Comparative dose rate assessment for VVR-S Nuclear Research Reactor Hot Cells decontamination

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Abstract. The present paper aims to assess and compare the dose rates potentially received by the workers involved in Hot Cells decontamination of a VVR-S nuclear research reactor under decommissioning. Dose rates were estimated based on the activity concentration in the floor hot spots using both standard and numerical methods (RESRAD Build code). The standard method assessment took into consideration the following exposure scenarios: (1) dosimetrist performing Hot Cell floor scanning to identify the hot spots (H*(10) measurements); (2) mechanical worker performing Hot Cell floor decontamination. The penetrant external dose is relatively high. The internal committed effective dose is low due to the worker mask filter efficiency. The dose rate assessed using RESRAD Build code is 32 % lower than the dose evaluated by standard method.

KEYWORDS: *Hot Cell, decommissioning, decontamination, dose rate*

1 INTRODUCTION

The IFIN-HH, VVR-S (water cooled and moderated nuclear research reactor) was operated between 1957 and 1997 having as main purpose radioisotopes production for medical and industrial applications and research in physics, biophysics and biochemistry. Due to safety reasons, the facility was under decommissioning between 2010 and 2020. During operation period, the radioisotopes production was performed using four Hot Cells. Detailed description of design, purpose and usage is presented in paper [1]. Hot Cells decommissioning consisted on waste evacuation, internal surfaces decontamination and dismantling (equipment's and stainless-steel lining). The wastes from the Hot Cells no. 3, 2 and 1 were remotely controlled evacuated using the mechanical arms as well as a trolley. The wastes from the Hot Cell no. 4 were manually evacuated due to the mechanical arms malfunction. The internal surfaces decontamination was performed manually. The internal surfaces were scanned after the waste's evacuation in order to identify the contamination level inside the Hot Cells. The measurements revealed that the floors were contaminated as a result of the irradiated substances spilling from vials or capsules during the operation period [1].

In order to prevent the workers over exposure, the dose equivalent was assessed for dosimetrists involved in contamination measurements and for mechanical workers who performed the floor decontamination.

2 METHODS

The dose assessment was estimated prior Hot Cell decontamination based on in-situ activity concentration measurements by standard method as well as by numerical calculation method using RESRAD-BUILD code modelling. The dose was estimated for Hot Cell no. 4, taking into account that the mechanical arms were defective.

2.1 Standard method

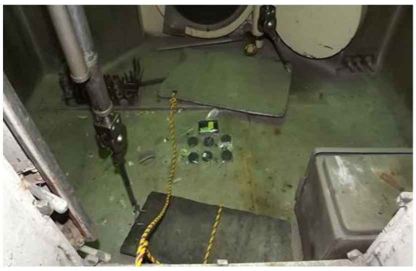
The standard method was used for the assessment of the potential exposure of the dosimetrist involved in the Hot Cell internal surfaces scanning as well as for the mechanic involved in Hot Cell surfaces' decontamination. The dosimetrist performed the ambient dose equivalent H*(10) direct measurements inside of the Hot Cell using a Thermo Scientific™ FH 40 G type portable digital survey meter, with FHZ 612-10 gamma dose rate probe according to a specific procedure [2]. For this purpose, the detector was placed less than 1 cm above the surface. Seven hot spots were identified on the Hot Cell floor [1].

During the scanning process the dosimetrist was located at about 70 cm of the hot area, along its axis (see Fig. 1) for 5 minutes. Then, parallel measurements were made using dosimeters with thermo-luminescent detectors (TLDS), GR-200A type high sensitivity tissue equivalent. The TLDS placed on each hot spot for an hour (see Fig. 2). A detailed description of the equipment used is presented in paper [1].

The hot spots activities were estimated by indirect measurement of the samples taken from about 100 cm^2 surface, using a gamma-ray spectrometry system with a GEM60P4-95 high-purity germanium coaxial detector (HPGe) [1]. The measurements were performed in compliance with EN/ISO IEC 17025:2005, according to [2–4] the specific procedures.

Figure 1: Floor contamination scanning [1]

Figure 2: TLDS emplacement [1]



The penetrant dose rate for the workers was calculated using the activity concentration of the radionuclides of each hot spot, according to the methodology presented in paper [1]. For this purpose, we assumed that the sampling yield for activity measurement is 10 % and the activity is concentrated in the hottest point (with a total activity equal with the sum of all hot spots).

The internal committed effective dose, E (50), was calculated considering that in the air is concentrated just 10^{-4} of the floor total activity and that the worker wears the mask having 99% filter retention efficiency [1].

