RERTR 2010 — 32nd INTERNATIONAL MEETING ON
REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS

October 10-14, 2010
SANA Lisboa Hotel
Lisbon, Portugal

SAFETY ANALYSES OF IRT - SOFIA LEU CORE: AIRBORNE EFFLUENTS DOSE ASSESSMENT FOR IRT - SOFIA NORMAL OPERATION

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ABSTRACT

Assessment of doses obtained by population as a result of radioactive airborne releases during research reactor normal operation is recommended by the International Atomic Energy Agency (IAEA) and requested by Euratom Treaty and Bulgarian Nuclear Regulatory Agency (NRA) - National Regulatory Body, requirements. Airborne effluents dose assessment results for IRT - Sofia research reactor are presented in this paper. Effluent evaluations of C-14 and H-3 were done by methodology developed in ITN, Portugal for RPI research reactor and for the first time applied for IRT - Sofia. Dose calculation was done using the PC-CREAM code developed and used for such evaluations in the European Community. The results were obtained for conservatively evaluated radioactive effluents and will be included into the IRT - Sofia Safety Analyses Report and Operated Limits and Condition. These results show that even for operation at 2000 kW population doses are far below the accepted limits.

1. Introduction

In the frames of HEU to LEU conversion of the IRT – Sofia research reactor an updating of the Safety Analyses Report (SAR) was in the list of regulatory task solution. Updating of the SAR chapters with neutronics, thermal hydraulic and accident analyses is discussed in a separate paper [1]. Updating of the assessment of the doses obtained by population as a result of radioactive airborne releases during research reactor normal operation is presented in this paper. This assessment is recommended by the International Atomic Energy Agency (IAEA) and requested by Euratom Treaty and Bulgarian Nuclear Regulatory Agency (NRA) - National Regulatory Body, requirements. The previous [2] airborne effluents dose assessment was updated by additional including of C-14 and H-3 in the list of evaluated nuclides and by application of the PC CREAM98 code for calculation. Methodology [3, 4] developed in Instituto Tecnologico e Nuclear (ITN), Portugal for Reactor Português de Investigação (RPI) research reactor was adopted for the C-14 and H-3 effluents' evaluation at IRT-Sofia. The PC CREAM code procurement in 2009 was provided thanks to the International Atomic Energy Agency (IAEA) financial support. This support covered also the INRNE representative training in the PC CREAM usage at ITN, Portugal. The RPI was successfully converted in 2007 and that is why a study and application of the ITN experience was especially important for IRT – Sofia.

2. IRT-Sofia airborne effluents

The airborne radioactive effluents at the IRT - Sofia that were considered are: noble gases, I-131, H-3 and C-14. For noble gases and I-131 the annual rejection levels were used the previous evaluation data [2].

Noble gases

Among the noble gases Ar-41 ($T_{1/2}$ = 1.83 h, produced by the reaction $^{40}Ar(n,\gamma)^{41}Ar$) is dominated (almost 99.5% [2]). Natural argon in air dissolved in the pool water and from the beam tubes is the source for Ar-41 production. Other noble gases that may be released (Xe and Kr isotopes) are fission products that could escape the fuel matrix are in significantly smaller quantities and were not taken in consideration. The noble gases could not be retained by HEPA filters located in the reactor stack and that is why there whole produced quantity releases to environment. According to conservative estimation at 2 MW power level [2] the Ar-41 effluent rate could not exceed 3.22E+9 Bq/h that gives annual production equal to 28.2 TBq/a for continuous reactor operation. This quantity was used for evaluation of public doses because of noble gases effluents. Available measurement data [5] for Ar-41 effluent rate for IRT2000 operation gives significantly lower value that means that the evaluation is conservative.

Iodine - 131

The iodine isotope I-131 is generated by fission. The I-131 effluents rate after iodine and aerosol filters was estimated at 2 MW power level [2] as not exceeded 3.24 Bq/h that gives annual production for continuous operation equal to 0.0284 MBq or 56.8 MBq without filter.

