MODELLING OF THE DOSE RATES AND RISKS ARISING FROM HOT-CELLS CLEAN-UP ACTIVITIES IN THE DECOMMISSIONING OF THE VVR-S RESEARCH REACTOR

A.O. PAVELESCU, V. POPA, M. DRĂGUŞIN

"Horia Hulubei" National Institute of Physics and Nuclear Engineering (IFIN-HH),
P.O. Box MG-6, RO-077125
Bucharest-Magurele, Romania
E-mail: apavelescu@ifin.nipne.ro, vpopa@ifin.nipne.ro, dragusin@ifin.nipne.ro

Abstract. In the paper, the dose rate and the associated risk related to the clean-up and decontamination of hot cell no. 4 were calculated using RESRAD 3.5 Build code. Three nuclide sources were considered: Co-60, Cs-137, Sr-90, these nuclides most probable in the hot cell. Using the measured doses, the activity of these sources was estimated. This was done, due to the lack of a spectroscopy analysis in order to determine the exact nuclide sources and their activity. The presumed time for clean-up and decontamination operation is 1 month, and therefore the estimation was made for this period. Due to quite high dose/risks involved, complying with the ALARA principle, the utilization of a robot is proposed in stead of a human operator.

Key words: research reactor, hot cells cleanup, dose rate modelling.

1. INTRODUCTION

The VVR-S research reactor was shut down 13 years ago, in 1997, after 40 years of operation, and therefore a significant contribution to the radionuclide inventory can only have the radionuclides with half live higher than one year.

Radioisotope production generated a significant contamination in the reactor main building, ventilation system and radioactive leakage drainage, overflow and collecting system. Major radioactive contaminants generated by this activity, with the half life higher than one year, are: Co-60, Cs-134, Cs-137, Sr-90, Eu-152, U-238 and Am-241 [1].

Four hot cells, a transfer room, a preparation room (chemical laboratory) and a decontamination solution preparation room are placed in the basement of the reactor hall for the processing the radioactive materials coming from the reactor. The hot cells and the transfer room are disposed one next to another and the communication between them was performed through a transfer channel in which a transfer truck, carried materials inside the hot cells.

Hot cells 2, 3 and 4 were used for processing the irradiated materials. The access to the hot cells for different activities is made through sealed cast iron doors acting as biological shielding. The doors are placed opposite the wall and are fitted with windows and handling devices.

The hot cells are ventilated through suction and the radioactive gas inrush in the working rooms can be avoided by maintaining an internal depression between 3÷5 mm water columns compared to the neighbouring rooms. The water containing radioactive impurities run off through the openings in the hot cells floors in the radioactive water collection system and are directed to the liquid radioactive waste tank (30 m^3).

Hot cells are highly contaminated and contain a lot of radioactive sources and activated materials. For this reason, this area is inaccessible and contamination measurements are not possible. The total activity of materials abandoned in these rooms it is not known, but it is expected to be of about 15 Ci (0.555 TBq) [2]. During the VVR-S clean-up these sources and materials will be evacuated.

The cleanup of the hot cells will be carried out under preservation license on the basis of an Activity Plan approved by Romanian National Commission of Nuclear Activities (CNCAN) [1].
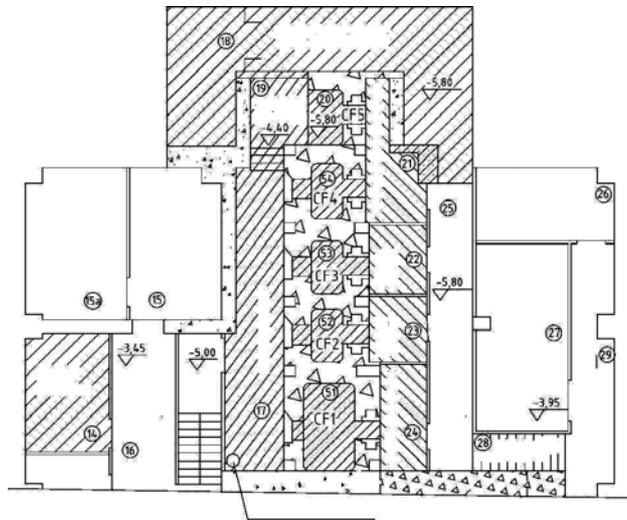
2. LAYOUT OF THE HOT CELLS

Fig. 1 – The hot cells complex (CF1-CF5) [1].

The hot cell no. 4 denoted CF4 in Fig. 1 above, has the following dimensions: 2 000 mm length, 1 200 mm wide, 2 600 mm height (2 000 mm without the light compartment) [1]. The access in hot cell 4, is made by a closed

metallic door from cast iron with a thickness of 350 mm towards room 17 and a thin door (for protection against contamination) made from stainless steel towards the hot cell. The access corridor dimensions are: 1 250 mm length; 600 mm wide; 1 200 mm height. The hot cells are entirely covered with stainless steel plate.

Two mechanical hands were utilized for manipulation the objects inside the hot cells. The visibility was assured de by lead glass, and the illumination by lamps introduced in separated niches into the ceiling. The hot cells are ventilated inside ensuring an inside depression of 5 mm H_2O versus the exterior. The air is evacuated from hot cells through HEPA filters.