For the mechanical worker dose calculation, it was considered a decontamination process performed in three steps (4 minutes each). In the first step, the worker sprayed decontaminant (DeconGel type 1108) on the floor, from 90 cm (on vertical axis) respective 45 cm (on horizontal axis) relative to the contaminated area (see Fig. 3 a). Then, the hydro gel coating was spread with a V-tooth trowel, the worker being positioned at 40 cm (on vertical axis) and 45 cm (on the horizontal axis) relative to the contaminated area (see Fig. 3 b). In the last step, the worker removed the gel film after drying from a position similar with the first step (see Fig. 3 c).

Figure 3: Floor decontamination [1]

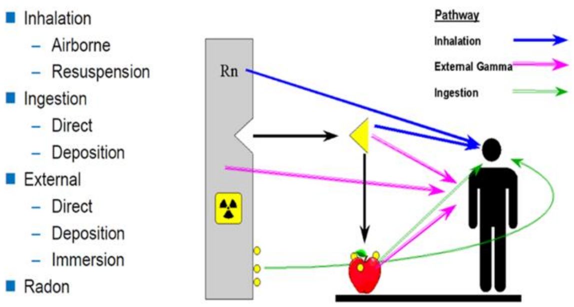
2.2 Numerical method - RESRAD-BUILD code modelling

Taking into account that the mechanical worker exposure could be much higher than that of the dosimetrist, a supplementary assessment was performed for the mechanical worker using RESRAD Build computer code (3.5 version). The code is specifically designed for radiation doses and risks estimation of RESidual RADioactive materials on radioactively contaminated sites [5].

The external radiation penetrating the walls, ceilings or floors is calculated based on the input parameters for shielding material type, thickness and density. Shielding material can be specified between each source-receptor pair. The internal exposure is calculated based on the air quality model that considers the air exchange between compartments (rooms) and with outdoor air [5].

The code takes into consideration the following exposure pathways [5]: the external exposure due to the source, materials deposited on the floor as well as air submersion, the internal exposure due to the airborne radioactive particulates inhalation, inhalation of the aerosol's indoor radon progeny, the inadvertent ingestion of the radioactive material directly from the source or materials deposited on the surfaces (see Fig. 4).

Figure 4: RESRAD Build code exposure pathway [5]



The total external dose at time t, over the exposure duration, ED, to a volume source containing radionuclide n in compartment i, $D_{iV}^{n}(t)$, was calculated using eq. 1:

$$D_{iV}^{n}(t) = (\frac{ED}{365})F_{in} \cdot F_i \cdot \overline{C_{sV}^{n}} \cdot DCF_{V}^{n} \cdot F_G^n \quad (1)$$

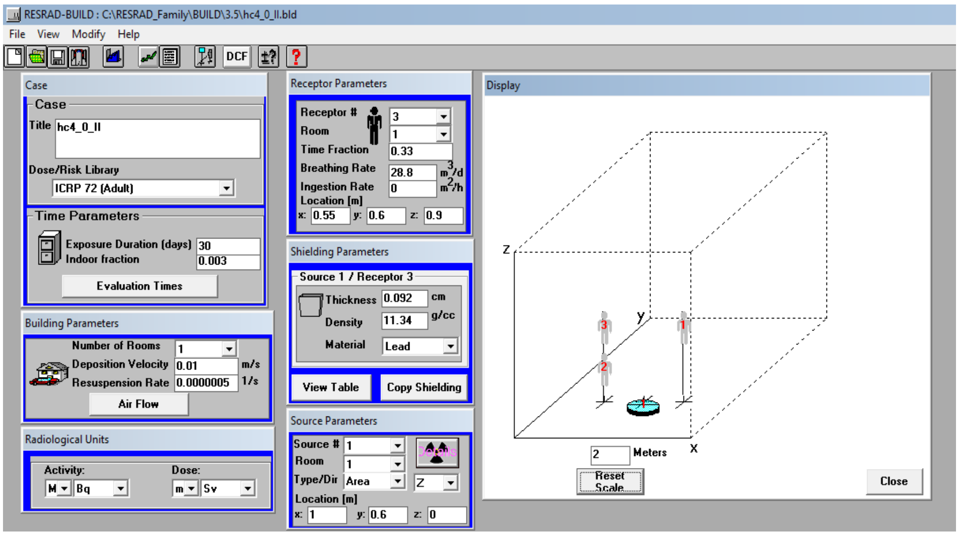
Where: ED = exposure duration (days), total length of time considered by the dose assessment, including intervals during which receptors may be absent from the building or a contaminated indoor location; 365 = time conversion factor (days/year); F_{in} = fraction of time spent indoors; F_i = fraction of time spent in compartment i; DCF_{V}^{n} = FGR-12 dose conversion factor for infinite volume source [(mrem/yr)/(pCi/g)]; F_G^n = geometrical factor for finite area, source thickness, shielding, source material, and position of receptor relative to the source for radionuclide n; $\overline{C_{sV}^{n}}$ = average volume source concentration (pCi/g) of radionuclide n over the exposure duration, ED, starting at time t.

