



Fontenay-aux-Roses, 12 April 2024

The Chairman of the French Nuclear Safety Authority (ASN)

IRSN OPINION NO. 2024-00051

Subject: Cigéo project construction licence application – “GP1” - Evaluation of the basic data adopted for the Safety Assessment.

Ref.: Letter ASN/CODEP-DRC-2023-030596 of 7 June 2023. Examination of the Cigéo project construction licence application file - Referral ref. SAISI-DRC-2023-0093.

In its letter in reference, the French Nuclear Safety Authority (ASN) requested the opinion of the Institute for Radiation protection and Nuclear Safety (IRSN) regarding the construction licence application for the Cigéo project related to the deep geological disposal of high-level (HLW) and intermediate-level long-lived (ILW-LL) waste, as submitted by the French national radioactive waste management agency (Andra).

ASN requested a technical review of this construction licence application, structured in three thematic groups:

- the basic data used for the Cigéo safety assessment ("GP1" review);
- the safety assessment related to the operational phase ("GP2" review);
- the safety assessment related to the post-closure phase ("GP3" review).

ASN also identified several cross-cutting themes to be incorporated into the review of these three thematic groups. These include the elements used to define the industrial pilot phase, the preliminary specifications for waste package acceptance, the reversibility (including disposal adaptability and waste package retrievability), as well as the consequences of climate change.

This opinion concerns the GP1 technical review. ASN asked IRSN in this regard to examine the knowledge compiled and the assumptions used by Andra for the Cigéo safety demonstration, in relation to:

- the so-called "reference" and "reserve" waste inventories and their radiological, physical and chemical properties, in particular the process used to compile these inventories, the waste package characteristics and the waste package disposal chronologies;
- the site chosen for the Cigéo facility and its evolution over time (including after closure), in particular the surface environment (initial state of the environment and its meteorological, geotechnical and hydrological characteristics), the geological context, including any natural resources, the hydrogeology (including its modelling and the predictive geomorphology of the site) as well as the initial properties of the host rock formation;

- the properties of the various disposal system components and their evolutions, with particular emphasis on thermo-hydro-mechanical and hydraulic-gas transients arising from the construction and operation of Cigéo, waste package behaviour and release models, the evolution of cementitious, metallic and clay materials, and lastly, the behaviour of radionuclides and toxic chemicals in these various media.

ASN asked that particular attention be paid to the data acquisition methodology, the adequacy of data with regard to the models used, and the estimation of the uncertainties considered at this stage.

In addition, this technical review was the subject of a technical dialogue organised by the National Association of Local Information Committees and Commissions (*Association nationale des comités et commissions locales d'information - ANCCLI*), the Local Committee for Information and Follow-up of the Bure Laboratory (*Comité local d'information et de suivi du laboratoire de Bure - CLIS de Bure*) and IRSN, with the dual aim of taking the concerns of civil society into consideration in order to make IRSN's review more robust, and of allowing civil society to form its own opinion and therefore to participate in the process leading up to the public decision.

The topics addressed below are based on IRSN's technical review of the submitted safety case and the information provided by Andra during the review. The resulting recommendations, as well as the commitments made by Andra to ASN in light of this review, are listed in the appendices to this opinion. This IRSN technical review will be presented to the members of the Advisory Committee of Experts on Waste (GPD) at their meeting on 24 and 25 April 2024, which will also be attended by members of the Advisory Expert Committees on Laboratories and Plants (GPU) and on Radiation Protection for workers, the general public, patients and the environment (GPRP).

1. INVENTORIES, WASTE PACKAGES AND ADAPTABILITY

In order to define the Cigéo reference inventory, Andra adopted a scenario that assumes a 50-year operating life for the current fleet (which includes the EDF reactors in operation as well as the Flamanville EPR), as well as a multi-recycling of all spent fuel from that fleet. Based on these assumptions, the reference inventory represents approximately 10,000 m³ of HLW waste (nearly 56,000 primary packages) and 73,000 m³ of ILW-LL waste (nearly 167,000 primary packages). Andra has also defined an additional reserve inventory, with a view to carrying out adaptability studies for Cigéo, based on other prospective industrial scenarios considering, for example, an extension to 60 years of the operating life of part of the current fleet, early cessation of spent fuel processing, or geological disposal of some long-lived low-level waste (LLW-LL).

