

RADIOLOGICAL ASSESSMENT IN CASE OF AN INCIDENT AT THE HOT CELLS CLEAN-UP

by

Cristian A. DRAGOLICI* and Adrian ZORLIU

National Institute of R&D for Physics and Nuclear Engineering "Horia Hulubei", Magurele, Romania

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The clean-up and decontamination of the hot cells will be performed in the second phase of the WWR-S research reactor decommissioning. Identification of possible incidents or accidents is the key element in radiological assessment and prevention. As major incident it was considered a fire burst that occurred during the progress of the clean-up operations. The postulated incident has, as a consequence, thick smoke generation from the burned radioactive material and the dispersion of this material in the environment through the technological ventilation system and the evacuation chimney. From the performed analysis it can be seen that in the case of an incident to the reactor hot cells, an operator engaged in intervention operations could take an effective dose of 5.29 Sv per event, coming from both external and internal exposure. Such an incident, if it happens, would be classified of level 3 on the INES scale.

Key words: hot cell, radiation protection, dose assessment, incident scenario, fire burst

INTRODUCTION

The WWR-S research reactor owned by the National Institute of Research & Development for Physics and Nuclear Engineering "Horia Hulubei" (IFIN-HH), Magurele, Romania, was commissioned in 1957 and it was shutdown in 1997. The facility is a light-water-cooled-moderated-and-reflected, heterogeneous, thermal reactor. It is a tank type Russian origin research reactor used mainly for radioisotope production and for applied and fundamental research performed in the Institute [1]. In 2002, Romanian Government decided that the WWR-S reactor will be permanently shut down for decommissioning [2].

At the end of 2012, all the Russian origin fuel (10% and 36% enrichment in ^{235}U) was completely removed from the site and sent back to the Russian Federation, creating a wide working front for the decommissioning activities.

The decommissioning of the WWR-S reactor of IFIN-HH will be accomplished through a process including three successive stages [3]. This process corresponds to the method entitled by International Atomic Energy Agency (IAEA) as immediate dismantling method, after an authorized period of preservation [4, 5]. Because immediate dismantling operations

will be finished in several years after reactor stopping, workers exposure to radiation will be, generally, higher than for methods which use deferred dismantling and have, as a consequence, delay of works.

The clean-up and decontamination of the hot cells will be performed in the second phase of the WWR-S research reactor decommissioning, when the external systems are dismantled.

At the beginning of the clean-up and decontamination of the hot cells, the following systems should be operational:

- the mechanical manipulators,
- the carriage for transportation between hot cells,
- the cutting machine,
- the electric lifting systems for opening the radioactive sources storage lid and the gates between the hot cells, and
- the lighting system.

Decommissioning activities of the hot cells are subjected to complex laws and regulations in the nuclear field. Thus, radiological assessment should be conducted systematically during the hot cells decommissioning by implementing well-defined stages [6]:

- optimizing the radioprotection by planning the decommissioning activities in accordance with the chosen decommissioning strategy,
- identifying the radiological issues that may arise in the normal decommissioning activities and their engineering analysis,

* Corresponding author; e-mail: adrag@nipne.ro

- identification of possible incidents and accidents that may occur during decommissioning process and their engineering analysis,
- evaluation of the consequences of decommissioning activities on the personnel involved and on the population, both in the normal development of the decommissioning process and in the case of incidents/accidents,
- comparing the results with the relevant security evaluation criteria, and
- establishing measures for prevention and mitigation of the consequences [7, 8].

The present paper deals with the radiological assessment of a major incident that could affect the environment, but mostly the staff involved in mitigation activities. In our work the most important thing is to define the radioactivity source, based on the remained long-lived radionuclides from the inventory. It was found that the most important contribution to the total dose is given by ^{60}Co , ^{137}Cs , and ^{90}Sr . Source modeling, activity and dose calculations were performed using the MicroShield program. For mathematical modeling, it was also necessary to establish the time (steps) required for a worker intervention during the incident. Basically we will present a possible scenario for the hot cell no. 1 (HC1), which has the richest radioactive inventory and presents the highest risk in terms of radiological and health safety for the operating personnel involved in these activities.