To calculate the biological shielding of the hot cells, it has been considered that the highest activity which one works with is 2.69×10^4 Ci (aprox. 1 PBq) and the gamma radiation energy is 1.65 MeV. [1].

The biological shielding has the following characteristics [1]:
– The biological shield in the upper side is achieved through a 2 m concrete layer of 2.3 g/cm^3 density and laterally through a concrete layer of 75 cm of 4.2 g/cm^3;
– Lead-glass eye-sleds, with 0.72 m thickness;
– Between the hot cells, there are 0.65 cm thickness heavy concrete walls.

3. RADIOLOGICAL SITUATION

The presumed radionuclide inventory in 2003 is presented below in Table 1:

Table 1 [3]

Approximate contamination nuclide inventory and their half-life time in the hot-cells, reported in 2003, for the working activity cease in 1998

Radionuclide	$T_{1/2}$	Observations	Radionuclide	$T_{1/2}$	Observations
I-131	8.04 d	Fission product	Sr-90	29.1 y	Fission product
Mo-99	2.75 d	Fission product	Cs-137	30 y	Fission product
Au-198	2.69 d	Radioisotope	Zn-65	244 d	Radioisotope
Ir-192	74 d	Radioisotope	Cr-51	27.7d	Radioisotope
Y-90	2.62 d	Radioisotope	Fe-59	45.1 d	Radioisotope
Br-82	1.47 d	Radioisotope	Sc-46	83.8 d	Radioisotope
K-42	12.44 h	Radioisotope	La-140	1.68 d	Radioisotope
P-32	14.3 d	Radioisotope	Na-24	15 h	Radioisotope
Tc-99	6.02 h	Fission product	Co-60	5.27 y	Radioisotope
Cs-134	2.06 y	Fission product	Mo-99	2.75 d	Radioisotope
Ba-133	10.7 y	Radioisotope	Ni-63	96 y	Radioisotope

4. DOSE/RISK MODELLING USING RESRAD COMPUTER CODES PACKAGE

4.1. RESRAD Build 3.5 Code

RESRAD is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials (Fig. 2) [4]. The only code designated by Department Of Energy for the evaluation of radioactively contaminated sites. [4]

United States National Regulatory Commission (NRC) has approved the use of RESRAD for dose evaluation by licensees involved in decommissioning, NRC staff evaluation of waste disposal requests and dose evaluation of sites being reviewed by NRC.

RESRAD has been applied to over 300 sites in the U.S. and other countries. Environmental Protection Agency (EPA) Science Advisory Board reviewed the RESRAD model. EPA used RESRAD in rulemaking on radiation site cleanup regulations.

RESRAD code has been verified and has undergone several benchmarking analyses, and has been included in the IAEA's VAMP and BIOMOVS II codes to compare environmental transport models. RESRAD training workshops have been held at DOE, NRC, and EPA headquarters and Regional offices. Around 800 people have been trained at these workshops and RESRAD has been used by several universities as a teaching tool as well.
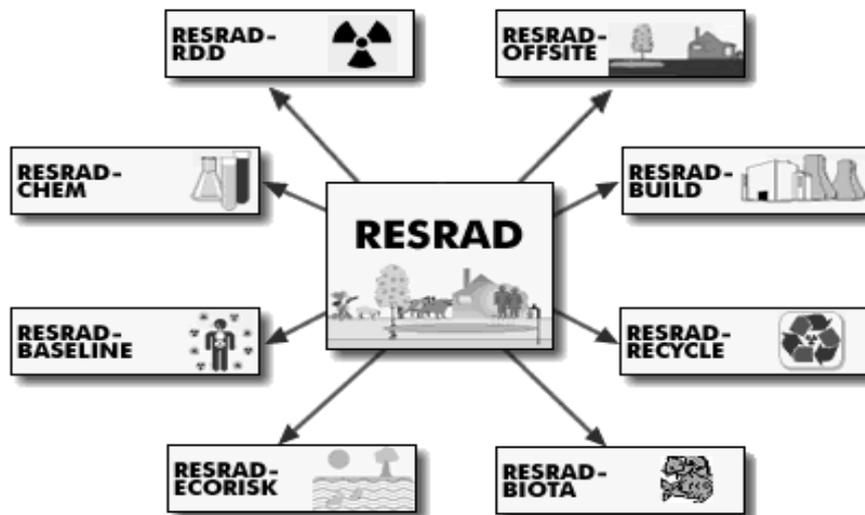

Fig. 2 – RESRAD computer code package [4].

The RESRAD Build Code is a model for analyzing the radiological doses resulting from the remediation and occupancy of buildings contaminated with radioactive material (Fig. 3) with the following features [5]:

