PRE-DECOMMISSIONING OF L-54M RESEARCH REACTOR: RADIOLOGICAL PRE-CHARACTERISATION OF STRUCTURES, SYSTEMS AND COMPONENTS

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ABSTRACT

This work describes the strategies and the results of the radiological pre-characterisation campaign of Structures, Systems and Components (SSC) of L-54M CeSNEF (*Centro Studi Nucleari Enrico Fermi*) plant, performed by NUCLECO SpA, with a special emphasis on *in-situ* gamma spectrometry, decontamination techniques and management of radioactive waste products. L-54M CeSNEF is the homogeneous fuel thermal research reactor (50 kWth nominal power) [1] housed in *Politecnico di Milano*, nowadays kept in safe storage condition (SAFESTORE). According to international operative guidelines [2,3] and to L-54M CeSNEF historical information analysis [1,4,5,6], sequential steps were carried out aiming at completing the radiological pre-characterization of the research reactor plant [4,7,8].

1. INTRODUCTION

Throughout the world, about 700 nuclear research reactors have been planned, built and used for research objects in field of reactor training and control, radiation physics, radiochemistry, nuclear medicine and for material development and neutron radiography. Most of these reactors have reached the end of their lifetime and have been continuously shutdown leaving only a small number (228) in operational status nowadays [9,10]. According to IAEA, more than 490 research reactors have been already shutdown or decommissioned to various phases [11].

Decommissioning is the final management phase of the life-cycle of a nuclear facility. It starts with the plant shutdown and ends with the total or partial removal of radiological restrictions imposed by the Competent Authority on the site [12]. The assessment of restoring the area to its original radiological state (Greenfield) or of re-using it for industrial purpose (Brownfield) depends on the owner's business plan and the necessary site remediation.

Actually, a nuclear facility is first designed and built to be efficient and safe during its operational state and most of the old ones have not been outlined with any final phase in mind [13]. The owner should prepare a decommissioning plan before of the final closure of the facility in order to identify, optimise and organise all the technical and administrative requirements needed for removing, partially or totally, the radiological constraints of the site. This attitude avoids to lose both operational data and the staff's historical memory that are critical factors.

Depending on political, economical, technological and social issue, three are the main strategies adopted during the decommissioning: 1) Immediate Dismantling (DECON), when the final phase starts just after the plant shutdown; 2) Safe Enclosure (Deferred Dismantling), when the dismantling takes place after decades from the final closure of the plant aiming to reduce the level of radioactivity during the dismantling operations; 3) Entombment, when radioactive matrices are covered and shielded in a long-term stable structure [14,15]. In many cases, even for a State with extensive resources and political support, the lack of a radioactive waste repository prevents to reach the decommissioning end state and implies a long Safe Enclosure as unique available option for all its nuclear facilities [16].

Research reactors mainly presents a wide spectrum of types and a wide variety of scientific studies and experimental works performed throughout their lifetime. Each decommissioning plan of a research reactor is a first-of-the-kind project that is related to a continuous development of knowledge and experience performed in these specific activities worldwide. A specific consideration has to be devoted to the management of the industrial projects that can produce any relevant impact to the population health and safety and also to the pollution level of the surrounding areas. This attention has a more binding character for all those works closely related to the decommissioning of nuclear research reactors and other small nuclear facilities, typically located inside of urban areas, because of the strong guarantees requested by the National Authority to perform these activities.

2. L-54M CeSNEF RESEARCH REACTOR

2.1 Plant History

L-54M CeSNEF is a thermal research reactor with a homogeneous fuel (50 kWth nominal power) commissioned in 1958 by *Politecnico di Milano* to Atomic International, the North America Aviation Division involved in the early development of nuclear technology for commercial and government applications. The reactor was housed in CeSNEF (*Centro Studi Nucleari Enrico Fermi*) site, a small fully-equipped research centre used for research purposes and studies of nuclear reactor physics and control, radiochemistry, radiation protection, materials irradiation, radiation detection and measurement [1].