IRSN considers that the families of primary packages in the reference and reserve inventories are clearly identified and consistent with the prospective industrial scenarios studied, which cover the possibilities envisaged by the Multiannual Energy Plan. IRSN considers that the knowledge presented relating to the reference inventory is appropriate for dimensioning and demonstrating the safety of the Cigéo facility. However, some uncertainties liable to impact the number of disposal cells and disposal chronologies remain, relating in particular to the volumes of primary waste packages for which the final packaging remains to be defined (STE2 sludge, PIVIC packages, etc.), the disposal methods (with or without a disposal container) and the processing of spent MOX and CEA fuels (commitment 2024-E2). These uncertainties will have to be accommodated by the flexible nature of the facility, which is one of the focuses of the GP2 review. Regarding the preliminary specifications for acceptance of primary packages, IRSN considers that their elaboration process and the choice of topics on which they are based to be satisfactory. The data presented for the reserve inventory appear to provide an adequate basis for the studies evaluating the ability to adapt Cigéo to the chosen prospective industrial scenarios and, where applicable, the disposal of LLW-LL. Any disposal of separated plutonium and MOX scrap would require a roadmap, however, in order to assess its feasibility (commitment 2024-E1). Overall, IRSN considers that assessing the dates of reception of the last packages for both the reference and reserve inventories is subject to significant uncertainties. In addition, IRSN points out that the overall approach for establishing the radiological inventory, which has not changed since the safety options file (DOS), is satisfactory; the approach for defining the inventory

of toxic chemicals to be considered for the Cigéo impact studies, on the other hand, would benefit from being consolidated (commitment 2024-E3).

For the purposes of the GP1 review, the consequences described by Andra of changes to energy policy that would result in disposal of the reserve inventory or an "enhanced reserve inventory" taking into account the main energy policy changes recently announced (namely, the extension of the operating life of the entire current fleet to 60 years and the commissioning of six EPR 2 units) were assessed by IRSN mainly in terms of disposal footprint. In some studied scenarios, the disposal footprint might exceed the current boundaries of the underground construction zone by a few hundred metres to a few kilometres, while remaining within the transposition zone for which the feasibility of a disposal facility was demonstrated in 2005. At this stage of the review (GP1), IRSN has not identified any geology-related knowledge liable to compromise Cigéo's ability to be adapted to the reserve inventories described by Andra. It will nevertheless be necessary to assess the safety impact of extending the disposal facility into areas where the siting criteria values would be different than those adopted when defining the current underground construction zone, taking into account uncertainties relating to the inventory and to unforeseen contingencies during construction of the facility (commitment 2024-E16).

2. THE MEUSE/Haute-MARNE SITE AND HOST ROCK

Andra has carried out new hydrogeological and geotechnical characterisation studies of the surface and sub-surface since the safety options file was reviewed in 2017, in particular concerning the Barrois limestones in the ramp area. IRSN considers that these new characterisations are appropriate but need to be pursued in order to fully understand the behaviour of the Barrois aquifer (commitment 2024-E4) and to detect any cavity liable to impact the stability of the planned buildings (commitment 2024-E6). The additional investigations in the shaft area, which were planned but had to be postponed, should be carried out as soon as possible (commitment 2024-E5).

In addition, IRSN acknowledges the significant work already undertaken to determine the radiological and chemical baseline state of the Cigéo project environment, and takes note of the planned new campaign, which should make it possible to update and supplement this baseline state (commitment 2024-E7). With regard to the natural hazard levels potentially impacting Cigéo, IRSN considers that the flooding, wind and tornado hazards have been satisfactorily assessed. IRSN considers that extreme temperature and snow values should be estimated taking into account data from longer return periods as well as more data representative of the conditions experienced at the site from historical records (commitments 2024-E8 and 2024-E9). Lastly, climate change should be taken into consideration, in terms of defining hazard levels that are subject to change and accommodating modifications to the facility to adapt to them (commitment 2024-E8).

