DESMANTELAMIENTO

INNO4GRAPH: DEVELOPMENT OF TOOLS FOR GRAPHITE REACTORS DECOMMISSIONING. GATHERING OF DATA FROM EUROPEAN GRAPHITE REACTORS

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INNO4GRAPH, a Euratom HORIZON -2020 program funded project, aims at developing a set of physical and digital tools and methods to be used for the decommissioning of graphitemoderated nuclear reactors. It is executed by a consortium of the following entities: GRAPHITECH, CEA, EDF, CYCLIFE Digital Solutions, ENRESA, SOGIN, Consorzio per la Ricerca Nucleare - Politecnico di Milano, Westinghouse, Univ. of Manchester, Lithuanian Energy Institute, Ansaldo Nucleare, ARTTIC and TECNATOM (https://www.inno4graph.eu). As part of its activities, there is one consisting in data gathering from a set of European graphite reactors (Chinon A2, and CEA G1 and G2, in France; Ignalina in Lithuania; Latina in Italy; Vandellós 1 in Spain, and CeSNEF L-54 M in Italy), and more specifically, from its operational history, core design, and result of physical-chemical and radiological analyses of their graphite material. The investigation made has produced a list of information and data that has been organized in a very simple Excel spreadsheet. The assessment of this information has made evident that radiological characteristics of irradiated graphite are well known, and most of it would mainly fit in what could be called a low level long-lived waste category (waste classification varies between countries); that some physical characteristics of irradiated graphite, which could be relevant for the decommissioning, have to be more studied; that some behaviors are clear (loss of density); and that, at the same time, graphite seems to be in quite good mechanical condition after typical operation periods of 20 years, but further investigations are needed.

INTRODUCTION

INNO4GRAPH, a Euratom HORIZON -2020 program funded project, aims at developing a set of physical and digital tools and methods to be used for the decommissioning of graphite-moderated nuclear reactors, and is executed by a consortium of the following entities: GRAPHITECH, CEA, EDF, CYCLIFE Digital Solutions, ENRESA, SOGIN, Consorzio per la Ricerca Nucleare - Politecnico di Milano, Westinghouse, Univ. of Manchester, Lithuanian Energy Institute, Ansaldo Nucleare, ARTTIC, and TECNATOM (https://www.inno4graph.eu). As part of its activities, there is one consisting in data gathering from a set of European graphite reactors (Chinon A2, and CEA G1 and G2, in France; Ignalina in Lithuania; Latina in Italy; Vandellós 1 in Spain, and CeSNEF L-54 M in Italy), and more specifically, from its operational history, core design, and result of physical-chemical and radiological analyses of their graphite material.

The objectives of this task were:

- Gather the available information about graphite, to serve as basis for the rest of INNO4GRAPH project activities.
- Identify gaps and lack of information, to plan for future characterization activities where needed.
- At the same time graphite information was gathered, another objective was also to collect data about other elements that could have influence on the dismantling process: info about internal core structures, enclosure structures (in both cases typically made of steel or concrete), etc.

SCOPE OF THE INFORMATION SEARCHED

As mentioned before, the facilities for which information was collected are the following:

- Chinon A2 (France, 800 MWt, 1965-1985, CO_2, 26 bar, spherical steel vessel) (Figure 1).
- CEA G1 (France, 46 MWt, 1956-1968, air cooled, 1 bar, horizontal pile) (Figure 2).
- CEA G2 (France, 260 MWt, 1958-1980, CO_2, 15 bar, horizontal pile) (Figure 3).
- Ignalina (Lithuania, RBMK-1500, 1983-2004, 4800 MWt, graphite cooled by He+N_2, enriched U) (Figure 4).
- Latina (Italy, MAGNOX, 840 MWt, 1963-1986, CO_2, spherical steel vessel) (Figure 5).