C-14 and H-3

The tritium and C-14 production in the IRT – Sofia reactor pool was evaluated using methodology developed for RPI at ITN [3, 4]. A Microsoft Excel Spreadsheet was used for calculation of these nuclides saturation level of activity concentration as well as for determination their activity annual rejection. The coolant average evaporation rate of 0.004 m^3/h used in this calculation was evaluated on the base of IRT2000 records [5] describing periodical water adding to the pool for the evaporation compensation. The evaporated effluent annual production was calculated for conservatively evaluated thermal neutron flux level in the pool. The C-14 and H-3 annual rejection levels were evaluated as 0.550 GBq and 0.326 GBq correspondingly for reactor power level equal to 2 MW and continuous rector operation.

3. PC CREAM calculation

PC-CREAM is a suite of six programs [6]. The system is based on a comprehensive methodology for the assessment of radiation doses resulting from the routine release of radionuclides into the environment. The methodology consists of a series of mathematical models to represent the transfer of a wide range of radionuclides through atmospheric, terrestrial and aquatic environments and hence to people. It can be used to estimate individual and collective radiation doses together with the associated health detriment. One of the six programs included in the suite is PLUME that could be run separately. PLUME is used to evaluate the dispersion and deposition of activity released to the atmosphere continuously at a reasonably constant rate from a point source. Under specified meteorological conditions the program facilitates the evaluation for each radionuclide of the following information, as a function of distance and direction from the discharge location:

- activity concentration in air (Bq m^{-3});
- deposition rate (Bq $m^{-2}s^{-1}$);
- effective dose from external gamma irradiation from airborne activity (Sv y^{-1}).

The model implemented in PLUME is the semi-empirical Gaussian plume model. PLUME evaluates the quantities of interest at specified distances for a specified discharge rate of each radionuclide considered. Other input options include the type of stability category scheme required, the effective release height and the roughness length parameter. PLUME is used to calculate activity concentrations in air and other results in each stability category separately and in the case of a uniform windrose the annual average activity concentration in air is obtained as the mean of the concentration in each category weighted by the frequency of occurence of the category. This approach is extended to calculate the annual average activity concentration in air in each sector angular width of α (radians) if the frequency with which the wind blows into each sector in each stability category is known. For a uniform windrose $\alpha=2\pi$ (ie, there is only one 360° sector) and results appropriate to sectors of different width may be obtained from the results by multiplying by $2\pi/\alpha$ (the number of sectors).

We used the PLUME program for evaluation of radiological consequence of the IRT – Sofia normal operation.

3.1. Discharged rates and release height

The radionuclide considered and their annual discharge rates used in calculation are presented above in the section 2. Calculations were performed for the release height equal to 40 m that corresponds to the IRT – Sofia stack height.