– Considers external exposure, inhalation of dust and radon, and ingestion of soil/dust.
– Up to 10 sources and 10 receptors can be modelled.
– Sources geometry can be point, line, plane, or volume.
– Building can be any structure composed of up to three compartments.
– Radioactive contamination can be on surface or in building material.
– Exposure scenarios considered include building occupancy (residential use and office worker) and building remediation (decontamination worker and building renovation worker).
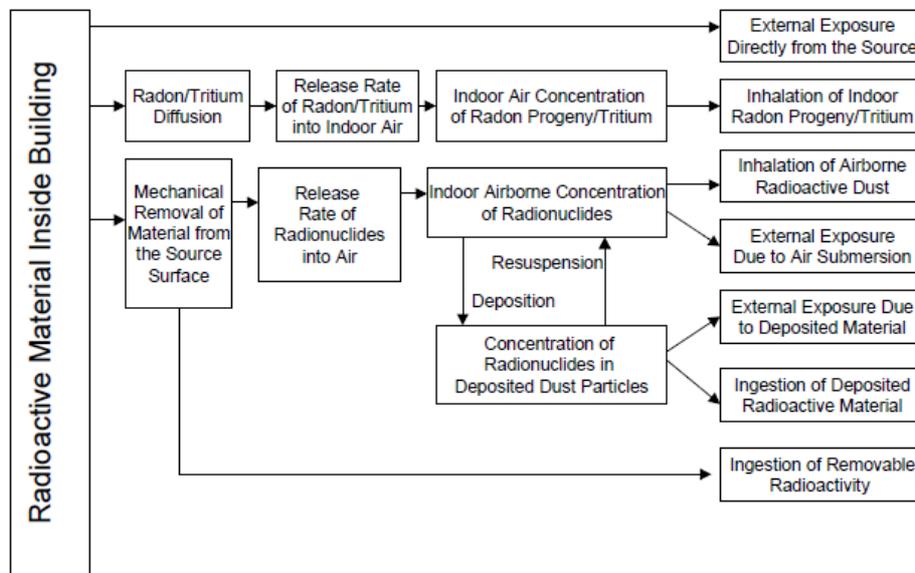

Fig. 3 – Exposure Pathways Incorporated into the RESRAD-BUILD Computer Code [6].

Table 2

Key parameters used in the building occupancy and building renovation scenarios [7]

Parameter	Unit	Building Occupancy[a]	Building Renovation[b]	Remarks
Exposure duration	days (d)	365.25	179.00	To match the occupancy period of 365.25 days in NUREG/CR-5512 building occupancy scenario (Beyeler et al. 1999 [8]) and renovation period of 179 days in NUREG/CR-5512 building renovation scenario (Wernig et al. 1999 [9]).

Indoor fraction	_[c]	0.267	0.351	To match the 97.5 d/yr time in building in NUREG/CR-5512 building occupancy scenario (Beyeler et al. 1999) and 62.83 days spent in the building during renovation period in NUREG/CR-5512 building renovation scenario (Wernig et al. 1999 [9]).
Receptor location	m	0, 0, 1	0, 0, 1	At 1-m from the center of the source.
Receptor inhalation rate	m^3/d	33.6	38.4	For building occupancy scenario it matches with 1.4 m^3/h breathing rates in NUREG/CR-5512 (Beyeler et al. 1999 [8]) and for building renovation scenario it matches with 1.6 m3/h breathing rate of moderate activity given in the EPA Exposure Factor Handbook (EPA 1997 [9]).
Receptor indirect ingestion rate	m^2/h	1.12×10^{-4}	0	Value for the building occupancy scenario is the mean value from the distribution and for the building renovation scenario it is assumed the ingestion is only from the direct contact with the source.
Source type -	_	Area	Volume	For building occupancy scenario it is assumed that contamination is only on the surfaces, whereas for the building renovation scenario is volumetric
Direct ingestion rate	1/h (area) g/h (volume)	3.06×10^{-6}	0.052	Calculated from the default ingestion rate of 1.1×10^{-4} m^2/h in NUREG/CR-5512 building occupancy scenario (Beyeler et al. 1999 [8]). The effective transfer rate from NUREG/CR-5512 building renovation scenario for ingestion of loose dust to the hands and mouth during building renovation (Wernig et al., 1999 [9]).
Air release fraction	_	0.357	0.1	For the building occupancy scenario, it is the mean value from the parameter distribution. For the building renovation scenario, a smaller fraction is respirable.
Removable fraction	_	0.1	NR[d]	10% of the contamination is removable (NUREG/CR-5512 building occupancy scenario default [10]). The parameter is not required for the volume source.
Time for source removal or source lifetime	d	10,000	NR	Value for the building occupancy scenario is the most likely value from the parameter distribution. The parameter is not required for the volume source.
Source erosion rate	cm/d	NR	4.1×10^{-4}	For the building renovation scenario, it is assumed that the total source thickness of 15 cm can be removed in 100 years of building life.

[a] Parameter values used in the building occupancy scenario.
[b] Parameter values used in the building renovation scenario.
[c] A dash indicates that the parameter is dimensionless.
[d] NR = parameter not required for the analysis.

4.2. CALCULATION OF THE INTAKE RATES
AND TIME INTEGRATED CANCER RISKS

RESRAD is able to calculate lifetime cancer risks resulting from radiation exposure. The radiation risk can be computed by using the U.S. Environmental Protection Agency (EPA) risk coefficients with the exposure rate (for the external radiation pathways) or the total intake amount (for internal exposure pathways).

The EPA risk coefficients are estimates of risk per unit of exposure to radiation or intake of radionuclides that use age- and sex-specific coefficients for individual organs, along with organ-specific dose conversion factors (DCF). The EPA risk coefficients are characterized as best-estimate values of the age-averaged lifetime excess cancer incidence risk or cancer fatality risk per unit of intake or exposure for the radionuclide of concern. Detailed information on the derivation of EPA risk coefficients and their application can be found in several EPA documents (EPA 1991a,b; 1994, 1997; Eckerman et al. 1999 [11]). The methodology used in the RESRAD code for estimating cancer risks follows the EPA risk assessment guidance (EPA 1997) and is presented in the following section.