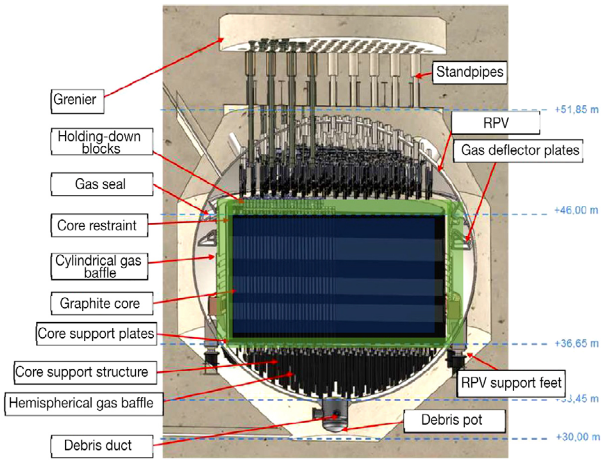

Figure 1. Chinon A2.

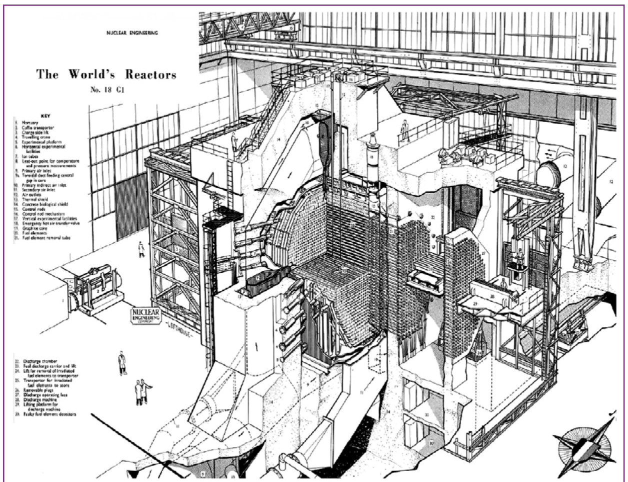

Figure 2. CEA G1.

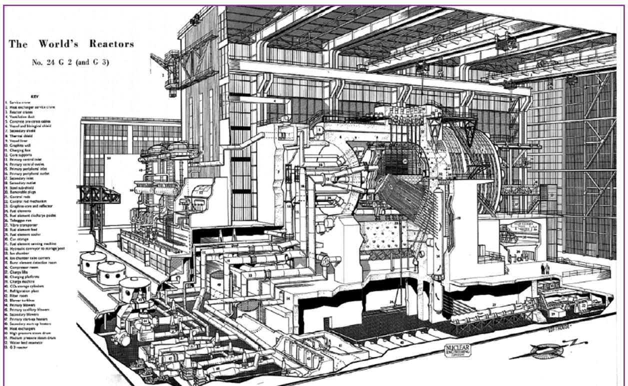

Figure 3. CEA G2.

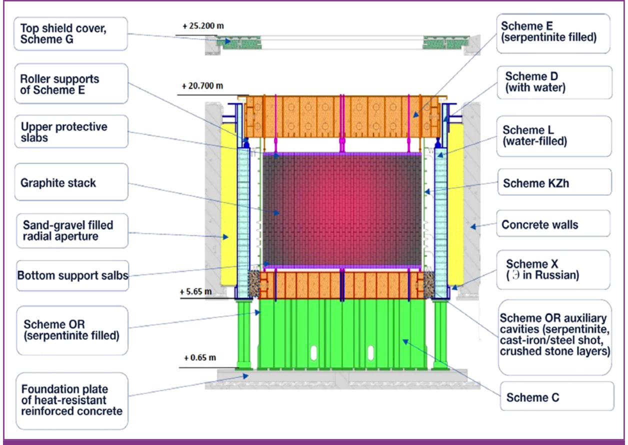

Figure 4. Ignalina.

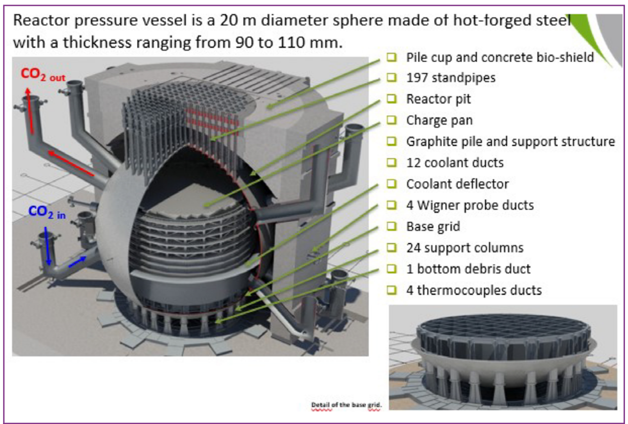

Figure 5. Latina.