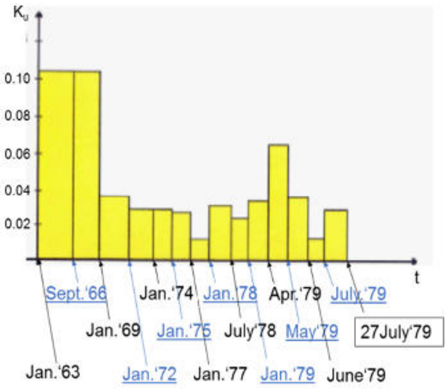

Figure 1. L-54M Utilisation Factor

L-54M CeSNEF achieved first criticality on July 27th of 1959 and historical data shows that the reactor worked for 20 years discontinuously and rarely at its nominal power. For this reason, its mean neutron fluence ($1.62 \cdot 10^{18}$ $n \cdot cm^{-2}$) had been evaluated performing the one-group diffusion theory analysis on a L-54M simplified geometry and considering the reactor lifetime divided in 14 constant-power periods, as shown in Figure 1 [5]. During the reactor operating life, no operational breakdown had been recorded. In the second half of the 1970s, CeSNEF research centre was completely included in a highly-populated area due to the growing urbanization of Milano. After a planned shutdown (27th of July 1979), the Competent Authority did not relinquish the licensee to restart the nuclear reactor that was put in Safe Storage since late 1979 [5,6,7].

2.2 Safe Storage and Pre-Decommissioning Activities

During the ’80s, the lack of a radioactive wastes national repository and some legislative gaps led inevitably to the safe storage option as the only available strategy for the Italian permanent shutdown nuclear installations [7].

One of the benefits of putting a facility into the deferred dismantling mode is to allow the decay of short lived radionuclides. Placing a research reactor in a safe storage configuration for some years reduces residual radioactivity to low levels. ^{60}Co decay is relevant in reactors from which the fuel has been removed and this fact offers significant benefits in terms of the doses that workers may receive during the future dismantling phase even if the enclosure period were less than 50 years. Additionally, except for some regulatory controls and maintenances required on the plant during the deferred dismantling period, no active or specialised big staff is needed in the management of a permanent shutdown nuclear facility [14]. Especially when the owner is a public institution, this strategy offers a useful waiting time to find and assure the relevant funds that a decommissioning program implies [17,18].

Technically, the willingness to keep safe the facility through the years makes necessary perform several steps on a nuclear plant: after removing the fuel from the reactor, early authorised dismantling of some components and early authorised processes and removals of some radioactive materials are the preliminary actions for the safe storage of the remaining parts of the installation [19,20].

Concerning the safe storage of L-54M CeSNEF reactor [5,6,7,21], a skilled team of *Politecnico di Milano* accomplished the followed authorised operations:

1979 – Fuel Extraction: the enriched uranyl sulphate solution was convoyed from the reactor primary circuit to a 31.2 L shielded storage tank by a pressurized transfer system

1979 – First Cleaning of the Primary Circuit: aiming to decontaminate the pipes, an acidic chemical cleaning solution flowed inside the primary circuit and was stored in shielded tanks. The removal of liquids residual radioactivity was later performed by using nuclear grade ion exchange resins

1994 – Safe Storage Condition: L-54M spent fuel was sent to the reprocessing Italian spent fuel facility EUREX located in Saluggia

1994 – Second Cleaning of the Primary Circuit

2001 – Core Extraction: containing more than 99% of the ^{60}Co plant activity, the core had been inserted in a special shielded container. It is currently stored *in-situ*

2014 – Start-Up Source (Ra-Be) Extraction: previously located in a graphite block inside of the reactor monolith, it was stored in a shielded neutron-absorbent container and sent away from L-54M CeSNEF plant one year later.