Intake rates calculated by the RESRAD code are listed in the INTRISK.REP report generated after each execution. They are listed by radionuclide and pathway and correspond to specific times. Intake rates for inhalation and ingestion pathways are calculated first for all of the principal radionuclides and then multiplied by the risk coefficients to estimate cancer risks.

For inhalation and soil ingestion pathways (p = 2 and 8, respectively), the intake rates (Bq/yr or pCi/yr) can be calculated by using the following Equation (1) [11]:

$$(\text{Intake})_{j,p}(t) = \sum_{i=1}^{M} \text{ETF}_{j,p}(t) \times \text{SF}_{i,j}(t) \times S_i(O) \times \text{BRF}_{i,j}, \tag{1}$$

where: $(\text{Intake})_{j,p}$ (t) = intake rate of radionuclide j at time t [Bq/yr or pCi/yr]; M = the number of initially existent radionuclides; $\text{ETF}_{j,p}$ (t) = environmental transport factor for radionuclide j at time t [g/yr]; p = primary index of pathway; $\text{SF}_{ij}(t)$ = source factor; i,j = index of radionuclide (i for the initially existent radionuclide and j for the radionuclides in the decay chain of radionuclide i); $S_i(0)$= initial soil concentration of radionuclide i at time 0.

The cancer risk at a certain time point from external exposure can be estimated directly by using the risk coefficients, which are the excess cancer risks per year of exposure per unit of soil concentration. Because the risk coefficients are derived on the basis of the assumptions that the contamination source is infinite both in depth and lateral extension and that there is no cover material on top of the contaminated soil, it is necessary to modify the risk coefficients with the cover and

depth, shape, and area factors to reflect the actual conditions. Non-continuous exposure throughout a year also requires that the occupancy factor be considered when calculating the cancer risks.

Consequently, the RESRAD code uses the environmental transport factor for the external radiation pathway, along with the risk coefficient and exposure duration, to calculate the excess cancer risks as seen in Equation (2) [11]:

$$(\text{Cancerrisk})_{j,1}(t) = \sum_{i=1}^{M} \text{ETF}_{j,1}(t) \times \text{SF}_{ij}(t) \times S_i(O) \times \text{BRF}_{i,j} \times \text{RC}_{j,1} \times \text{ED}, \qquad (2)$$

where: $\text{RC}_{j,1}$ = risk coefficient for external radiation [risk/yr]/(pCi/g]; ED = exposure duration [30 yr].

For the inhalation and ingestion pathways, the cancer risks at a certain time point are calculated as the products of intake rates, risk coefficients, and exposure duration. Unlike the intake rates, cancer risks from inhalation of radon and its decay progeny are reported as total risks that include radon and progeny contributions. Therefore, the radon risks are the sums of the products of the individual radon or progeny intake rates and their risk coefficients.

4.3. HOT CELL NO. 4 MODEL DESCRIPTION

The wastes from HC4 are indentified using photos obtained with the occasion of opening the HC4 from 24.07.2006 for dose rate measuring (see Fig. 4).

Fig. 4 – Interior of the hot cell no. 4, opened in July 2006 [12].

Table 2

Dose rate measurements in hot cell 4 (in 24.07.2006 dosimetric service conf. AC-PO-DDR-501-01) [12]

No.	Device	Detector	Measuring Location	Measuring Value
1	Eberline	γ	Margins of opened exterior iron-cast protection door	42 μSv/h
2			Margins of plated interior door	280 μSv/h
3			Protection metal plate of the visitation window from transfer truck tunnel	200 μSv/h
4			HC4 Centre at 0,5 m above the floor	1.4 mSv/h
5			HEPA filter level (near the filter)	0.7 mSv/h
6			Room Centre, floor level	9.2 mSv/h
7			Room centre, 1,5 m above floor level	0.3 mSv/h
8			Near floor drainage	4.4 mSv/h
9			Near the wall, left of the entrance	1.4 mSv/h
10			Middle waste tray. Probably the 2 bars from plastic bag contain sources	18 mSv/h

Due to the fact that a spectroscopy analysis could not be made in the short period of HC4 opening, only dose rates were determined. This data was used to estimate the existing activity using Rad Pro 3.26 Software [13]. For that purpose, three most probable radiation sources were considered in the current model: Co-60, Cs-137 and Sr-90.
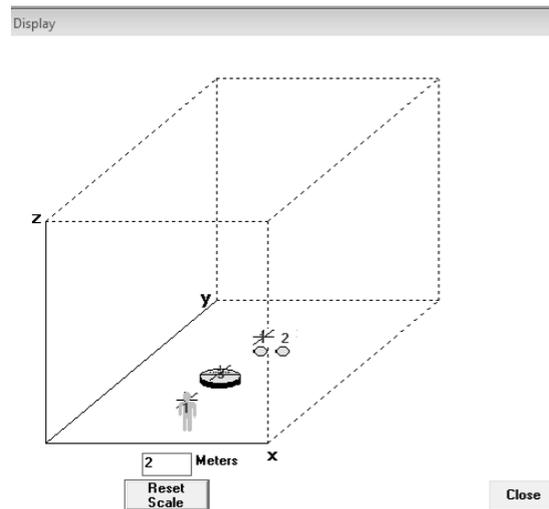

Fig. 5 – Hot cell no. 4 interactive model from RESRAD BUILD 3.5 module.