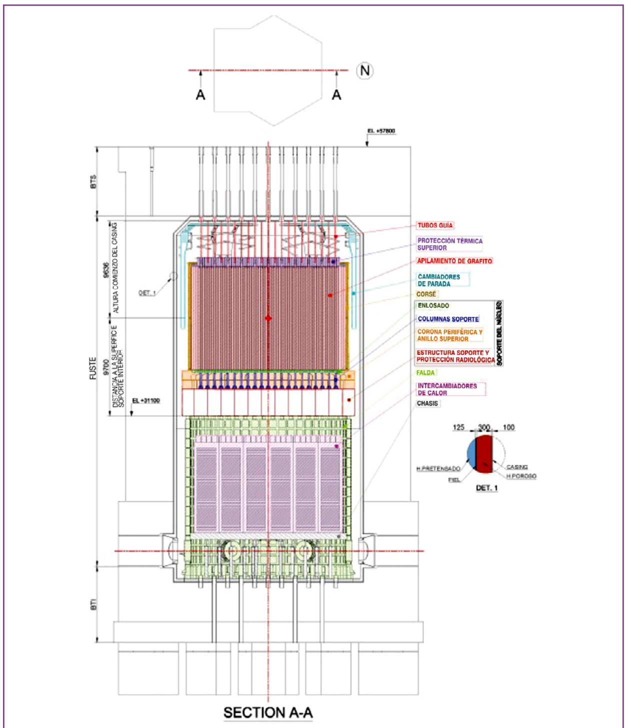

Figure 6. Vandellós 1.

- Vandellós 1 (Spain, UNGG, 1670 MWt, 1972-1989, CO_2 28,5 bar, reinforced concrete vessel) (Figure 6).
- CeSNEF L-54 M (Italy, research, 50 KWt, 1959-1979, U 20%, water cooled) (Figure 7).

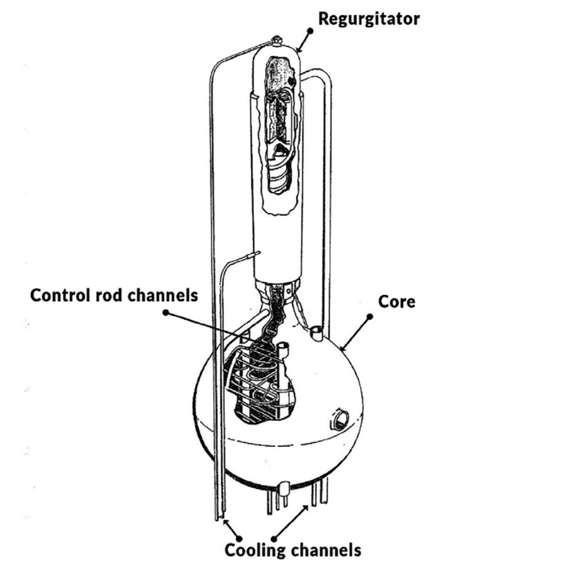

Figure 7. CeSNEF L-54 M.

A set of empty tables with the information needed was sent to all the INNO4GRAPH partners that have access to plant information, in order to fill in these tables as much as possible. The data were organized in the following sections:

- Reactor general information
- Graphite physical information
- Internal structures physical information
- Enclosure structures physical information
- In-core information
- Graphite radiological information
- Internal structures radiological information
- Enclosure structures radiological information
- Atmosphere radiological information
- Model radiological information

The information about graphite is clearly of the highest priority, whilst the information about the rest of the elements (structures, atmosphere...) is to be provided depending on its availability and importance.

The radiological information requested is basically direct radiological measurements and radioactivity content in samples (radionuclide specific).