In early 2014 a teamwork of *Politecnico di Milano* decided to carry out a feasibility study of L-54M CESNEF overall decommissioning, starting with the radiological pre-characterisation of the activated nuclear grade graphite and the reinforced concrete of the reactor monolith [6]. In 2016 a radiological characterisation of the CeSNEF topsoil was completed to get the reference blank for the forthcoming decommissioning operations [7]. In the same year, *Politecnico di Milano* entrusted the radiological pre-characterisation of L-54M CeSNEF Structures, Systems and Components (SSC) to NUCLECO SpA in order to assess the activity concentrations of hard and easy-to-detect radionuclides and the consequent radioactive waste volume that decommissioning operations will produce. All these data are required by the Italian Competent Authority (*ISPRA Ambiente - Istituto Superiore per la Protezione e la Ricerca Ambientale*) to fulfil the L-54M CeSNEF decommissioning application before the beginning of the active dismantling activities. They also offer a better insight into the funds that this Greenfield program requires.

2.3 L-54M CeSNEF Reactor and Plant Description

L-54M core is a special steel (AISI 347) sphere of 20 cm radius that was loaded with a uranyl sulphate solution enriched by 19.94% of ^{235}U. The core position is strongly asymmetric inside the reactor monolith which offers a flexible irradiation configuration within the fixed neutron channels (see figure 2). The standard objective of a research reactor is to provide neutron fluxes of wide and specific range of energy and intensity. The neutron moderator and reflector is made of nuclear grade graphite bricks set around the core that fit together in a parallelepiped of 7 m^3 (about 11 t). This shape is well fixed using an aluminium container. A 3.6 m^3 graphite thermal column was also placed on the top of the monolith, shielded by aluminium and boral slabs. Figure 3 shows the biological shield of the monolith, made of reinforced concrete and built as single block of 79 m^3 (about 281 t). For radiation protection purposes, the minimum wall thickness is 170 cm and the concrete mixture presents boron enrichment due to the use of magnetite and colemanite ($Ca_2B_6O_{11}$). In special barriers, as the

2 removable doors, the beam-catchers and the thermal column block, small steel rods (10 mm length) were added to the blend [1,5,6,7].

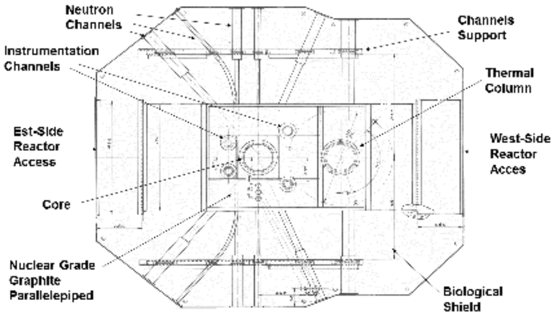

Figure 2. L-54M Structure Plan

Figure 3. L-54M CeSNEF Monolith

During the radiological characterisation plan performed by NUCLECO SpA team in 2016, an identification code had been assigned to each classified and analysed area of CeSNEF plant for an easier data reference of all the characterised structures, systems and components [4].

The reactor monolith and its platform roof (T035) house in the reactor hall (I001). In this open-space room (L= 21 m; W=15 m; H= 9.5 m), each reinforced concrete wall is approximately 480 mm thick and all the inner surfaces are completely covered with two different layers: the innermost is made out of wood to guarantee thermal insulation and a removable polyvinyl chloride layer of 1mm thickness to avoid any case of concrete contamination. The access to the hall is feasible by three independent entrances that are closed by air-tight doors. One of these allows the introduction of big research components and systems in the reactor area. Two independent ventilation systems are connected to the reactor hall: the first one was used to inject the proper airing during the normal operative phase of the plant with the exit line connected to absolute particulate filters (ε = 99.98%; d= 0.3 μm). The second air-line is an emergency ventilation system that had never worked. It was planned to come into operation just in case of accident, with the goal to offer the possibility of releasing a controlled gas through a 22-meter-high stack provided with absolute particulate filters (ε = 99.98%; d= 0.3 μm) [1,5,6,7].