3.2. Site description

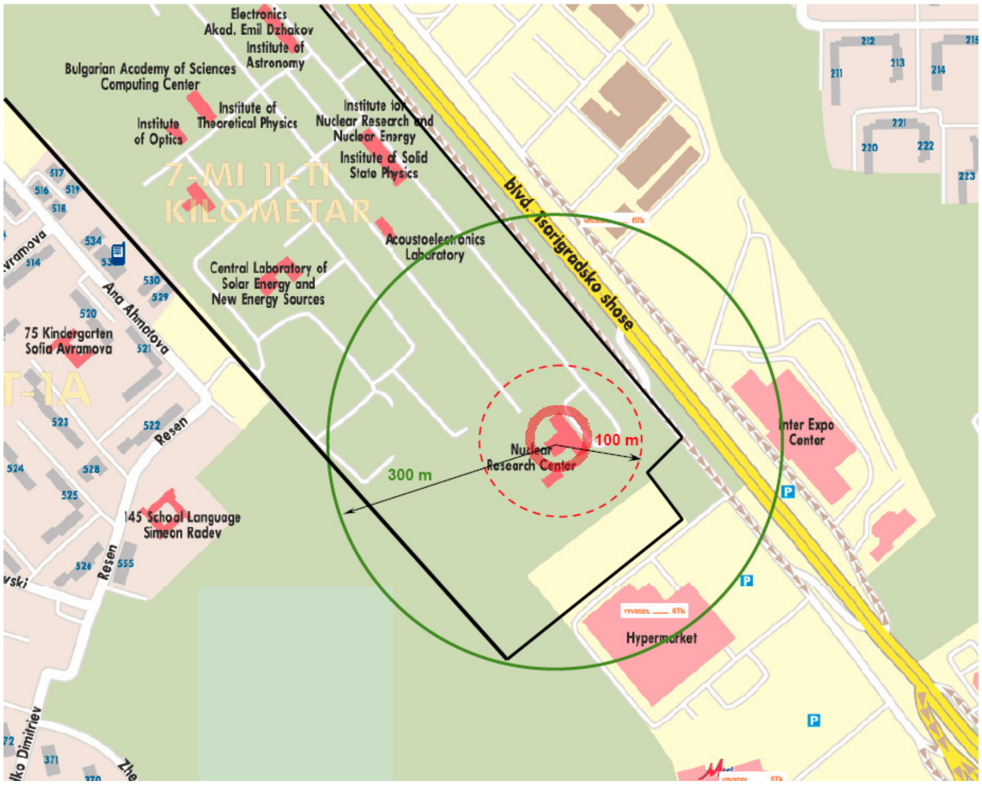

Figure 1 IRT – Sofia site map

The building in which the nuclear reactor IRT – Sofia is situated in the boundaries of the science complex of Bulgarian Academy of Sciences, city of Sofia. The city is located in the western part of Bulgaria, in a plain of the same name.

The reactor building is located at the eastern corner of the scientific complex site (Figure 1). The complex area is about 400 m wide (from south-west to north-east) and 1200 meters long (from south-east to north-west). The complex is surrounded by the complex fence. The distance from the reactor building to the complex fence varies from 100 to 1000 m. There is a transformer for reactor building power supply nearby. Inside the scientific complex the reactor building is surrounded by two rows of the physical defence fences (partly coincided with the external and internal fences). The internal fence provides strictly limited access to the reactor building. There is a police control at the entrance to the territory surrounded by the internal physical defence fence. The distance from the reactor building to this fence varies from 42 to 220 m. The external physical defence fence surrounds territory with limited access. The distance from the reactor building to this fence varies from 120 to 300 m.

The construction of any house is forbidden at the complex area. The complex area is bounded (130 m from the reactor building) on the north-east side by a boulevard with a heavy traffic. There is a big shopping centre “METRO” to the south-east (180 m) of the reactor building). The city residential buildings are located to the south-west, north-west and north-east of the reactor building. The nearest to the reactor building residential building is located in the south west direction at a distance exceeded 300 m. Accordingly in calculation receptor positions were selected along the 247.5° clockwise direction from the north.

3.3. Meteorological conditions

Pasquill stability classification scheme was used in the IRT – Sofia calculation. The site specific data were provided by Institute for Meteorology and Hydrology of Bulgarian Academy of Science (IMH - BAS) [7]. Wind rose data in eight equal azimuth sectors were available from the previous SAR version [2]. For the surface roughness characterization was used the roughness length equal to 1 m recommended for a city/woodland landscape [6].

4. PLUME results

The results of the IRT – Sofia PLUME calculation for the input data described in the previous section of this paper are shown in the Table 1 and depicted in Figure 2. The individual annual dose results are presented in three age groups i.e., one year old infants, ten year old children and adults.

Table 1: PC CREAM effective annual total dose results

Distance, km	Infant dose, μSv	Child dose, μSv	Adult dose, μSv
0.3	4.20E-01	3.60E-01	3.50E-01
0.4	3.10E-01	2.70E-01	2.70E-01
0.5	2.50E-01	2.20E-01	2.20E-01
0.6	2.10E-01	1.80E-01	1.80E-01
0.7	1.70E-01	1.50E-01	1.40E-01
0.8	1.50E-01	1.20E-01	1.20E-01
0.9	1.30E-01	1.10E-01	1.00E-01
1	1.20E-01	9.50E-02	9.20E-02
2	5.60E-02	4.30E-02	4.10E-02
3	3.50E-02	2.70E-02	2.50E-02
4	2.40E-02	1.80E-02	1.70E-02
5	1.80E-02	1.40E-02	1.30E-02

The maximum annual dose (0.42 μSv) as could be expected is encountered for infant at a minimum distance from the stack. In all cases annual doses are far below the dose limit of 1 mSv/y stated by Bulgarian Law [8] and European Council Directive [9].