Concerning the sub-surface at the Meuse/Haute-Marne site, Andra has acquired sufficient knowledge to assess the safety of Cigéo at the construction licence application stage, in particular as regards the site's tectonics, structural context and predictive geological evolution. In addition, IRSN agrees that there are no natural resources of interest at the site. IRSN holds the opinion, however, that a host formation survey programme should be carried out in the area around the deep structures identified in 2010 by geophysical survey in the northern part of the facility area, in order to adapt the design of the underground facility if necessary. This aspect is addressed in recommendation No.1 appended to this opinion.

Regarding the hydrogeology of the Oxfordian and Dogger aquifers, IRSN encourages Andra to continue to improve their representation in the hydrogeological model, taking into account in particular the data it intends to acquire via boreholes in both the Oxfordian (particularly the "Grey series") and Dogger aquifers, as well as predictive geology evolutions that factor in climate change.

Lastly, concerning the initial properties of the Callovo-Oxfordian host rock, IRSN considers that the knowledgebasis developed by Andra relating to the hydrodynamic and chemical containment processes involving the insolubilisation and sorption of species in the Callovo-Oxfordian host rock is a high-quality baseline

supporting its safety demonstration. IRSN considers, however, that the possible influence of hydraulic overpressure, combined with a bounding hydraulic conductivity value with respect to the measurements made, should be assessed as part of a sensitivity study of the overall performance of the disposal system, taking into account scenarios featuring hydraulic shortcutting of the host rock (commitment 2024-E10).

3. EVOLUTION OF DISPOSAL SYSTEM COMPONENTS

The geological disposal system consists of waste packages, engineered features made of clay (e.g. sealing plugs and backfill), metal or cementitious materials (disposal containers, linings or civil engineering structures, etc.) and the host rock. The initial properties of these components are subject to change as a result of the transient thermal, hydraulic, mechanical and chemical disturbances to which they will be exposed.

With regard to geomechanical disturbances attributable to the construction of the disposal facility, Andra has adequate knowledge of the thermal and hydromechanical disturbances induced by the HLW disposal cells, and of the long-term evolution of the area of damaged rock surrounding the ILW-LL cells. Some aspects require further consolidation, in particular regarding the possible influence of differences in depth or lithology between the main level of the Meuse/Haute-Marne underground laboratory and that of Cigéo. Given the importance of effectively sealing the access shafts leading to the underground facility, from a post-closure safety perspective, particular attention should be paid to the excavation method used for the shafts. Accordingly, IRSN considers that this method should be based on the best available techniques and must cause no more damage to the rock than a mechanical excavation method. This aspect is addressed in recommendation No.2 appended to this opinion.

With regard to the hydraulic-gas transient, the main challenge is to ensure that the pressure resulting from significant production of gas due to anoxic corrosion and radiolysis after closure does not lead to "large-scale" fracturing of the host rock. The digital model used to simulate this transient has been improved, in particular by taking into account non-zero gas inlet capillary pressures, although this has yet to undergo full experimental validation. This model leads to a median (i.e. non-conservative) estimate of the maximum gas pressure in the disposal facility that is below the "large-scale" fracture threshold of the host rock. However, it does yield a value close to this threshold for a combination of assumptions that Andra considers to be very unrealistic, although the uncertainty relating to that result is not accurately known. Accordingly, IRSN considers that it is necessary, firstly, to continue the digital model validation process and to clarify the related uncertainties (relating to the phenomena taken into account, the multiple parameters, the "gas source term", etc.) and secondly, to define a requirement relating to the maximum acceptable gas pressure, including a margin with respect to the rock fracturing threshold and providing for *in situ* rock strength checks as construction of the Cigéo facility progresses (commitments 2024-E13 and 2024-E14).

Regarding the effects of chemical disturbances on the containment properties of the host rock, IRSN considers that the assessment presented by Andra of the consequences in terms of concrete-induced alkaline disturbance and the saline plume from ILW-LL is generally satisfactory. Current research studying the complex-forming species created as organic compounds present in the aforementioned components degradation also represents a significant step forward in terms of assessing the influence of such species on radionuclide mobility.