The described hall is on the ground floor of the whole Reactor Building. Downstairs another level had been built and used to install and keep the maintenance during the years of all the auxiliary services that the reactor needed to work. For this reason, this floor (L= 21 m; W =15; H= 2.5 m) presents a complex layout due to the multiple areas and rooms that had to host the heat exchanger and cooling water supply system (S009), the reactor gases recombination system (S009), the fuel shielded storage tank (S009), the liquid waste management system (S006), the experimental exposition area (S004), the hydraulic valves control room (S007), the primary circuit decontamination system (S008), the reactor storage zones (S010a,b,c), the buffer and safety zone at the main downstairs entrance (S005). Depending on the systems housed inside, the access to each room is possible by an air-tight door and several reinforced concrete wall of variable thickness (900 mm – 25 mm) shield the work areas. Once again, all the surfaces are covered of a removable polyvinyl chloride layer of 1mm thickness and 10 mm thick steel liner covers the walls of the room exactly under the pile [4,6,7].

Between Reactor Building and Building 19, which is next to it, a buffer zone was built with two floors to allow their connection. Here, at the same level of the reactor hall, is located the decontamination line (T019, T020, T021, T022, T023) used by workers during the L-54M CeSNEF operational phase and the bottom reactor entrance corridor (T031). On the upper floor is placed the reactor control room (T001, T002a) and the top reactor entrance aisle

(T027). One more time, the access to these two parts of the plant is achievable by two independent air-tight doors.

Another classified area of the research facility is the downstairs of Building 19, next to the south side of the reactor hall. Here are set the radiochemical laboratories (T013, T014), the two shielded hot cells (T016), the radiation protection laboratory (T032), the shielded measurement room (T012), the hot discharge pipe (T022) and hot bathroom (T021), the decontamination line (T021, T023), the radiochemical office (T034).In this area, all the laboratories present the same layout based on independent ventilation system with air extraction through the specialised fume-hoods equipped with absolute particulate filters and common water supply system.

3. L54-M CeSNEF RADIOLOGICAL PRE-CHARACTERISATION

3.1 Pre-characterisation objective and plan

In order to schedule the decommissioning plan of L-54M CeSNEF research reactor, focused strategies and resolutions can be made as soon as detailed data are available from the radioactive inventory of the nuclear installation. A preliminary radiological characterisation program has to be scheduled to provide the information related to the types, the physical-chemical states, the activity concentrations and the volumes of the plant radioactive matrices in order to make better decisions for the whole decommissioning project management (phases planning, SSC decontamination and dismantling, radiation protection of areas and workers, radioactive waste management, research of funds) [8].

The residual radionuclide inventory of a nuclear reactor plant is divided into two categories: radionuclides inside the activated matrices (core, moderator, reflector, and biological shield) and radionuclides in materials contaminated by the activation products coming from corrosion and erosion processes and by fission products, both conveyed and confined into the primary circuit.

Politecnico di Milano entrusted the radiological pre-characterisation of L-54M CeSNEF Structures, Systems and Components (SSC) to NUCLECO SpA, an Italian qualified and specialised operator in the field of nuclear site remediation and decontamination, decommissioning of nuclear facilities and management of radioactive waste.

In order to set up an effective L-54M CeSNEF characterisation plan, NUCLECO SpA experienced work-team agrees to manage the research reactor analysis with these initial steps:

- review of historical L-54M CeSNEF plant information [1,5,6,7]
- definition of L-54M CeSNEF radionuclide library (^{3}H, ^{14}C, ^{36}Cl, ^{55}Fe,^{60}Co, ^{59}Ni, ^{63}Ni ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{152}Eu, ^{154}Eu, ^{232}Th, ^{235}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am)
- preparation of a specific sampling plan based on an appropriate statistical approach provided by MARSSIM [2]
- choice of effective instrumentations for an accurate radiological survey and characterisation [8]
- planning a dedicated radiation protection procedures and equipment for workers

Once all information was provided, a skilled NUCLECO SpA team started with the radiological characterisation activities.