HOT CELLS DESCRIPTION

During 40 years the hot cells served for production of radioisotopes used for research, medical and industrial purposes. As a raw example we can mention $^{99\text{m}}\text{Tc}$ ($1.85 \cdot 10^{12}$ Bq per year), ^{90}Y ($7.4 \cdot 10^{10}$ Bq per year), ^{99}Mo ($1.85 \cdot 10^{12}$ Bq per year), ^{198}Au ($1.85 \cdot 10^{12}$ Bq per year), ^{131}I ($3.7 \cdot 10^{12}$ Bq per year), ^{192}Ir ($3.145 \cdot 10^{14}$ Bq per year), used in medicine, ^{42}K ($1.48 \cdot 10^{11}$ Bq per year), ^{82}Br ($7.4 \cdot 10^{10}$ Bq per year), ^{32}P ($1.11 \cdot 10^{11}$ Bq per year), ^{35}S ($1.11 \cdot 10^{10}$ Bq per year), used in radiochemistry, and ^{60}Co ($1.85 \cdot 10^{11}$ Bq per year) for industrial applications. All these elements were obtained by irradiation in the reactor active core channels. Before irradiation, the materials were carefully packed in cylindrical aluminum containers having the dimensions of $\varnothing 37 \text{ mm} \times 140 \text{ mm}$ and $\varnothing 22 \text{ mm} \times 140 \text{ mm}$. After irradiation, the containers were lowered by a wire into HC1 through a connection tube. Here, the containers were cut with a cutting machine and the radioactive sources were extracted by mechanical hands and shielded in special containers. Therefore, hot cells inventory is very rich in radioactive waste and sources. From the known history, we presume that hot cells contain also bottles and ampoules with solutions of ^{60}Co , ^{134}Cs , ^{133}Ba , ^{63}Ni , and aluminum containers with fission products like ^{90}Sr , ^{137}Cs , and ^{134}Cs used

for experiments. Of course, short-lived elements are already vanished but long-lived nuclides are still a concern. Estimations have been made in order to establish the quantity and the activity of the hot cells inventory [9]. Also, it should be noted that in HC1, areas can be found, which contain significant quantities of combustible substances (possibly contaminated): lubricants, solvents, plastic sheets and rags, wooden structures (small scaffolding, supports, *etc.*), plastic boxes and ampoule holders, wipe pads of gauze and cotton, filter papers, clogged filters and rubber hoses. The location of the HC1 is illustrated in fig. 1.

Thus, room no. 21 corresponds to hot cells no. 5 and 4, and room no. 22-24 correspond to the hot cells no. 3, 2, and 1. Furthermore, at the end of corridor no. 25 one can find the room no. 18, where the control panel is located, which commands the hot cells gates and the carriage that provide material and equipment movement to and from the hot cells. On the other side, on the opposite direction of the operator's rooms, is the corridor no. 17, which provides the access to the rear part of the hot cells through massive lead and steel doors. At the opposite end of the corridor no. 17 entrance area, is room no. 19, which allows the access to the hot cell no. 5. HC1 has the following dimensions: 3.1 m long, 1.8 m wide and 2.6 m high. In the middle of the HC1, the radioactive sources storage can be found, which is believed to accommodate most of the high active sources produced during time. The radioactive sources storage has a cylindrical shape with $\varnothing = 400 \text{ mm}$ and is located at 600 mm beneath the HC1 floor level. The storage has a thick lead lid above which can be lifted with a mechanical system, together with the metal rack carrying the radioactive sources. In order to establish the basis for realistic estimation of the radiological risk, the operator staff made direct measurements of the equivalent dose and equivalent dose rate inside HC1. To measure the equivalent dose received by a worker who is participating at the cleaning operation of HC1, an individual dosimeter with direct reading, similar to those worn by operating personnel engaged in these activities, was introduced inside the hot cell. The introduced dosimeter is of Saphydose type and can measure an equivalent dose of gamma radiation in the range of $1 \mu\text{Sv}$ -10 Sv. The dosimeter was introduced in HC1 through the transport carriage serving the transportation between the hot cells (fig. 2). The measurement point was located at the entrance of HC1, at about 1 m away from the center, and the measurement time was 5 minutes. During the measurements, the metal rack with radioactive sources was lowered in the down position in the storage. After the measurement, the device was removed from the HC1, in the same way as it was introduced. The equivalent dose recorded by the device during 5 minutes was 19.897 mSv.