Regarding the evolution of packages, cementitious materials and steels, Andra uses radionuclide release models and related parameter values for the primary packages in the reference and reserve inventories that are consistent with contemporary knowledge of the degradation of the constituent materials of primary packages. For cementitious materials, Andra intends to use - for supports and linings in ILW-LL galleries and cells, and for sealing plug supports - a Portland cement-based concrete for which it has good quality research providing a thorough understanding of the associated chemical disturbances and mechanical consequences in the short, medium and long term. IRSN considers that a development programme would be necessary if the use of low pH concretes is again envisaged, to ensure that the chosen formulation achieves the desired performance. With regard to steel for linings in HLW cells and HLW disposal containers, IRSN notes that the first formulation of the cementitious material intended for use in the annular space between the rock and the lining, which was tested by Andra at the construction licence application stage, leads to significant corrosion rates liable to compromise the mechanical and watertight functions assigned to those components. IRSN takes note of the ongoing programme to develop alternative formulations for this material, the initial results of which point to lower corrosion rates. This programme must yield convincing results in order to confirm the design basis of these components before the first HLW cell is excavated; it is therefore important to specify the programme in time for the GP3 review (commitment 2024-E12).

With regard to seals, the main function of which is to "prevent water circulation" in the disposal facility, Andra is now using "gas-permeable" reference concepts to reduce gas pressure inside the facility. IRSN notes that these concepts, featuring a clay core as the main component (the exact composition of which remains to be defined), are still at the stage of design principles. The installation of ramp and gallery sealing demonstrators is planned as soon as construction of Cigéo begins. As a ramp seal is faster to resaturate than a gallery seal, it should be possible to observe the first indications of hydraulic performance during the pilot phase. IRSN considers that a summary of the results of these demonstrators should be presented in time for the pilot phase review, in order to consolidate the full reference concept for each type of seal (i.e. in shafts, ramps and galleries), including all stages of their implementation, as well as the performance achieved by the seals in the surface-to-underground links (commitment 2024-E15).

4. CONCLUSION

In conclusion, IRSN considers that the knowledge developed by Andra in the areas of waste packages, Meuse/Haute-Marne site, Callovo-Oxfordian formation and cementitious materials is based on sufficient data for the safety assessment of Cigéo at the construction licence application stage. This knowledge is based on detailed hydrogeological and geotechnical characterisations, an appropriate assessment of meteorological hazards and an adequate understanding of the properties of the host rock, cementitious materials and waste packages, as well as their evolution under the effect of transient thermal, water, mechanical and chemical disturbances.

Regarding the reference and reserve inventories, the data collected by Andra is generally relevant, both for the Cigéo safety demonstration and for the adaptability studies considering the chosen prospective industrial scenarios. Some uncertainties remain, however, including uncertainties relating to the reference inventory that may impact the number of disposal cells and the disposal chronologies; these will have to be addressed through the flexibility of Cigéo while in operation. In addition, considering the possibility of a future fleet (eight additional EPR 2, SMR, RNR, etc.), the capacity of the facility to dispose of more waste will have to be assessed on the basis of further adaptability studies, considering time horizons that can be defined once the decisions relating to the future fleet have been taken.

At this stage of the construction licence application review (GP1), IRSN has identified two topics that require particular attention, respectively relating to HLW cells and to sealing structures, which refer to the pilot phase. Regarding HLW cells, it is important to provide the supporting evidence for the design basis of metal components before the first HLW cell is excavated, and to resolve the uncertainty regarding the possibility of flexures affecting the host rock at the location of the future HLW disposal zone. For sealing structures, which are still at the stage of design principles, efforts must be made to minimise damage to the rock while excavating the facility's shafts in areas that are subsequently to be sealed. Particular attention must also be paid to the definition of these structures and the *in situ* demonstration of their operability.

This review is supplemented by the Cigéo operational and post-closure safety demonstration reviews, carried out for the GP2 and GP3 technical reviews, respectively.