3.2 Measurement instrumentations

Depending on the required radiological measurements (dose rate, superficial or total matrices contamination, radionuclides concentration activities) and looking for high data resolution and accuracy, during the *in-situ* characterisation campaign NUCLECO SpA crew used those gas-filled, scintillation and solid-state detectors:

- FH 40 TG Teleprobe Thermo Scientific with two energy compensated GM tubes (energy range: 82 keV to 1.3MeV)

- LB 124 SCINT Berthold, a portable contamination monitor equipped with a ZnS(Ag) scintillation detector (170 cm^2) for total alfa and total beta-gamma measurement (^{137}Cs sensitivity: 43%)
- LB 2046 Berthold, a ZnS(Ag) scintillation counter for alfa (^{241}Am efficiency: 27%) and beta-gamma (^{36}Cl: 8 %; ^{14}C: 40%) measurement of wipe samples or dusted filters (diameter: 60 mm)
- Portable coaxial High Purity Germanium FALCON 5000 Canberra (energy range 50 – 3000 KeV / 5 -1500 KeV; efficiency 50 – 55 %; resolution 1.9 to 1.33 MeV) leading an integrated gamma analysis software Genie 2000 that combines the detector gamma spectrum response with the source geometry (Geometry Composer) and also assesses the efficiency curve

3.3 L-54M CeSNEF Non-Destructive Analyses (NDA)

Based on a preparation plan and MARSSIM [2] and MARSAME [3] guidelines, operating activities aimed at defining both radiation fields distribution and residual radionuclide inventory in L-54M CesNEF plant. During the "*on-line*" techniques, NUCLECO SpA team devoted continuously special attention to the management of radiation protection procedures, in order to identify and control risks due to radiation exposure. For this reason, defined and sequential steps were carried out during the radiological mapping of every L-54M CeSNEF area:

1) a preliminary radiological survey that provided to the operators *in-situ* radiation protection information (dose rate and smear test measurements)
2) some required chemical decontamination actions to eliminate removable contamination and fix the other one. These processes aim at reducing the worker doses and also the total volume of radioactive wastes.
3) the management and movement of removable sources, systems and components from the analysed area after their radiological survey and quick gamma characterisation [3] (real time: 10 min)
4) dose rate evaluations and also total / removable surface contamination measurements of structures, systems and components (SSC) based on a planned square grid scheme (1m x 1m) [2]
5) several Non - Destructive Analyses (NDA) performed by *in-situ* gamma spectrometry to estimate the radionuclides concentration activities on surface samples that are representative of the selected homogeneous matrices [2]. Based on *in-situ* performed surveys, a number of 100 NDA points provided appropriate statistical information on the gamma inventory of L-54M CeSNEF plant. The choice and management of operational parameters (data acquisition time, detector distance from source, *in-situ* specific background, 1mm source layer) in the characterisation process are essential to define the Minimum Detection Activity (MDA) [21] for every measurement
6) Data analysis and report using Genie 2000 and Geometry Composer

Section 4.1 shows the NDA data analysis and the MDA range in the characterised areas .