The equivalent dose rates, measured by the health physics division operators within the HC1 are

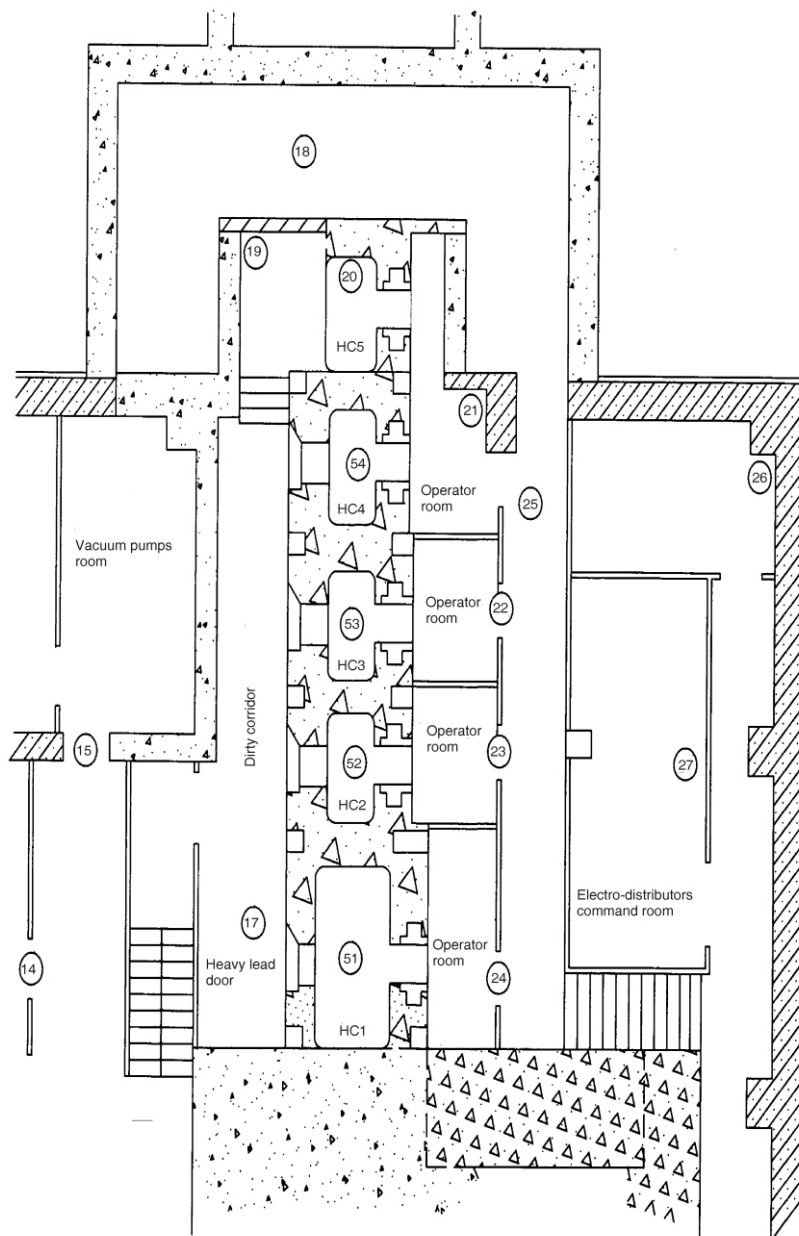


Figure 1. Location of HC1



Figure 2. Introduction of a dosimeter in HC1

presented in tab. 1. The measurements were made using a Thermo FH 40 GX type dosimeter with a 612-10 FHZ attached probe that can record dose rate values between $0.1 \mu\text{Sv/h}$ - 10Sv/h . Because the estimates for this type of measurements had foreseen very high dose rates, for the operating personnel safety and for the accuracy of the results it was decided to lower the measuring probe from reactor lids through the dry channel 43/4, inside the HC1 (fig. 3). For this purpose, between the dosimeter and the probe a special measuring cable 20 m long, was interposed.