IRSN
Director General
By delegation
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APPENDIX 1 TO IRSN OPINION NO. 2024-00051 OF 12 APRIL 2024

IRSN recommendations

Recommendation no. 1

IRSN recommends that Andra conduct a Callovo-Oxfordian survey programme in the northern part of the underground construction zone (HLW disposal zones), aligned with the north-south faults identified in the Triassic-early Jurassic rock on the basis of 3D seismic data, in order to remove doubt regarding the possible impact of these faults on the properties of the Callovo-Oxfordian formation, in preparation for the pilot phase review and in any case before excavating the connecting galleries serving the HLW disposal zone.

Recommendation no. 2

IRSN recommends that Andra describes, before excavation of the shafts, the excavation method that Andra intends to adopt at least locally for the future areas to be sealed, so as not to cause more damage to the rock than with a mechanical excavation method.

APPENDIX 2 TO IRSN OPINION NO. 2024-00051 OF 12 APRIL 2024

Commitments by the operator declared by letter ref. Andra DG-24-0123 dated 7 March 2024

Commitment no. 2024-E1

In addition to the adaptability studies based on the reserve inventory, the content of which was approved as part of the fourth PNGMDR waste management plan, Andra has committed to produce, in advance of the public inquiry, a roadmap for completing a supplemental feasibility assessment regarding the disposal of separated Pu and MOX scrap.

Commitment no. 2024-E2

In updating the construction licence application file before the public inquiry, Andra has committed to quantify, for the families of primary packages in the reference inventory, any uncertainties - particularly those relating to packaging - that may impact the number and volume of primary packages.

Commitment no. 2024-E3

Andra has committed to present, before the public inquiry, a research programme aimed at consolidating the inventory of toxic chemicals to be considered for the Cigéo impact study. This programme is to be developed in the light of:

- chemical substances that are either highly toxic or introduced in large quantities into the disposal facility from the various primary waste package components (i.e. the waste, matrix and container);
- the most likely physicochemical and/or toxic forms of these substances encountered in the disposal facility;
- discrimination in terms of the degree of confidence in data reported by waste producers and the related margins.

Commitment no. 2024-E4

Andra has committed to transmit, no later than at the start of earthworks for the platforms in the ramp area and in the shaft area during the initial construction works, the results of the additional investigations and studies carried out to refine the characterisation of the Barrois limestone. The synthesis of these results will be to differentiate the various aquifers present in the shaft area and ramp area.

In the light of the results of earlier research and the planned experiments on excavation spoil piles, Andra will propose an updated monitoring programme for the Barrois aquifers, by the time of commissioning at the latest.

Commitment no. 2024-E5

Andra has committed to transmit the results of the planned geotechnical investigations in the shaft area within 12 months of their completion.

Commitment no. 2024-E6

Following up on the characterisation work that will be carried out during the preliminary development phase, Andra has committed to carry out additional investigations centred on the platforms that will accommodate building EP1 and the top of the package ramp, and on the shaft infrastructures if justified by safety considerations, with the aim of preventing instability of said structures. In this context, Andra will define the means of characterisation, including geophysical investigations, intended to yield an all-round understanding of the Barrois limestones near the aforementioned structures. The reports summarising the investigation results and any related processing will be submitted to IRSN before the first concrete is poured for the relevant structures.

Commitment no. 2024-E7

Andra has committed to present, before the facility is commissioned, the results of the planned new campaign to characterise the radiological and environmental chemistry baseline in the Meuse/Haute-Marne area. This campaign will:

- include the elements likely to be present in the environment, whether naturally or as a result of human activities unrelated to Cigéo. For any elements not previously detected, existing analytical techniques will be used to cross-analyse the impacts and related costs;
- include the elements contained in the spoil piles, if warranted by the research of their environmental effects;
- cover the various environmental compartments, using the best available techniques.