3.4 L-54M CeSNEF Destructive Analyses (DA)

According to historical information of the research centre and its specific gamma inventory performed during the NDA campaign, some matrices of L-54M CeSNEF SSC may contain important amounts of radioisotopes which are difficult to measure with gamma detection equipment. These so called hard-to-detect (HTD) radionuclides are alfa, pure beta and week X-ray emitters and the determination of their inventory and activity concentrations is essential to complete the radiological pre-characterisation of the plant. On the basis of the most relevant L-54M CeSNEF HTD radionuclides (^{90}Sr, $^{59+63}$Ni, ^{55}Fe), more extended physical-chemical treatment [22] and long selective radiochemical separations [23,24] had to be performed in NUCLECO SpA laboratories ("off-line" techniques) on representative and homogeneous SSC matrices aiming to assess the requested activity concentrations and total alfa-beta measurement by the use of an ultra-low-level liquid scintillation spectrometer (PerkinHelmer QUANTULUS 1220). From selected L-54M CeSNEF areas (S004, S005, S006, I001, I016, I032), a skilled NUCLECO SpA team decided to get 10 destructive samples of different SSC matrices (concrete, metal, plastics, crud) on the order of grams [22] in line with the following criteria:

- historical review and analysis information of the plant
- specific SSC importance and functionality during the facility operational phase
- radiological homogeneity and statistical representativeness compare to performed NDAs (10%)
- hot spots analysis for a better intercomparison between “in-line” and “off-line” measurements
- cost analysis of the DA operations

Due to the lower MDA range available in NUCLECO SpA laboratories ($3 \cdot 10^{-4}$ - $5 \cdot 10$ $Bq \cdot g^{-1}$) [21], firstly a gamma spectrometry was performed on each sample to corroborate the measurements achieved in the same material during the *in-situ* NDA campaign (gamma intercomparison).

Depending on the specific areas and their matrices, the activity concentration of difficult-to-measure nuclide in the whole research facility will then determinate by “Scaling Factor Method”: it achieves a statistical correlation of the performed data between the L54-M CeSNEF HTD radionuclides measured in NUCLECO SpA labs and the key radionuclide (^{60}Co, ^{137}Cs, ^{152}Eu, ^{232}Th) measured *in-situ* by gamma spectrometry [10].

Section 4.2 shows the DA results.

4. L54-M CeSNEF CHARACTERISATION RESULTS

4.1 NDA Results

Due to the large amount of information produced during the *in-situ* gamma characterisation (NDA), a focused data analysis is needed. Making a distinction between key radionuclides and others, tables of section 4.1 resume the gamma inventory and the mean total activity of gamma emitters in structures (s) and components (c) of different L-54M CeSNEF areas. Table 1 shows the radionuclides MDA range performed in (s) and (c) measurements in each characterised zone. Table 2 and Table 3 offer information on radionuclides activations and contaminations of the plant. ^{60}Co and ^{152}Eu are mainly present as activation products in components exposed to reactor flux but their presence is also checked in some labs. The diffuse ^{137}Cs contamination is due to an accidental spillage of liquid ^{137}Cs source in auxiliary reactor area. Used as tracers and liquid gamma sources, ^{137}Cs and ^{241}Am contamination was also found in some labs. Traces of ^{238}U and ^{235}U point out to the liquid fuel old management.

		Key Radionuclides			**Others**				
		Co-60	**Cs-137**	**Eu-152**	**Am-241**	**Eu-154**	**Ag-108m**	**U-238**	**U-235**
		MDA [KBq]			**MDA [KBq]**				
Labs	**S.**	0.23 - 2.24	0.03 - 0.72	0.89 - 8.75	-	-	-	-	-
	C.	0.21 - 4.61	0.10 - 0.77	0.27 - 13.8	0.38	-	-	-	-
Reactor Hall	**S.**	0.29 - 1.52	0.38 - 24.4	0.99 - 64.4	-	-	-	-	-
	C.	0.03 - 0.78	0.04 - 1.04	0.10 - 3.06	-	-	-	-	-
Auxiliary Rooms	**S.**	0.25 - 1.45	0.02 - 7.87	0.96 - 5.43	-	-	-	31.4	-
	C.	0.23 - 5	1.25 - 19.7	1.55 - 27.1	-	0.80	0.1 - 0.2	227 - 748	0.77
Storage	**S.**	0.22 - 0.31	0.34 - 0.88	0.82 - 1.45	-	-	-	-	-
	C.	0.13 - 0.33	0.02 - 0.34	0.50 - 1.13	-	-	-	1.95 - 1.31	0.11 - 0.59