To prevent separation of the probe from the connection jack and damage of the measuring cable, a "reinforcement" steel cable of $\text{Ø} = 4 \text{ mm}$ tied in parallel with it was used. The detector along with the connections, has been shrink wrapped and a lead weight tied

Table 1. Measurements of the equivalent dose rate in HC1

No.	Measurement point in HC1	From	To
1	Connecting pipe entry in HC1	20 cm left 488 mSv/h	20 cm right 760 mSv/h
2	Sources storage area	Left 810 mSv/h	Right 1.9 Sv/h
3	Metallic rack with sources	First drawer 1.98 Sv/h	Around it 4.40 Sv/h
4	Metallic rack with sources	Second drawer 4.50 Sv/h	Around it 4.80 Sv/h
5	Metallic rack with sources	Third drawer 5.01 Sv/h	Around it 6.32 Sv/h

**Figure 3. Lowering the 612-10 FHZ probe into the HC1 through the channel 43/4**

to the same steel cable, was attached at a distance of 40 cm from the probe bottom.

In the HC1, the measurements were made handling the probe by means of mechanical manipulators. The probe was taken from the inlet to the HC1 by one of the manipulators and was randomly “walked” over materials and objects in order to detect hot spots with high activity. The detected hot spots were recorded in a log book by an operator.

DESCRIPTION OF SITE SURROUNDING AREA

The WWR-S reactor is located in Magurele City, 8 km away in a straight line from the Bucharest downtown. Magurele City comprises 11 041 of inhabitants spread over a total surface of 45 km², about 245 residents per square kilometer. The reactor site is surrounded by a round forest 1.6 km in diameter. At the end of the forest, the first group of houses of the Magurele City inhabitants can be found on a plane field. We can estimate that the critical group of population could be found between 800 and 1000 m away from the reactor location, around the circular forest. This area accommodates about 47 houses where approximately 277 people live.

SCENARIO PRESENTATION

Analysis of the incident mentioned in the title is based on the information from the reference [6]. The event entitled “Fire in the facility due to the damaged electrical system” is possible to occur because the initial electrical installation of the WWR-S reactor will also be used during the decommissioning process. Cable insulation may be damaged, so the occurrence of ignition sources is not totally excluded. It is assumed that the fire broke out in the HC1.

Cleaning and decontamination of hot cells is a hard work which presents radiological risks for the operating personnel. This work should be done in the following sequence: removal of the radioactive materials and decontamination of hot cells.

As the first step in cleaning the hot cells we have to consider evacuation of those objects that show high activity and may contain radioactive sources.

It is assumed that during the cleaning process of the HC1, it will be necessary to lift the lid from the radioactive sources storage to facilitate the emptying of the metal rack drawers. The rack for the sources storage has a cylindrical shape and contains 3 compartments (drawers) for storage. When the rack is completely lifted from the storage, the operator activates the moving system of the cutting machine to move it away from the area and to facilitate the access of the manipulators in taking the aluminum containers with the radioactive sources.

Due to the friction between the cable insulation of the motor power supply (which moves the cutting machine) and the sharp edges of aluminum scraps scattered around the hot cell, an electrical spark may occur if the cable insulation is damaged. In that case, fire breaks out and will be extended to the whole cable insulation and beyond. It is assumed that the fire may be extended to the area of combustible materials. We suppose that the fire will burn over an area of 2.7 m ×

1.5 m = 4.05 m² with a high flame releasing a significant amount of heat at a high temperature that will ignite the air filter located at the top of the hot cell. As a function of the burning time, the maximum temperature of the fire was established through the “time-temperature” curve described in ISO-834 from references [10] and [11]. The maximum calculated temperature to be reached by the fire is 548 °C.

Spreading of the fire to the surrounding areas is unlikely, but not impossible. The fire could spread to the hot cell no. 2 through the channel of the transport carriage and could affect the room 24 and the corridor 25 by emission of smoke with radioactive particles besides manipulators seals.

It is assumed that after the fire outbreak the air filter situated on the top of the HC1 is set on fire and destroyed. Inside the HC1 the fire generates smoke and ash into the air which causes spreading of radioactive particles from the burned materials. In the absence

of filter retention, they are fully absorbed by the technological ventilation system and discharged into the environment through the ventilation chimney which has a height of 40 m and a diameter of 2 m.

To minimize the fire effects and to prevent its extension, fire emergency suppression measures have to be taken. These measures consist of removing of those parts from the combustible materials that have not yet been consumed by the flames and extinguishing the fire with appropriate fire extinguishers. The only way to extinguish the fire quickly and effectively is sending a team of three operators (two mechanics operators and one health physics operator) to act in corridor no. 17 by opening the massive lead and steel door that blocks the access to the HC1.