Commitment no. 2024-E8

In order to take into account the impact of climate change throughout the operating life of Cigéo, Andra has committed to, prior to commissioning:

- define hydrological and meteorological hazard levels representative of foreseeable climate situations potentially encountered at the end of the operating phase;
- provide supporting evidence of the conservativeness of the temperatures adopted for its safety demonstration, considering temperatures associated with a target exceedance rate of 10^{-4} /year and estimated using recent data, taking into account the impact of climate change through adverse climate forecast scenarios, for a time horizon consistent with the facility's operating phase;
- for hazards defined above, present evidence relating to the facility's ability to adapt to the hazards defined above, in order to maintain protection against hazard levels that may change as the result of climate change;
- present a detailed strategy for monitoring advances in terms of understanding of climate change and its impact on the hazard levels adopted for the facility.

Commitment no. 2024-E9

Andra has committed to supplement the snow risk assessment by carrying out, prior to commissioning, an in-depth study of the available historical data on snow levels observed within a radius representative of the conditions experienced at the site.

Commitment no. 2024-E10

In addition to the normal and altered evolution scenarios, Andra has committed to analyse the robustness of the overall performance of the disposal system, simultaneously considering (i) the bounding hydraulic conductivity of the Callovo-Oxfordian rock on a large scale, deduced from the statistical analysis of the measurements and (ii) a vertical hydraulic gradient that takes hydraulically-induced overpressure into account. It will present the relevant insights as inputs to the GP3 review.

Commitment no. 2024-E11

For the areas to be sealed, Andra has committed to choose a shaft excavation technique that avoids damaging the Callovo-Oxfordian rock (especially the silto-carbonated unit) to an extent liable to compromise shaft sealing performance. This choice will be made no later than at the end of the project and construction studies. It will be based in particular on a cross-analysis of excavation methods that, in addition to assessing the impact on damage, uses the best available scientific and technological knowledge to address the processing capacity of the Callovo-Oxfordian rock at the time of completion of the shaft seals.

Commitment no. 2024-E12

Andra has committed to clarify, by the end of June 2024, its research programme to study corrosion of metal components in HLW cells during the pilot industrial phase. This programme will consolidate the design basis of the HLW cell components, prior to the excavation of the first cell in the pilot HLW zone that will hold HAO packages.

Commitment no. 2024-E13

In preparation for underground excavation works, Andra has committed to define:

- a requirement relating to the maximum acceptable gas pressure in the disposal facility, incorporating a margin with respect to the "large-scale" fracture threshold of the Callovo-Oxfordian formation;
- a programme to locally characterise the in situ stress state and correlated fracture strength under fluid loading during construction of the underground facility, in order to verify compliance with the maximum gas pressure requirement.

It will present its chosen measurement methodology, with a view to its operational implementation before excavation of the first cells intended to receive disposal packages.

Commitment no. 2024-E14

Regarding the assessment of the maximum acceptable gas pressure in the disposal facility, in preparation of the pilot industrial phase assessment, Andra has committed to:

- assess the need to take into account the effects of hysteresis, if necessary supplement the chosen calculation model accordingly, and then continue the process of numerical verification and experimental validation of the model on representative structures;
- use this new model to refine the sensitivity study in order to assess the influence of the various (physical and/or software) parameters, phenomena and other uncertainties such as the source term, and thereby ensure that the calculated maximum gas pressure in the disposal facility complies with the specified fracture threshold requirement.

Commitment no. 2024-E15

In preparation for the assessment of the pilot industrial phase, Andra has committed to present a summary of the results, in particular from the in situ sealing demonstrators, making it possible to consolidate the full reference concept for each type of seal (i.e. in shafts, ramps and galleries). This will include:

- in operational terms, construction activities from removal of the lining/support segments to installation of the concrete support blocks and/or backfill, including the means enabling prior monitoring of the rock, works inspections and qualification of materials and components;
- the performance achieved for the surface-to-underground links.

Commitment no. 2024-E16

Andra has committed, in the event of energy policy changes resulting in the identification, at the end of the pilot industrial phase, of scenarios in which the disposal facility is extended beyond the underground construction zone, to assess the safety impacts of the extension. These analyses will include margins to accommodate various uncertainties, relating to inventories in particular. They will be carried out before the pilot industrial phase assessment.