4.4. INPUT PARAMETERS OF THE PROPOSED CLEAN-UP SCENARIO

Input parameters of the model are the following**:**

a) Dose/Risk Library ICRP72.

b) Time parameters:
- Exposure duration: 30 days, considering this is the necessary amount of time for clean –up and decontaminate HC4
- Indoor fraction: 1
- Times for calculation (years): 1 day (0.002 years), 1 week (0.02 years), 2 weeks (0.04), 3 weeks (0.06 years), 1 month (0.08 years).
- For time integration, maximum number of points for dose/risk: 17.

c) Building parameters
- Number of rooms: 1
- Dust particle deposition velocity: 0.005 m/s
- Dust particle resuspention rate: 0.00005 1/s
- Room Exchange Rate: 2 1/h
- Area: 2.4 m^2
- Height: 2.6 m
- Input/output air flow: 12.48 m^3/h.

d) Receptor parameters
- Receptor: 1
- Indoor Time fraction: 1
- Breathing rate: 20 m^3/d
- Ingestion rate: 0.0002 m^2/h
- Location:
  o x: 0.8 m, y: 0.6, z: 0.

e) Shielding parameters: No shielding.

f) Source parameters:
- Hypothetical source of Co-60 source on a tray
  o Location:
    - x: 0.8 m, y: 1.5 m, z: 0 m
  o Type: Point
  o Geometry: Circular
  o Area: 0.00005 m^2
  o Release:
    - Air fraction: 0.1
    - Direct ingestion: 0 1/h
    - Removable fraction: 1
    - Lifetime: 0.00069
 o Calculated activity from measured dose rate using Rad Pro Calculator 3.26 Software : 15.8 mCi (584.6 MBq).
- Hypothetical source of Cs-137 source on a tray
  o Location:
    - x: 1 m, y: 1.5 m, z: 0 m

o Type: Point
o Geometry: Circular
o Area: 0.00005 m^2
o Release:
  • Air fraction: 0.1
  • Direct ingestion: 0 1/h
  • Removable fraction: 1
  • Lifetime: 0.00069
o Calculated activity from measured dose rate using Rad Pro Calculator 3.26 Software: 63.6 mCi.
– Hypothetical Sr-90 contamination on the floor sink area
  o Location:
    • x: 0.8 m, y: 1 m, z: 0 m
  o Type: Area
  o Geometry: Circular
  o Area: 0.25 m^2
  o Release:
    • Air fraction: 0.1
    • Direct ingestion: 0.1 1/h
    • Removable fraction: 1
    • Lifetime: 30 d
  o Calculated activity from measured dose rate using Rad Pro Calculator 3.26 Software : 15.5 mCi (573.5 MBq).
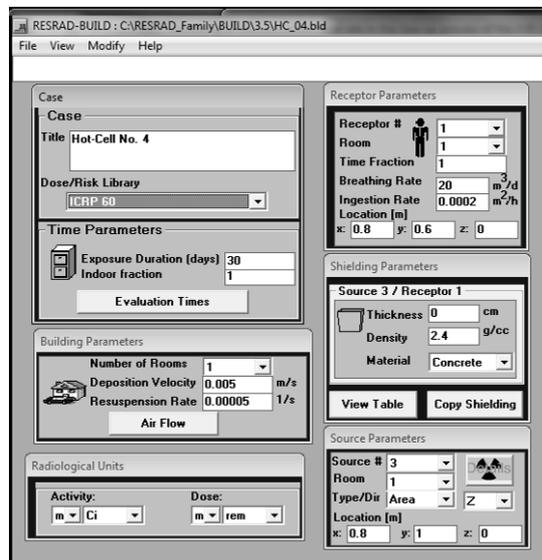
Fig. 6 – RESRAD BUILD 3.5 module graphical user interface for parameter input.

4.5. RESULTS

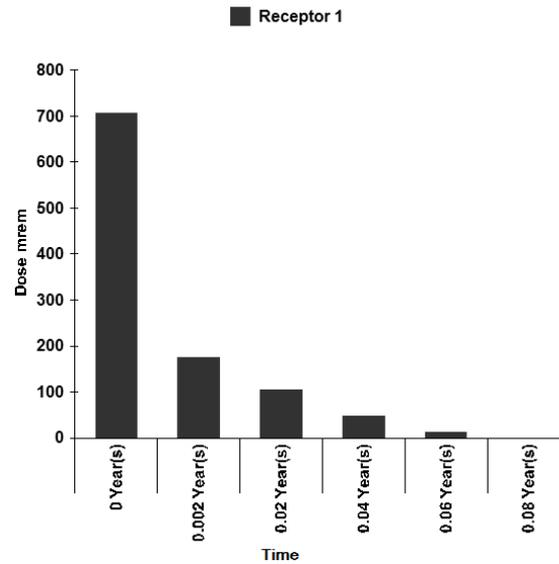The obtained results are illustrated in Figs. 7–12:

Fig. 7 – Received dose by time and receptor for summed nuclides and external exposure pathways only. Dose decreases from 7 mSv and to 0 after 1 month of operations (1 mrem = 0.01 mSv).
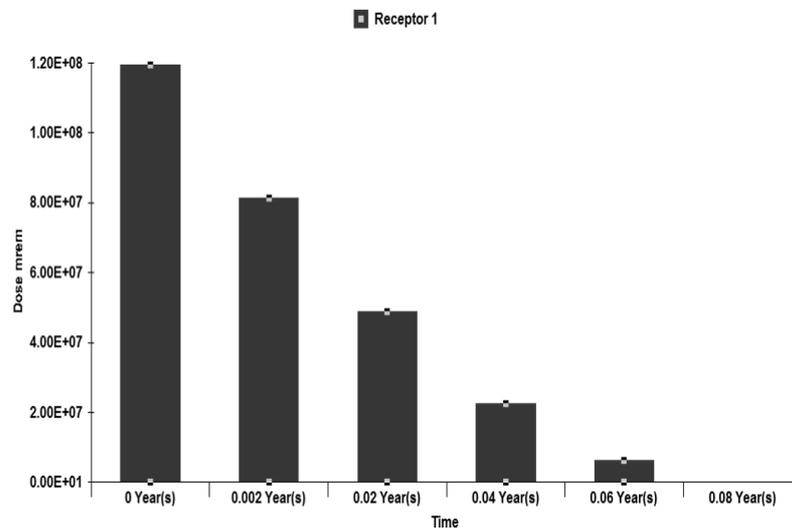

Fig. 8 – Received dose by time and receptor for summed nuclides, summed sources and summed exposure pathways. Dose decreases from 1.2 MSv to 0 after 1 month of operations
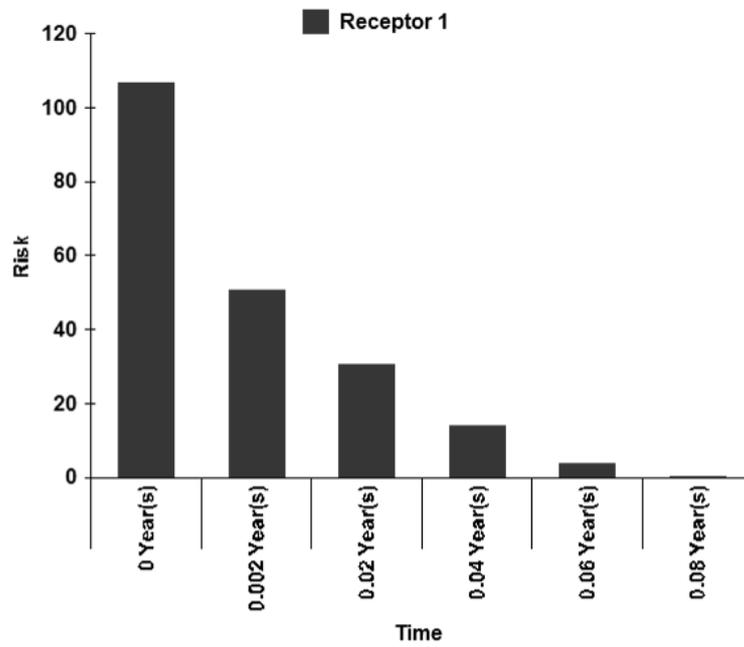(1 mrem = 0.01 mSv).

Fig. 9 – Risk by time and receptor for summed nuclides, summed sources
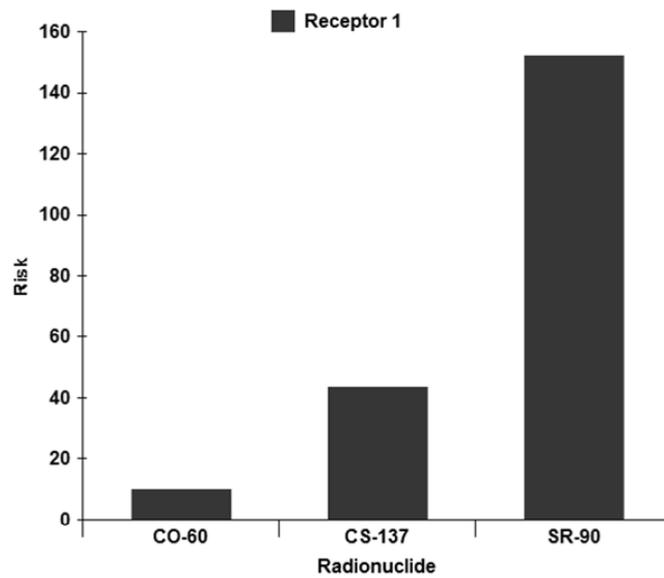and summed exposure pathways.