For the studied case (Hot Cell no. 4), the following input data was taken into consideration (see Fig. 5): 1 compartment, the source - a 2 m radius circle located in the Hot Cell centre. RESRAD Build considers the area source as being a small thickness volume source (0.01 cm) with up to five layers any one contaminated [5]. Three distinct receptor (the mechanical workers) (x, y, z) positions relative to the source were also considered: R1 (1.45 m, 0.60 m, 0.90 m) – the receptor 1 performing decontaminant spraying, R2 (0.55 cm, 0.60 cm , 0.45 cm) - the receptor 2 spreading the decontaminant, R3 (0.55 m , 0.40 m, 0.90 m) – the receptor 3 removing the gel film.

The receptor inhalation rate is 28 m^3/day (1.2 m^3/h x 24 h); the receptor ingestion rate is 0 (the workers wearing respiratory mask) and the air release fraction (fraction of mechanically removed material that becomes airborne) is 0.0001. The removable fraction and time for source removal (source lifetime) are not required for this kind of scenario - building renovation; the source erosion rate (cm/day) is 0 due to very short time of the decontamination.

We assume that is necessary to perform 3 decontamination cycle, 12 min each. The dose rate was calculated: initially, after: 7 days, 14 days, 21 days and 28 days considering the exposure duration of 30 days and the indoor fraction (report between the working time and the exposure duration) of 0.003.

Figure 5: RESRAD Build code input parameters on floor decontamination



3 RESULTS

The mean value of the ambiental dose equivalent H*(10) for the six hot spots is 15.6 mSv/h determined by floor contamination scanning and respectively 28.6 mSv/h for TLD measurements. The main risk for dosimetrist during contamination scanning is due to A_7 hot spot. For this point, the ambiental dose equivalent is about 26 (27 for TLD) times higher than the mean value of the other six hot spots.

Table 1: Ambiental dose equivalent H*(10) [1]

Hot spots	H*(10)scan [mSv/h]	$H^*(10)_{TLD}$ [mSv/h]	Probe position above the hot spot [cm]	TLD position toward the hot spot [cm]
A_1	23.00 ± 2.76	31.70 ± 4.08	1.22	1.04
A_2	9.40 ± 1.13	31.80 ± 4.54	0.90	0.49
A_3	17.00 ± 2.04	31.87 ± 4.71	0.83	0.61
A_4	15.00 ± 1.08	41.40 ± 7.63	0.89	0.53
A_5	18.00 ± 2.16	23.97 ± 2.37	0.57	0.50
A_6	11.00 ± 1.32	10.70 ± 0.94	0.90	0.91
A_7	400.00± 20.00	782.00 ± 6.07	6.49	4.64

In the hottest point, A_7, ^{60}Co activity (4.57E+08 Bq) is 3 orders of magnitude higher than the mean value of the other six hot spots (3.60E+05Bq) and the results for the ambient dose rate measurements are confirmed. For ^{134}Cs, ^{137}Cs and ^{108m}Ag, the activities are 3 and 2 times lower than for ^{60}Co activity.

The penetrant dose rate for the workers was calculated by standard method assuming that the sampling yield for the activity measurement is 10% and that the entire activity is concentrated in the hottest point. The values are presented in Table 2. According to Romanian legislation the professional exposed dose limit is 20 mSv/year, and for 2000 working hours/year the dose rate is 10 µSv/hour.

For the dosimetrist, the penetrant dose rate is 3.39 mSv/h, respectively 0.28 mSv for five minutes exposure. The risk is quite high, consequently the working time for future activities must not be longer than 5.9 hours/year. For the mechanical worker, the penetrant dose rate is 7.97mSv/h, 1.59 mSv for 12 minutes. The risk is also very high, consequently the working time must be less than 2.5 hours/year for future activities.
The internal committed effective dose E (50) was calculated for mechanical worker performing floor decontamination (see Table 2). We assume that inside of the hot cell is spread only 10^{-4} of the total

activity and the worker wearing a mask with filter (99% retention efficiency). The internal irradiation could be due to the A_7 the hottest point presence (1.62 μSv). The dose is low enough and the internal irradiation does not affect the worker due to the high efficiency of the filter [1].