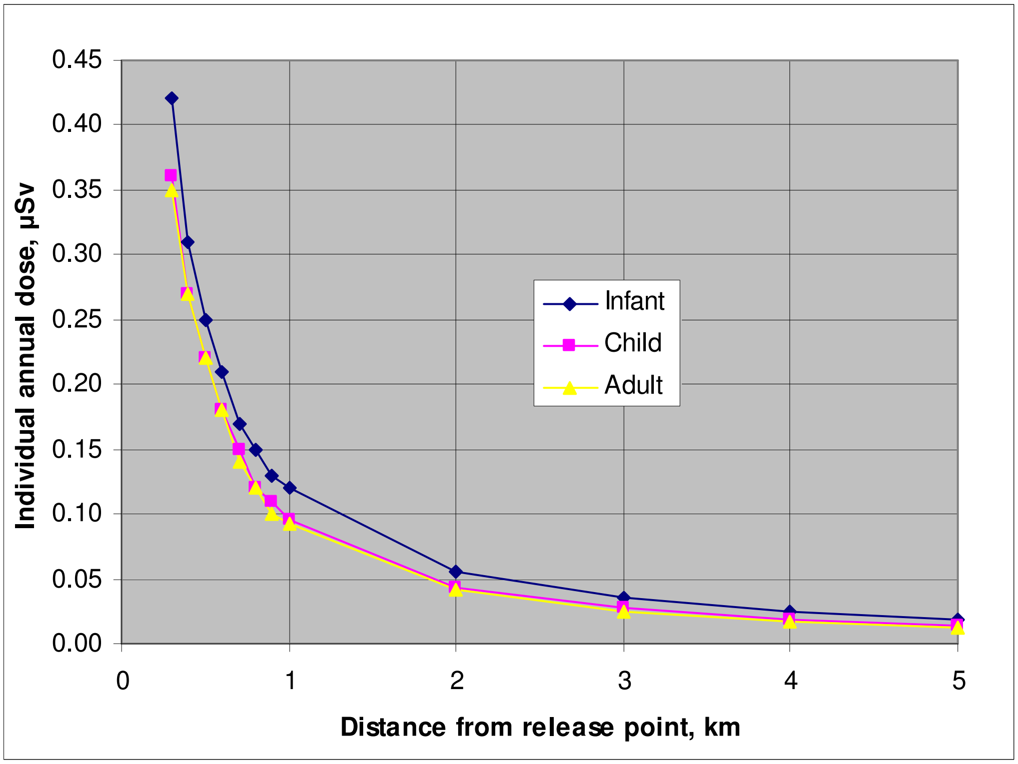

Figure 2: Effective annual dose distance dependence for the IRT - Sofia

5. Conclusions

The results of new radiological analyses for the IRT - Sofia normal operation are presented. These results include evaluation of C-14 and H-3 effluents that were not considered in the previous version of the IRT – Sofia SAR. The annual public doses were evaluated using the PLUME program from the PC CREAM98 system not applied previously for the IRT – Sofia normal operation analyses.

The results obtained demonstrate that even for the applied conservative assumptions for all three age groups annual doses are far below the dose limit of 1 mSv/y stated by Bulgarian Law [8] and European Council Directive [9]. More over the obtained results show that the IRT – Sofia will have negligible radiological impact to the environment.

The results of the presented radiological analyses will be included in to the next version of the IRT – Sofia Safety Analyses Report. The evaluated conservatively maximum rejection levels of airborne radioactive effluents will be presented in the Operated Limits and Conditions (OLC) section and the dose evaluations in the section showing radiological impact of the IRT – Sofia normal operation.

6. Acknowledgement

The authors would like to express deep thankfulness to ITN/PRI stuff (and especially to Dr. Jose Marques) for assistance in application of ITN/RPI developed methodology for H-3 and C-14 discharges evaluation as well as for training in the PC CREAM usage. We would like also to acknowledge the International Atomic Energy Agency (IAEA) (and especially Mr. Pablo Adelfang) for comprehensive assistance and support of expert missions.

7. References

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