Fig. 10 – Risk by nuclide and receptor for summed time, summed sources
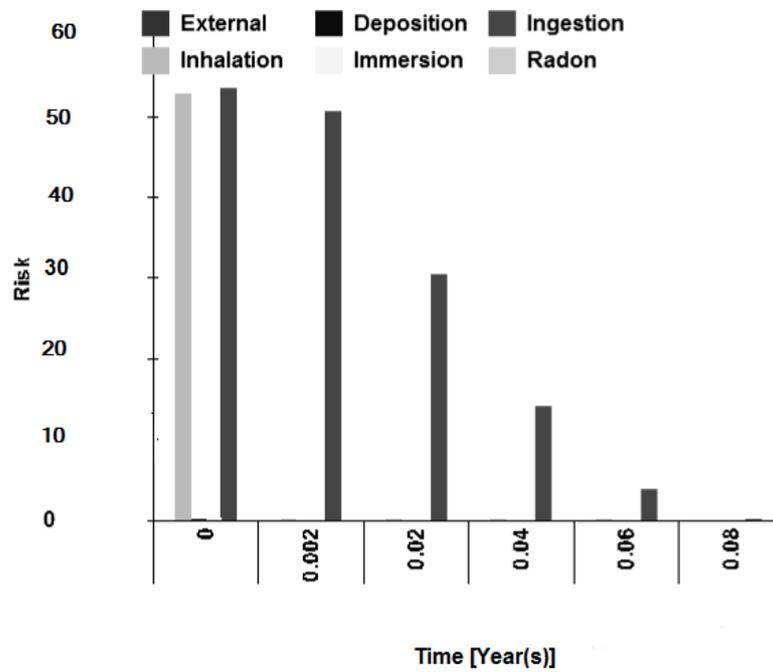and summed exposure pathways.

Fig. 11 – Risk by time and exposure pathway for summed nuclides, summed sources for receptor 1.
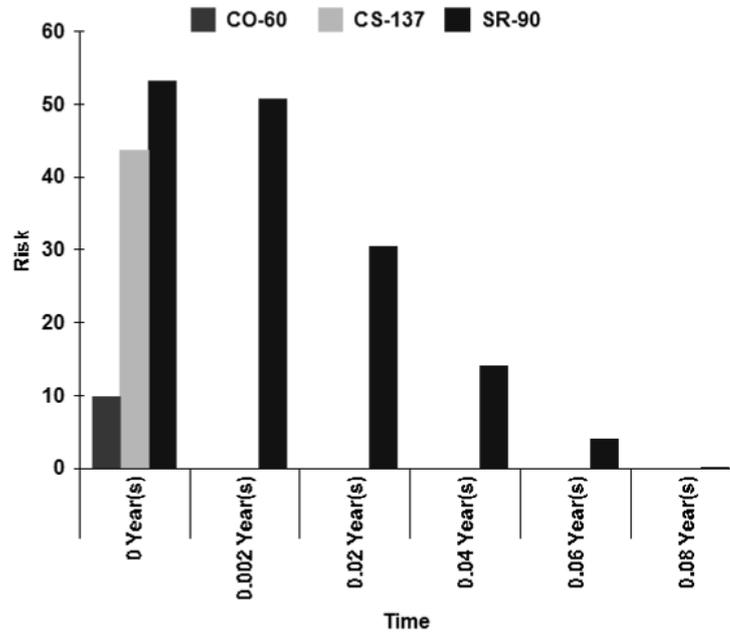

Fig. 12 – Risk by time and nuclide for summed sources, summed exposure pathways for receptor 1.

5. CLEAN-UP AND DECONTAMINATION ACTIVITIES

The interior of HC 4 will be decontaminated by washing with a water jet with detergent first and then only water. A pressure installation will be used in this activity and consequently small fine drops of water will be produced, drops that can contaminate the protection suit and the HC 4 transfer corridor.

The decontamination solution is evacuated from HC 4 by removing the tap from the room drainage hole using the manipulating hand. If the drainage is stuck, the decontamination solution will be recovered by peristaltic pomp (80 l/h) and are flowed in the active sewage pipe from corridor 17.

When reaching an acceptable dose rate (60—100) μSv/d) measured in the room centre, the operator can enter in the HC 4 and in order to decontaminate the walls with a wet cloths using organic solvents. These cloths are collected in used recipients situated in the transfer corridor. The operation will continue until reaching of dose rate, measured in the centre of HC 4 lower than 60 μSv/d. Due to high dose/risks involved, complying with the ALARA principle, the utilization of a robot is proposed in stead of a human operator (Fig. 13). Using this robot, endowed with a high versatility arm (6 degree of freedom), the room will be cleared of remaining objects. The robot will afterwards be capable to perform all the decontamination operations, thus eliminating the need of a human operator.

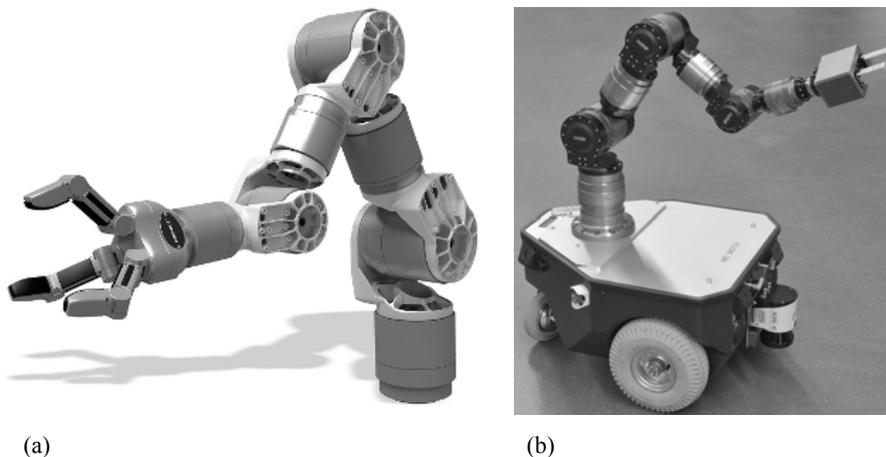(a)   (b)

Fig.13 – Schunk robotic arm (a) mounted on a Neobotix Platform (b) [14].