Table 2: Dose rate assessed by standard method

Hot spot	$\dot{H}_p(10)_{scan}$ [mSv/h]	$\dot{H}_p(10)_{decon}$ [mSv/h]	$E(50)_{decon}$ [mSv]
A_1	5.36E-03	1.12E-02	3.33E-06
A_2	1.18E-03	2.45E-03	7.48E-07
A_3	2.09E-03	4.71E-03	1.14E-06
A_4	2.41E-03	5.85E-03	1.16E-06
A_5	1.19E-03	2.87E-03	5.74E-07
A_6	2.45E-03	5.52E-03	8.55E-07
A_7	3.37E+00	7.93E+00	1.62E-03
Total	3.39E+00	7.97E+00	1.63E-03

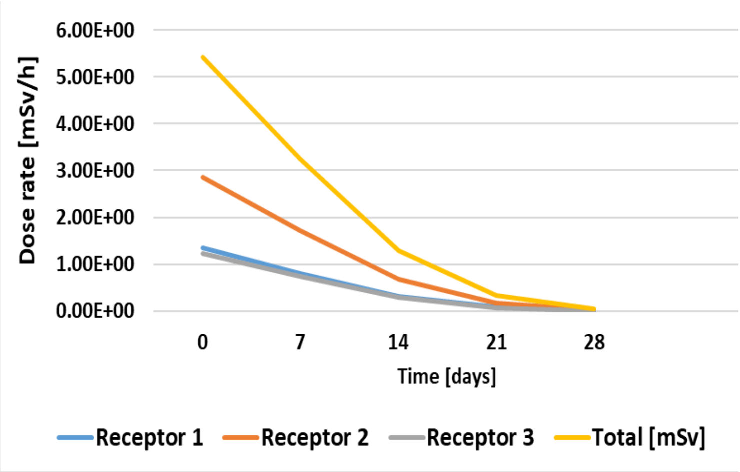
The dose rates for mechanical workers (receptors) who performed the floor decontamination, assessed using RESRAD Build code modelling, are presented in Table 3 as well as in the Fig. 6. The dose was calculated based on hottest spot activity (A_7) considering a 30 days exposure duration. The assessment was performed: initially, after 7 days, 14 days, 21 days and 28 days respectively considering that the initial activity (Ai) decreased in time from 100% to 15%.

Table 3: Dose rate assessed by numerical method

Time [days]	A_i [%]	A_i	R1 [mSv/h]	R2 [mSv/h]	R3 [mSv/h]	Total dose rate [mSv/h]
0	100	4.57E+09	1.34E+00	2.86E+00	1.22E+00	5.42E+00
7	60	2.74E+09	8.04E-01	1.71E+00	7.30E-01	3.24E+00
14	40	1.10E+09	3.20E-01	6.80E-01	2.91E-01	1.29E+00
21	25	2.74E+08	7.97E-02	1.70E-01	7.25E-02	3.22E-01
28	15	4.11E+07	1.20E-02	2.54E-02	1.09E-02	4.82E-02

At the inception of decontamination process, the highest potential dose rate was received by the receptor 2 (R2) who spread the decontaminant on the floor. The resulted dose is similar for receptor 1 (R1) performing decontaminant spraying and receptor 3 (R3) performing decontaminant coating gel removal.

Figure 6: RESRAD Build dose rate



The potential dose received by R2 is 2.1 times higher than the dose received by R1 and respectively 2.3 times higher for R3. Although, dose rate decreased after 28 days (the end of floor surface decontamination) the value it is at about 5 times greater than the limit of 10 µSv/hour.

By comparing the total initial dose rates for a mechanical worker performing all decontamination steps, it can be noticed that the RESRAD dose (5.42 mSv/h) is 1.5 lower than the dose evaluated by standard method (7.97 mSv/h). The difference can be explained by RESRAD model complexity. Consequently, the working time of the mechanical worker must be less than 3.7 hours/year. The risk is very high due to the fact that the decontamination was performed manually.

The radiation level remains significant after thee decontamination cycles due to the fact that the stainless-steel lining is activated.

4 CONCLUSIONS

Dose rates received during a nuclear research reactor Hot Cells decontamination were assessed by a standard as well as a numerical method.

For both assessments resulted that the dose for professional exposed is higher than the limit. The risk is very high due to the fact that decontamination process was performed manually. After three decontamination cycles, the radiation level remains significant due to the fact that the stainless-steel lining is activated.

The dose rates calculated with RESRAD Build code are lower and more accurately than the those obtained by standard method due to model complexity. In spite of small differences, it can conclude that both methodologies are in agreement and useful for similar exposure situations.

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