Wearing appropriate protective suits and respiratory masks for the whole face with particle pair filters, equipped with hooks and portable fire extinguishers and under strict supervision of the health physics operator, the two mechanical operators will cautiously approach the affected area trying to take the best possible visibility through the thick cloud of smoke.

Taking into account the measurement of the equivalent dose described above, it is considered that in the place where operators will act, the equivalent dose received for a 20 minute of intervention will not exceed 80 mSv. The health physics operator will continuously monitor the dosimeter (Thermo FH 40 TG) with the telescopic probe extended to maximum (4 m), warning the two operators when time has expired. The personnel of the team have been trained not to exceed the established maximum admissible dose of 100 mSv for the intervention. When the armored door of HC1 is opened for operator intervention, it creates a sudden depression in the HC1 access passage, which forces the thick smoke to completely occupy the entire volume of the passage and come out into the corridor no. 17. This dispersion of radioactive smoke from HC1 to access corridor and, respectively, to corridor no. 17, produces a decrease by about 102 times of the initial isotope activity contained in the cloud. In addition to sudden reducing visibility, thick smoke and high temperature soon lead to filter clogging of the operators masks. Their effectiveness drops sharply to 55%.

Trying to remove from the fire some aluminum containers which are supposed to have great activities, the operators wrong handled the hook and overturned the rack with the radioactive sources. The sources are kept in cylindrical containers made of aluminum, which can roll easily and spread everywhere, including in the access passage of the HC1 at the foot level of the three operators.

The thick smoke from HC1 prevented the operators to observe the rolling containers coming inside the access passage. This accident can happen suddenly without any prior warning, exposing the 3 operators to an equivalent dose rate of 6.32 Sv/h.

Due to the small dimensions (0.9 m × 0.4 m) of the access passage, and to the low oxygen concentra-

tion (below 17%) that causes dizziness, the two mechanical operators lose their balance, slip on the aluminum containers and fall down in the corridor no. 17. Following this accident the operator's fractures one of their upper limbs, the shock and the lack of oxygen resulting in loss of consciousness.

This accident may result in exceeding the time of 20 minutes provided for intervention in the affected area. In this case, for the recovery of injured operators it must be sent a second emergency team consisting of 5 people (4 mechanics operators and one health physics operator). Depending on the situation and the time spent in the field of radiation, the doses undertaken by the operating personnel can be even fatal.

EXPOSURE ASSESSMENT

We assume that all materials and objects in HC1 are contaminated with the following isotopes: ^{60}Co (1 TBq), ^{137}Cs (2 TBq), and ^{90}Sr (0.5 TBq). Therefore, the smoke will contain these radioactive isotopes, but it is supposed that due to the promptly intervention of the operators only 15% of their initial activity will be discharged into the environment. The remaining 85% will remain in HC1 in the form of smoke with contaminated airborne particles.

To calculate doses and assess the impact to the population, we use the model analyzed in reference [6]. Radiation doses for the population were calculated using the methodology and the coefficients from [12]. The main exposure pathways for the population, considered for this scenario are:

- external exposure to airborne material,
- external exposure of the material deposited on the ground for 24 hours, and
- internal exposure due to ingestion of airborne radioactive material.

Dose equivalents were calculated for whole body (the effective dose). The calculation method has been presented in [13]. Factors released into the atmosphere were calculated using the method from [14]. Taken into consideration the data presented in tab. 2 we can calculate the collective dose for the critical group of population of $2.97 \cdot 10^{-7}$ Sv. Due to the technical and administrative measures, the impact to the people and environment is strongly reduced. Because the incident influence on the public and environment is negligible, we will present just the results which are listed below in tab. 2 and fig. 2. Further, we will focus only on the impact on the operating personnel involved in intervention for mitigation purposes.

