the reactor (Fig. 1) was used to moderate the flow of thermal neutrons and consisted of 6 graphite discs placed on a mobile trolley, encased in aluminum cylinders with the thickness of the front walls of 20 mm. The thermal column and the most activated/contaminated aluminum components were decommissioned between 2013-2017. The activity inventory was obtained based on gamma spectrometric measurements of samples taken from the thermal column, thermal neutron flows obtained using the DORT code and theoretical calculations as well. [1]

## 3. Modeling

### 3.1. Incident scenario

A low probability incident is assumed at the intermediate radioactive waste storage, fire causing the material and combustion products to be released in the atmosphere from the segments of the reactor's graphite column, together with associated radioactivity. Electrical cables under tension accidentally fall on the graphite mass resulting from the decommissioning and processing of the graphite column of the reactor. An electric arc is formed that incenses the graphite. The fire develops in the space closed to the storage building. The building is supposed to remain structurally intact until the graphite stock is exhausted. The combustion products are completely absorbed by the technological ventilation and discharged to the chimney, in the atmosphere, at the normal flow rate of 30000 m3/hour.

Examination of a series of models in the literature supports the idea that open fires (outdoor) and closed fires (in confined spaces) need to be modeled considering the differences in the phenomenology of those processes. The concept of closed fire adopted implies, once again, the existence of a mass of graphite processed at decommissioning, in a form close to that of a “sprayed coal bed” (current term in thermos-energy) – the form that could favor the ignition/oxidation of a material such as graphite – known as ignition – occupying a specified area, on the floor of the storage building.

The fire – initiated by the electric arc that could occur when electrical cables accidentally fell on the graphite bed (ignition of graphite requiring a temperature of at least 400 C) in the storage is assumed to be able to self-maintain, at a linear rate of burning of the graphite bed of 0.175 mm/minute – which is approx. 1/10 of the minimum combustion rate normally adopted for hydrocarbon-powered fires of 1-5 mm/minute. [2]

The fire, confined in the storage space, is supposed to conform to the behavior and laws described by the Sugara model [3] confirmed in real situations forming a vertical column current with temperatures of the order of thousands of degrees at the base, hundreds of degrees in the median area, and tens of degrees at the level of a ceiling with a height of 20 m – like that of the reactor hall, the level at which it is radially damaged to the walls, to be then absorbed by the normal ventilation of the building, directed to the exhaust basket and expelled, with a controlled flow, into the atmosphere.

As in the case of fuel fire, the area (radius) of the graphite bed and its linear rate of combustion determines the calorific power in the emission and the duration of the fire – equal to that of the emission; these sizes, together with ambient temperature, wind speed and atmospheric stability determine the effective height of the effluent plum and the rates of radioactivity release, and therefore the radiation doses at different distances from the emission source. According to literature [3], an aversion of graphite to oxidation/ignition/sustained fire can be observed as well as the refractory qualities of this material. It also possesses high ignition thresholds, exceeding 400 C.

It is presumed that the combustion products are completely taken over by the technological ventilation of the storage building and are discharged by the chimney, into the atmosphere, at the normal flow rate of 30000 $m^3$/hour. Low graphite oxidation rates are retained, ranging from 0.0001 to 1.1 %/day, strongly depending on temperature and causing long fire durations, ranging from hours to several days. The scenario of the graphite fire resulted in a slow emission at the heights relatively close to that of the storage exhaust chimney (40 m). The radius of the fire is considered 5 m and the linear rate of combustion is 0.16 mm/min.

The graphite mass of 4800 kg was considered as inpus data for the calculations, as well as the inventory of radionuclides presented in Table 1 [1]

**Table 1)** Calculated inventory of graphite radionuclides [1]

| | *Nuclide* | *Activity (Bq)* |
|---|---|---|
| 1 | H-3 | 0.90E+09 |
| 2 | C-14 | 2.45E+09 |
| 3 | Fe-55 | 2.35E+08 |
| 4 | Co-60 | 2.75E+08 |
| 5 | Ni-63 | 2.35E+07 |
| 6 | Eu-154 | 4.60E+06 |
| 7 | Cs-137 | 8.50E+06 |
| | Total | 1.20E+10 |