Table 1. Radionuclides MDA range performed in L54-M CESNEF characterised areas

		Key Radionuclides					
		Co-60		Cs-137		Eu-152	
		Total Activity [KBq]	Mean SD [KBq]	Total Activity [KBq]	Mean SD [KBq]	Total Activity [KBq]	Mean SD [KBq]
Labs	**S.**	-	-	2.26	0.14	-	-
	C.	-	-	8.97	0.54	-	-
Reactor Hall	**S.**	2.27	0.52	1200	76	-	-
	C.	-	-	11.5	0.6	-	-
Aux. Rooms	**S.**	3.44	0.17	15800	825	2.58	0.89
	C.	49.4	1.1	33700	1430	81.6	2.1
Storage	**S.**	13.1	0.4	349	20	28.9	0.8
	C.	33.5	0.8	16.9	0.8	125	2

Table 2. Key Radionuclides Total Activity and SD in radioactive wastes of L54-M CeSNEF

		Others									
		Am-241		Eu-154		Ag-108m		U-238		U-235	
		Total Activity [KBq]	Mean SD [KBq]	Total Activity [KBq]	Mean SD [KBq]	Total Activity [KBq]	Mean SD [KBq]	Total Activity [KBq]	Mean SD [KBq]	Total Activity [KBq]	Mean SD [KBq]
Labs	**C.**	1.13	0.36	-	-	-	-	-	-	-	-
Aux. Rooms	**S.**	-	-	-	-	-	-	162	11	-	-
	C.	-	-	2.10	0.38	3.08	0.10	35200	1710	74.4	3.0
Storage	**C.**	-	-	-	-	-	-	69.8	7.3	3.21	0.16

Table 3. Other Radionuclides Total Activity and SD in radioactive wastes of L54-M CeSNEF

4.2 DA Results

Destructive samples A – H (concrete, metal, plastic, crud) were picked up in several controlled areas of L-54M CeSNEF plant (S004, S005, S006, I001) and no alfa contamination is present in the results of their analyses. Table 4 shows that low fixed contamination of ^{137}Cs in these matrices is consistent with total beta activity concentration measured values (in line with MDA value of ^{90}Sr). The two hot spots I and L on S005 and S006 floor (concrete) present fixed contamination of ^{137}Cs, ^{90}Sr and $^{59+63}$Ni, the last ones as activation products coming from corrosion and erosion of components (see Table 5).

ID	TOTAL BETA			Cs-137		
	Act. Conc. [mBq·g^{-1}]	SD [mBq·g^{-1}]	MDAs [mBq·g^{-1}]	Act. Conc. [mBq·g^{-1}]	SD [mBq·g^{-1}]	MDAs [mBq·g^{-1}]
A	245	2	15.9	125	46	24.4
B	1.12	0.22	0.32	< MDA	-	7.53
C	443	41	38.8	238	24	7.06
D	< MDA	-	48.3	< MDA	-	29.3
E	248	40	53.9	56.2	15.6	7.78
F	47.2	4.2	0.52	38.8	24.1	13.5
G	2.06	0.14	0.04	1.96	0.62	0.31
H	0.30	0.03	0.04	< MDA	-	0.31

Table 4. Total beta and Cs-137 Activity Concentration, SD, MDA in destructive sample A - H

ID	TOTAL BETA			Cs-137			Sr-90			Ni-59+63		
	Act. Con.	SD	MDAs	Act. Conc.	SD	MDAs	Act. Conc.	SD	MDAs	Act. Conc.	SD	MDAs
	[KBq·g^{-1}]	[Bq·g^{-1}]		[KBq·g^{-1}]	[Bq·g^{-1}]		[KBq·g^{-1}]	[Bq·g^{-1}]		[Bq·g^{-1}]	[Bq·g^{-1}]	
I	30.1	17.8	14.4	15.6	981	0.76	2.13	2.31	0.26	1.55	0.008	0.004
L	0.004	0.24	0.03	0.002	0.130	0.01	0.0003	0.017	0.04	0.040	0.001	0.001