We assume that 85% of the radioactive inventory contained by the smoke is still in HC1 at the moment of operator's intervention, the remaining 15% being discharged through the reactor ventilation chimney. Considering that 15% of the outside discharged radioactive inventory is coming from the initial activity of

Table 2. The effective dose for the population

Distance [m]	Exposure to the radioactive cloud [Sv]	Ingestion [Sv]	Exposure to the radioactive materials deposited on soil [Sv]	Total effective dose [Sv]
200	9.54E-61*	6.38E-58	4.57E-59	6.84E-58
300	3.14E-37	2.10E-34	1.51E-35	2.25E-34
500	1.20E-21	7.99E-19	5.72E-20	8.58E-19
700	4.09E-16	2.73E-13	1.95E-14	2.93E-13
1000	1.50E-12	1.00E-09	7.16E-11	1.08E-09
2000	2.94E-09	1.96E-06	1.39E-07	2.11E-06
3000	1.79E-08	1.20E-05	8.45E-07	1.28E-05
4000	3.55E-08	2.37E-05	1.66E-06	2.54E-05
5000	4.84E-08	3.23E-05	2.25E-06	3.46E-05
6000	5.61E-08	3.75E-05	2.60E-06	4.02E-05
7000	6.02E-08	4.02E-05	2.77E-06	4.31E-05
8000	6.20E-08	4.14E-05	2.83E-06	4.43E-05
9000	6.22E-08	4.16E-05	2.83E-06	4.45E-05
10000	6.16E-08	4.12E-05	2.78E-06	4.40E-05
15000	5.44E-08	3.63E-05	2.38E-06	3.88E-05
20000	4.70E-08	3.14E-05	1.99E-06	3.35E-05

* 9.54E-61 read as 9.54 10⁻⁶¹

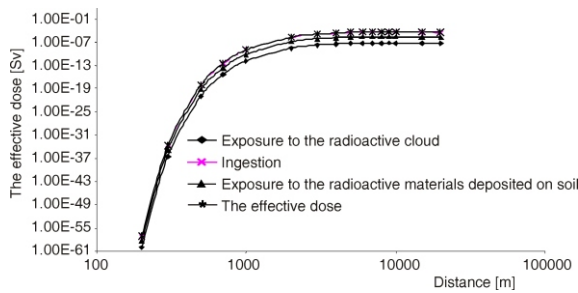


Figure 4. The effective dose for the population

considered isotopes, we can assume that the activities of remaining isotopes in HC1 are of the order 0.85 TBq (⁶⁰Co), 1.7 TBq (¹³⁷Cs), and 0.425 TBq (⁹⁰Sr).

The total dose taken by an operator considering the exposure by direct radiation and by inhalation is given by the following formula [15]

$$D_{tot} = D_{ext} + D_{inh} + \sum_j h(g)_{j,inh} J_{j,inh}$$

where D_{tot} [Sv] is the total dose taken by the operator, D_{ext} [Sv] – the dose due to external exposure to gamma radiation, D_{inh} [Sv] – the dose due to inhalation of the smoke with contaminated airborne particles, $h(g)_{j,inh}$ [Sv/Bq] – the committed effective dose per unit of incorporation through inhalation of a radionuclide j , and $J_{j,inh}$ [Bq] – the incorporation through inhalation of the radionuclide j .

Taking into account that:

- the volume of the HC1 is 3.1 m × 1.8 m × 2.6 m = 14.51 m³,
- the volume of the HC1 access passage is 0.9 m × 0.4 m × 1.6 m = 0.58 m³,

- the total volume of the HC1+ the access passage is 14.51 m³ + 0.58 m³ = 15.09 m³,
- the breathing rate for a worker is 1.2 m³/h [16],
- the intervention time (and for inhalation of radionuclides) is 20 minutes = 0.33 h,
- the activity of ⁶⁰Co = 0.85E+10 Bq,
- the activity of ¹³⁷Cs = 1.70E+10 Bq, and
- the activity of ⁹⁰Sr = 0.43E+10 Bq.

we can calculate the radionuclide concentration inside HC1:

- the concentration of ⁶⁰Co = 5.6E+08 Bq/m³,
- the concentration of ¹³⁷Cs = 11.3E+08 Bq/m³, and
- the concentration of ⁹⁰Sr = 2.9E+08 Bq/m³.

We also consider the values in tab. 3 [15].

Table 3. Workers committed effective dose per unit intake via inhalation

Isotope	$T_{1/2}$	Type	Inhalation		
			f_i	h (g)	
				1 μm	5 μm
Co-60	5.27 years	M	0.1	9.60E-09	7.10E-09
Cs-137	30.00 years	F	1.000	4.80E-09	6.70E-09
Sr-90	29.10 years	F	0.3	2.40E-08	3.00E-08

Due to the decrease of the protective mask filters efficiency, in 20 minutes of intervention an operator inhales 0.4 m³ of contaminated air with up to 45% of the radioactive isotopes activity remaining in HC1.