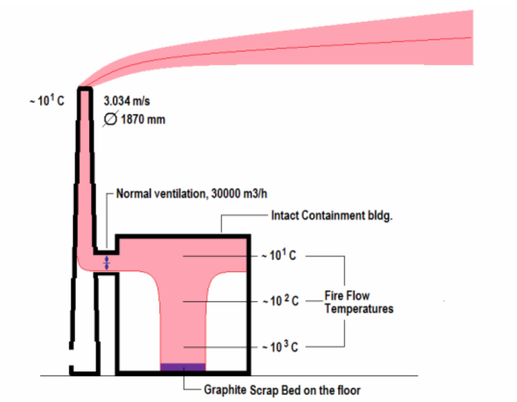


**Fig. 2.** Schematic representation of the fire with graphite – closed fire (confined), self-maintained.

### 3.2. Dose evaluations

For dose evaluation the code JRODOS 2019 for Windows was used. JRODOS is a real-time decision online support system for modelling the phases of a nuclear accident or incident created within Java programming language.

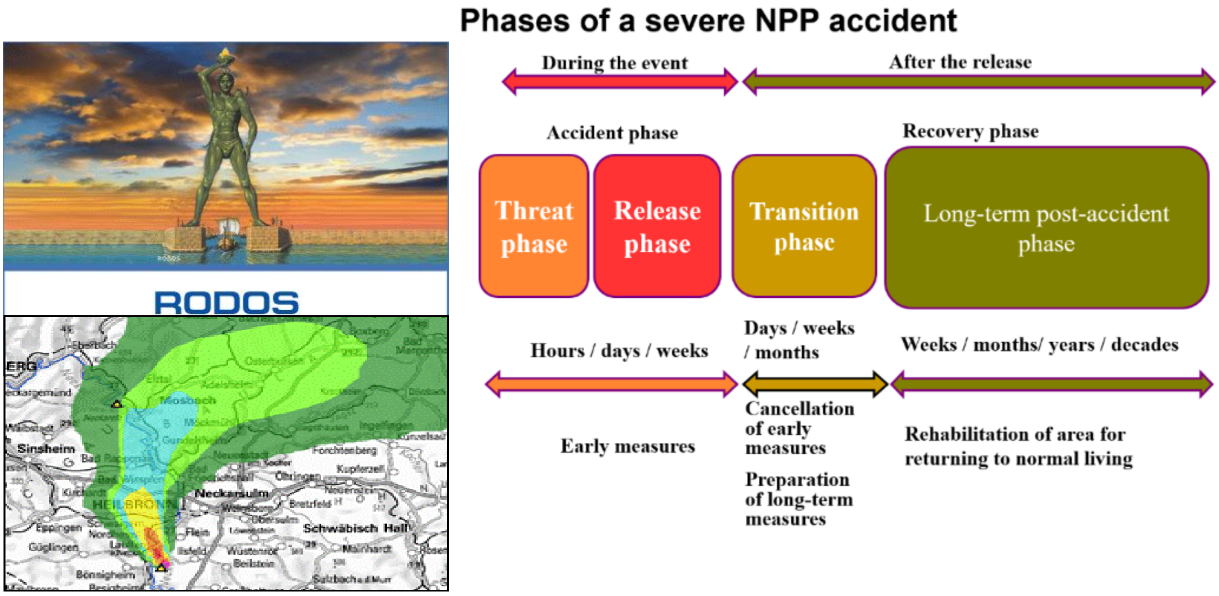


**Fig. 3.** JRODOS real-time decision online support system for modelling the phases of a nuclear accident [4]

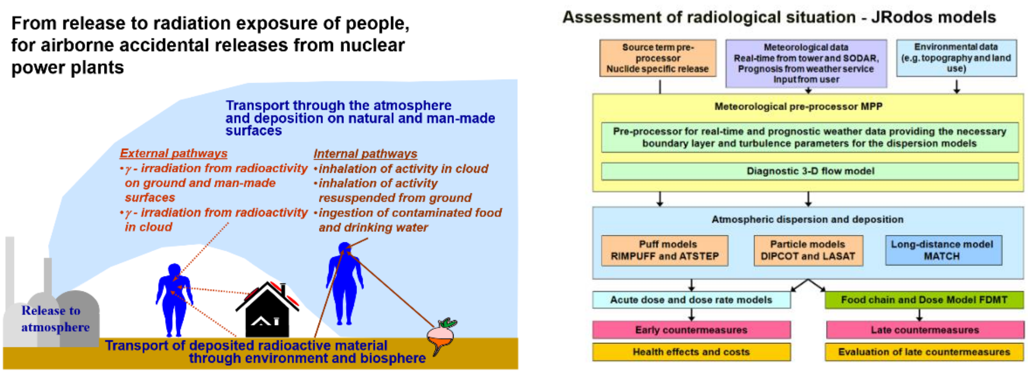


**Fig. 4.** JRODOS models for transport of deposited radioactive material through environment and biosphere using various models [4]

The calculations were made using the “Radiological Accident with Fire” module of JRODOS considering the set of values of the characteristics of the dispersion in the environment and the exposure of persons doses corresponding to the distance on the axis of the wind at which the calculation indicated the relative maximum values of the total effective equivalent dose, TEDE (mSv) [5], the dose-distance curve of TEDE, for distances chosen in the range 0.9 - 40 km to ensure a convenient view of the data distribution profile and the map circular lines of the relative maximum of the TEDE.

Although the duration of the emissions of about 20 hours, considerably extends the limits of acceptability for the notion of “short-term emission” under the wind in one direction (normal durations of persistence of wind direction varying in regulations between 1 and 4 hours), the indicated case will still be accepted as “the most severe”. The IFA tower building in the city of Măgurele, the nearest densely populated community, is considered as the most relevant reference point in the territory. Therefore, it can be conceivable to identify for any point chosen in the territory, the recommended areas for local limitation of access/stationing of the population in the event of an accident, due to the local distribution of exposure/contamination if the maximum exposure scenario would be achieved and the prevailing wind would be oriented exactly towards the point of interest.