The "physical" information requested comprises chemical composition and impurities of materials, as well as physical parameters as, for instance (in this case, for virgin graphite):

- Chemical impurities concentration
- Ash content concentration
- Density
- Porosity
- Thermal conductivity
- Heat capacity
- Electrical conductivity
- Water permeability
- Elastic modulus
- Compression strength
- Tensile strength
- Hardness
- Modulus of resilience
- Ductility
- Anisotropy

Partners could also add other properties if they had some additional data to report.

Model information was requested to get information about results of theoretical calculations with activation models.

In general, the search for data was made trying to envelope as many types of information as possible, since the future stages and results of other project activities may require or may highlight the importance of certain parameters and properties not initially believed relevant.

ASSESSMENT OF RESULTS

With respect of the amount and details of the information gathered, the following conclusions are obtained:

- Graphite radiological info is quite good in most cases.
- Activation model calculations have been performed in all cases.
- Physical data for virgin graphite is well furnished, since this info was important for reactor design. Physical info for irradiated graphite is not so frequent, and only some variables have been reported. If this info has to be completed for future dismantling operations, is still to be determined.
- Physical data for structures before irradiation should be available, since it was necessary for plant design; nevertheless, not much info has been provided, since it is generally believed that this is not the main purpose of this project. For irradiated structures, there is not much data available.
- Some data on structures radiological information is provided, anyway not being the highest priority.

With respect to the specific case of the graphite and the general information of the facilities, some average representative values are obtained, that are summarized here below (CeSNEF L-54 M is a different case since it was a research reactor, and also CEA G1 and G2 since they are older models).

- Years of power operation: 20 years
- Graphite total mass: 2000-3000 t
- Typical core dimensions: 10 x 10 m (height x diameter)
- Total neutron fluence (n/cm^2): 1.0E+22
- Total number of graphite bricks: 30000 - 40000 (commercial power reactors)
- Typical brick mass: 50-100 kg
- Typical brick dimensions: 0,5-1,5 m height, 250 mm brick diameter (or L x W)
- Virgin graphite density: 1.6 -1.8 t/m^3 (porosity 0.2-0.3). Irradiated: 1.5-1.7 t/m^3 (graphite wear around 6%)
- Virgin graphite compression strength: 30 MPa (irradiated: 40 MPa, but based only in one plant data)
- Virgin graphite tensile strength: 10 MPa (irradiated: no data).
- C-14: 1.00E+05 Bq/g
- H-3: 3.00E+05 Bq/g
- Co-60: 1.80E+04 Bq/g
- Cs-137: 3.6E+02 Bq/g
- Cl-36: great variation between 1E+00 and 1.00E+04 Bq/g.

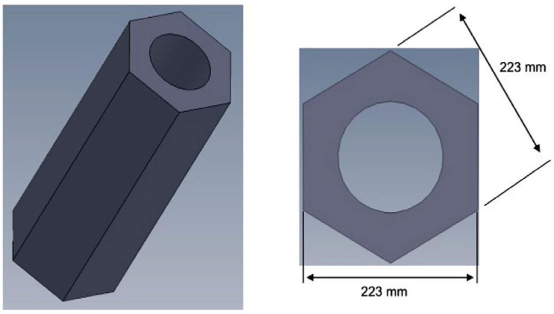

Figure 8. Typical graphite brick geometry.

CONCLUSIONS

- Irradiated graphite is well known from the radiological point of view, and mostly fits in what could be called a low-level long-lived waste category (waste classification varies between countries). H- 3 and C-14 are the highest contributors to the activity, but activation products as Co-60, Ni-63 and Fe-55 are also important, with relatively minor contributions of fission (Cs-137, Sr-90) and transuranic radionuclides. Cl-36 values present a huge dispersion, being this nuclide very sensitive for the long-term disposal viable options.
- Mechanical properties of irradiated graphite are not well known depending on partners, but it seems that the mechanical properties do not seem to worsen very much (compressive strength), although tensile strength is not tested so often.
- General conditions of irradiated graphite in the reactors are reported to be good: no fragments, no cracks, no relevant deformations.
- Irradiated graphite density loss is clear.
- Mechanical properties of irradiated graphite could be more deeply tested, in order to strengthen dismantling operations.
- As INNO4GRAPH goes on, the identification of what core and graphite properties are required to know may change, so the identified gaps may change and new additional information could have to be added to this database.