This means that during the intervention at HC1 an operator will intake 1.01E+08 Bq of ⁶⁰Co, 2.03E+08 Bq of ¹³⁷Cs, and 0.52E+08 Bq of ⁹⁰Sr.

With the above considered equation we can calculate the total dose for the internal and external exposure of a single operator

$$D_{tot} = 2.10 \text{ Sv} + (0.97 \text{ Sv} + 0.97 \text{ Sv} + 1.25 \text{ Sv}) = 5.29 \text{ Sv}$$

We can note that in case of an incident in the hot cells, an operator engaged in intervention may take a dose of 5.29 Sv coming from external and internal exposure.

The analysis performed on the scenario presented, indicate that the intake dose by an operator may exceed 5 Sv per event.

MEASURES TO BE TAKEN

The ultimate objective analyzing the presented scenario is to identify appropriate preventive, protective and mitigation measures, so the scenario does not happen and if it happens, the consequences are much lesser than calculated here.

Clean-up is the conventional and most frequent operation encountered to this type of installation and phase of activities, nevertheless, unexpected events can occur despite all measures taken. Therefore, step by step assessment is needed to evaluate the risks and

establish appropriate mitigation measures. The first measure taken should be reconsidering and revising the working procedures, so that no mistakes are allowed in sources manipulation and firefighting. Better training of the operators with emphasis on firefighting technique and procedures, should be also considered. Improvement of the protective suits by acquisition of aluminized flame proof and heat protection garment with independent breathing apparatus under the suit, is compulsory to face such events. Nevertheless, an important attention should be paid to careful examination and analysis of the best technique and procedures to be used for consequence mitigation.

CONCLUSIONS

The scenario considered above is the worst situation that could appear during the clean-up of the hot cells. It was selected on purpose to be conservative and due to the pristine condition of the hot cells this event has a significant probability to occur. It is based on a very close to reality HC1 inventory and on existing equipment and materials used regularly and in emergency cases by the reactor personnel. The conceptual model includes the most likely potential transfer pathways of radionuclides from the source (hot cell inventory) to humans. In the considered event the main exposure pathways for intervention staff are direct exposure to gamma radiation from radioactive sources and the inhalation of contaminated air, assuming that a certain percentage of the total contamination spread rises in air as contaminated dust and ashes. Slow processes like possible dermal contact with contaminated substances and airborne particles during intervention were not taken into consideration. Analyzing the consequences of the event it can be seen that the dose to the population is negligible while the impact to the intervention operators is at highest risk. Evaluating the event, in terms of radiological safety, is its classification on the INES scale [17]. Even though this incident did not result in a significant external release of radioactivity, nor of important degradation of in depth defense, the event is classified as Level 3 (serious incident), based on its highest risk for the intervention operators. Exposure rates of more than 1 Sv/h in an operating area and severe contamination in an area not expected by design, with a low probability of significant public exposure, justify the selected level. From this survey we can observe that even facilities like no fuel reactors or reactors being decommissioned, whether or not the fuel is still on-site, can raise serious problems during performing so called normal activities.

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AUTHOR CONTRIBUTIONS

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Кристијан А. ДРАГОЛИЦИ, Адријан ЗОРЛИУ

**РАДИОЛОШКА ПРОЦЕНА У СЛУЧАЈУ ИНЦИДЕНТА
ТОКОМ ЧИШЋЕЊА ВРУЋИХ ЋЕЛИЈА**

Чишћење и деконтаминација врућих ћелија биће обављени током друге фазе декомисије истраживачког реактора WWR-S. Идентификација могућих инцидената или акцидентата је кључни елемент радиолошке процене и превенције. Већим инцидентом сматра се избијање пожара током операција чишћења. Претпостављени инцидент има за последицу настајање густог дима од сагорелог радиоактивног материјала и расипања овог материјала у околну средину кроз вентилациони систем и димњак. На основу урађених анализа, види се да би у случају инцидента на реакторским ћелијама, техничар укључен у интервенцију могао да прими ефективну дозу од 5.29 Sv по догађају, која потиче и од спољашњег и од унутрашњег излагања. Овакав инцидент био би класификован као инцидент трећег нивоа на INES-овој скали.

Кључне речи: врућа ћелија, радијациона заштитна, процена дозе, сценарио инцидената, избијање пожара