6. CONCLUSION

In the paper, the dose rate and the associated risk related to the clean-up and decontamination of hot cell no. 4 were calculated using RESRAD Build 3.5 code.

Three nuclide sources were considered: Co-60, Cs-137, Sr-90, these nuclides most probable in the hot cell. The activity of these sources was estimated by utilising Rad Pro 3.26 software models, starting from the measured doses. This was done, due to the lack of a difficult spectroscopy analysis in order to determine the exact nuclide sources and their activity.

The presumed time for clean-up and decontamination operation is 1 month, and therefore the estimation was made for this period.

The calculation revealed an initial equivalent dose rate of 700 mrem = 7 Sv and a high associated risk of 120, due only to external exposure, which subsequently decreases in time as the hot cell no. 4 is cleared and decontaminated.

Furthermore, in the unlikely scenario that the exposure pathways are summed (inhalation, ingestion, immersion, external, deposition and radon) the equivalent dose rate is extremely high.

In the proposed scenario the greatest risk is presented by Sr-90 followed by Cs-137 and Co-60.

Due to high dose/risks involved, complying with ALARA principle, the utilization of a robot is proposed in stead of a human operator.

REFERENCES

1. M. Dragusin, A.O. Pavelescu, I. Iorga, *Good Practices In Decommissioning Planning And Pre-Decommissioning Activities For The Magurele VVR-S Nuclear Research Reactor*, Nuclear Technology & Radiation Protection Journal, ISSN 1452-8185, 2011 (in press).
2. M. Dragusin, et al., *IFIN-HH VVR-S Research Reactor Decommissioning Plan, Revision 10*, Institute of Physics and Nuclear Engineering – "Horia Hulubei" (IFIN-HH), Centre of Decommissioning and Radioactive Waste Management (CDMR), February 2010.
3. V. Popa, A.O. Pavelescu, et al., *IFIN-HH VVR-S Reactor Hot Cells Clean-up Plan,* "Horia Hulubei" Institute of Physics and Nuclear Engineering (IFIN-HH), 2011 (draft version).
4. C. Yu, A.J. Zielen, J.J. Cheng, D.J. LePoire, E. Gnanapragasam, S. Kamboj, J. Arnish, A. Wallo III,W.A. Williams, H. Peterson, *User's Manual for RESRAD Version 6*, Environmental Assessment Division, Argonne National Laboratory (ANL), ANL/EAD-4, July 2001.
5. C. Yu, D.J. LePoire, J.J. Cheng, E. Gnanapragasam, S. Kamboj, J. Arnish, B.M. Biwer, A.J. Zielen, W.A. Williams, A. Wallo III, H.T. Peterson, Jr., *User's Manual for RESRAD-BUILD Version 3*, Environmental Assessment Division, Argonne National Laboratory (ANL), ANL/EAD/03-1, June 2003.
6. B.M Biwer, et al., *Technical Basis for Calculating Radiation Doses for the Building Occupancy Scenario Using the Probabilistic RESRAD-BUILD 3.0 Code*, NUREG/CR-6755, ANL/EAD/TM/02-1, prepared by Argonne National Laboratory, Argonne, Ill., for Division of Systems Analysis and Regulatory Effectiveness, Office of Nuclear Regulatory Research, 2002.
7. S. Kamboj, et al., *Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-BUILD Codes*, NUREG/CR-6676, ANL/EAD/TM-89, prepared by Argonne National Laboratory, Argonne, Ill., for Division of Risk Analysis and Applications, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, May 2000.
8. W.E. Beyeler, et al., *Residual Radioactive Contamination from Decommissioning; Parameter Analysis*, NUREG/CR-5512, Vol. 3, Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Oct. 1999.

9. M.A. Wernig, et al., *Residual Radioactive Contamination from Decommissioning: User's Manual*, NUREG/CR-5512, Vol. 2, Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, May 1999.
10. U.S. Environmental Protection Agency, *Exposure Factor Handbook*, EPA/600/P-95/002Fa, Office of Research and Development, National Center for Environmental Assessment, 1997.
11. K.F. Eckerman, et al., *Cancer Risk Coefficients for Environmental Exposure to Radionuclides,* EPA 402-R-99-001, Federal Guidance Report No. 13, prepared by Oak Ridge National Laboratory, Oak Ridge, Tenn., for U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, 1999.
12. D. Stanga, et al*., Dose Rate Measurements in VVR-S Research Reactor Hot Cell No. 4* (Dosimetric Service Procedure conf. AC-PO-DDR-501-01), 2006.
13. R. McGinnis, *Rad Pro Calculator 3.26 Software Site Online*, Massachusetts Institute of Technology, http://www.radprocalculator.com/Index.aspx, 2011.
14. Schunk GmbH & Co., *LWA3 Lightweight Arm Modular Robotic Specification Sheet*, Catalog Automation Highlights, 2009.