The areas that satisfy the conditions described above were called, in this article, the area of preventive exclusion in the most severe case (“Worst Case Preventive Exclusion Areas” - PEAS) in the understanding that it would be recommended for the planning of the response to the accident at the graphite storage to have a record of them (appropriate maps, intervention teams to explore the land in advance) [6].

Preventive exclusion areas (PEAS), in the most severe case, were determined using the JRODOS 2019 code. It is worth noting that, unlike traditional intervention areas - shelter, evacuation, etc., people avoiding to access the PEAS can only help to avoid the receiving of higher doses than in the immediate vicinity of the point in the territory for which the area is defined. Although this advantage is not decisive, its assurance nevertheless conforms to the basic concept of ensuring that the population is at the lowest reasonably possible level (ALARA principle). Another advantage of PEAS is that the application of this concept makes sense not only for strong radioactive emissions, but can be made, in the case of weak emissions as well.

The following areas of preventive exclusion in the most severe case are obtained with the help of the JRODOS code, for 3 cases of atmospheric stability. The yellow marker in Fig. 5-7 marks the emission source, and the green circular symbol marks the reference point of the area, colored in red. In this area people from the vicinity would be advised not to enter or to station (until other recommendations), if the considered scenario would happen. The circular contours marked on the maps indicate the local (relative) maximum lines of total effective equivalent doses (TEDE, mSv) resulting from emissions in accordance with the scenarios chosen, for any possible wind direction.