Table 5. Total beta and RNs Activity Concentration, SD, MDAs in destructive I and L

4.3 Nuclear Grade Graphite and Concrete Results

In 2014, *Politecnico di Milano* performed a pre-characterisation of the monolith structures: few samples (3) were collected both along the entire activated nuclear grade graphite brick (120cm) and along the inner parts of concrete to evaluate the activity concentration gradient of these two matrices. Table 6 shows the mean activity concentration of ^{3}H, ^{14}C, ^{60}Co, ^{152}Eu and a conservative estimation of their total activity. A scarification process seems an available solution for the inner layers of the activated concrete.

Monolith	Nuclide	Total Activity [GBq]	Mean Activity Concentration [Bq·g^{-1}]	Mean SD [Bq·g^{-1}]	Mean MDAs [Bq·g^{-1}]
Graphite	**^{3}H**	24.8	2050	45	0.15
	^{14}C	1.16	98.3	9.9	0.15
	^{152}Eu	2.98	253.91	17.80	0.069
Barite concrete	**^{60}Co**	0.094	6.03	0.07	0.0058
	^{152}Eu	0.577	36.72	2.83	0.019

Table 6. RNs Total Activity and activity concentration in Graphite and Concrete

4.4 Radioactive Waste Volume Estimation

Matching the physical data of the plant SSC [27] with the ones coming from the radiological characterisation, Table 7 offers a conservative estimation of radioactive waste volumes divided by matrices. Reactor Hall Building volume estimation presents a big uncertainty due to its total or partial future dismantling (*****).

Area Matrix	Labs [m^{3}]	Reactor Hall [m^{3}]	Auxiliary Rooms [m^{3}]	Storage [m^{3}]	Control Room [m^{3}]	Stack [m^{3}]	Total Volume [m^{3}]
Building (min+max)	~ 38 ÷ 42	~ 16 ÷ 30 *	~ 5 ÷ 10	~ 13.5 ÷ 16.5	~ 1.5 ÷ 2	~ 20	~ 94 ÷ 120
Linoleum	~ 0.2	~ 0.5	~ 0.5	~ 0.05	~ 0.1	-	1.35
Linoleum + insulation	-	~ 65	-	-	-	-	~ 65
Plastic / conductor	~ 0.5	~ 2	~ 0.5	~ 2.5	~ 0.2	-	~ 5.7
Plastic	~ 3	~ 1	~ 0.5	~ 3	~ 0.5	-	~ 8
Metal (high empty fraction	~ 40	~ 66	~ 16	~ 23	~ 17	~ 27.5	~ 189.5
Wood	~ 17.5	~ 1.5	~ 1.5	~ 8	~ 0.5	-	~ 29
Mixed material	~ 5	~ 1.5	~ 26.5	~ 21.5	~ 2	-	~ 56.5
Biological shield	-	~ 73	-	-	-	-	~ 73
Graphite	-	~ 6	-	~ 6	-	-	~ 12
Paraffin	-	-	-	~3	-	-	~ 3

Table 7. L-54M CeSNEF Estimate Volume of Radioactive Wastes

5.CONCLUSIONS AND FUTURE WORKS

The objective of *Politecnico di Milano* is to achieve the Greenfield Status. The data produced during the L-54M CeSNEF pre-characterisation are required by the Italian Competent Authority to fulfil the decommissioning application of the plant and are necessary to assess the Clearance Levels. Italian Legislation [20] allows the submission of a decommissioning programme by intermediate phases (art. 55). *Politecnico di Milano* and NUCLECO SpA have already planned these sequential steps and the dismantling of the stack will be the first operative one. Also, a new and more detailed characterisation campaign of nuclear grade graphite is going to start, joined GRAPA Project (IAEA).

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