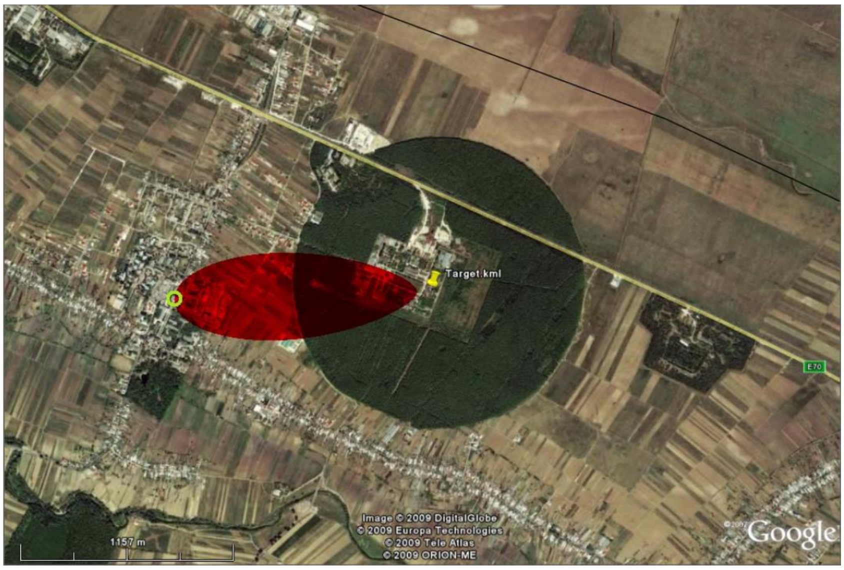


**Fig. 5** Preventive exclusion area (PEAS) for Class A of atmospheric stability


**Fig. 6.** Preventive exclusion area (PEAS) for Class D of atmospheric stability


**Fig. 7** Preventive exclusion area (PEAS) for Class F of atmospheric stability

The most severe case consists of prompt exposure, and involves a total effective equivalent dose (TEDE) of $1.49\times10^{-4}$ mSv at 0.3 km from the source in class A atmospheric stability (Fig. 5), of $1.37\times10^{-4}$ mSv at 0.9 km from the source in class D of atmospheric stability (Fig. 6) and $4.50\times10^{-5}$ mSv at 2.8 km from the source in class F of atmospheric stability (Fig. 7).

## 4. Conclusions

Considering the peculiarities of the oxidation/burning processes of graphite, it is estimated that the eventuality/probability of the releasing of contaminated graphite outside the perimeter of the decommissioning storage building is quite low in the considered hypothesis of a “slow fire”.

In case of residential agglomeration located at the smallest distance from the emission source (approximately 0.9 km) i.e., the city of Măgurele, the total effective equivalent dose (TEDE) is expected because of a slow emission scenario, including over-conservatively the entire complex network of exposure paths recommended by the IAEA. Therefore, it is recommended that radiological monitoring in the vicinity of the graphite depot should specifically aim for potential contamination of food and feed.

The prompt effective equivalent dose (TEDE in mSv) over the 7-day period of the so-called "early phase" of the accident (Early Phase) expected from a slow emission scenario (graphite fire) is within a range of order $10^{-4}$ - $10^{-8}$ mSv within a radius of 40 km around the emission source. It should be noted that the closest point of the Romanian border is situated at about 40 km from the emission source in a south-southwest direction, toward Bulgaria, therefore any significant cross-border radiological effect of the accident described should be considered.

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**References**

[1] A.O. Pavelescu, C. Tuca, Intermediate Storage and Long-Term Evaluation for Graphite and Aluminum Wastes Resulted from A VVR-S Type Research Reactor Decommissioning, Proceedings of AMNT 2019, 7-9 May 2019, Estrel Convention Center, Berlin, (2019).

[2] Comisia Națională pentru Controlul Activităților Nucleare - CNCAN, Norme privind calculul dispersiei efluenților radioactivi evacuați in mediu de instalațiile nucleare, Ordin nr. 360/2004, (2004)

[3] Sugawa O. (2001). Simple Estimation Model on Ceiling Temperature and Velocity of Fire-Induced Flow under Ceiling. Fire Science and Technology, Vol.21, No.1, pp. 57-67;

[4] Rodos: An off-site emergency management system for nuclear accidents, Annemarie Wengert, Karlsruhe Institute of Technology (KIT), 2017;

[5] McKenna T.J., Trefethen, J.A, Zhiguang Li. RC (2005). International RTM-95 Response Technical Manual. U.S. Nuclear Regulatory Commission, Washington, D.C. May, 1995

[6] International Atomic Energy Agency (2001). Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment. Safety Reports Series No. 19. IAEA, Vienna.