What Is to Be Done with Nuclear Waste?

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Summary

France is in a distinctive position. Almost all of the electricity it produces is carbon-free, thanks to its hydroelectricity and nuclear power. The "*Sauvons le Climat*"[1] organization endeavors to put forward the pathways that are best adapted and most efficient to further limit carbon dioxide emissions rapidly, thus mitigating the potentially considerable risks associated to uncontrolled climate warming. It is thus duty-bound to be involved in the recently launched debate on the PNGMDR (Plan National de Gestion des Matières et Déchets Radioactifs - *National Plan on Management of Radioactive Materials and Waste*).

"*Sauvons le Climat*" which was involved in the previous debates on radioactive wastes considers it is essential, in such a complex issue, to review basic data so as to enable our fellow citizens to make an informed judgment on the impact of radioactive waste and materials, as compared to the part played by nuclear science and technology in the struggle against climate change, and also in numerous other fields, such as medicine, industry, energy independence, competitiveness.

The "PNGMDR" was first published in May 2007. It follows from applying the framework legislation of June 28, 2006 on sustainable management of radioactive waste. Its drafting began in 2003 under the authority of the ASN (Autorité de Sûreté Nucléaire - French Nuclear Safety Authority).

The PNGMDR, is updated every three years. It draws up an appraisal of the existing management of radioactive materials and waste, it makes an inventory of foreseeable needs for storage and waste disposal, it indicates the necessary capacities for such installations and specifies storage duration.

This essential and highly technical document deals, for the 2019-2021 time frame, with all the issues relative to the management of radioactive materials and waste whatever their origin (industry, energy, medicine, education, national defense). It is based on a publicly available national inventory of radioactive materials and waste managed by ANDRA (Agence Nationale pour la gestion des Déchets RAdioactifs - National Agency for the Management of Radioactive Waste).

A public debate had been organized from September 2005 to January 2006 (https://www.vie-publique.fr/actualite/alaune/gestion-dechets-nucleaires-debut-du-debat-public.html), prior to the first publication of the document, in May 2006, and the passing of the bill on the management of radioactive waste which was enacted June 28, 2006.

Another, more encompassing debate was organized in 2013 but failed because of the obstruction from organizations that opposed, sometimes physically, any discussion on this subject (https://www.debatpublic.fr/options-generales-gestion-dechets-radioactifs-haute-activite-moyenne-activite-a-vie-longue).

1 https://www.sauvonsleclimat.org/fr/ and, in English "Save the Climate" https://www.sauvonsleclimat.org/en/

The PNGMDR itself in its 2019-2021 version is, for the first time since its first edition, submitted to public inquiry. The debate was initiated on April 17, 2019.

The present paper endeavors, in the frame of our action for the climate, to present an overall factual view on the amount of waste generated by nuclear reactors, on the management of said waste, and the truth on the risks to which the population is exposed. It focuses on the high level and long lived waste (HLW) that are to be emplaced in the CIGEO (Industrial Center for Geological Disposal) facility. "Save the Climate" may eventually discuss the other issues addressed in the PNGMDR.

Overview

Unlike industrial chemical waste comprising toxic elements such as arsenic, lead, cadmium, mercury whose duration is infinite, nuclear waste contains radionuclides which decay over time even if, for some, it takes a very long time. But, the longer the radionuclides last, the less radioactive they are! Indeed, a long half-life[i] implies a low decay rate. For example, the half-life of iodine 129 is 15 million years; it is 700 million times less radioactive than iodine 131, the one that induced thyroid cancers in Chernobyl, whose half-life is a mere 8 days. Yet, populations often imagine that these two instances of iodine are the same and have the same radiological consequences!

The existing waste, comprised of the fission products and minor actinides conditioned in glass packages have to be cooled during a few tens of years. They are temporarily stored in supervised surface or shallow depth facilities, without any consequences on public health being ever observed. The current practice of temporary surface storage is generally satisfactory, even if there is some room for improvement, and this as long as nuclear power generation continues.

When the power released becomes sufficiently low to no longer require cooling, the waste can be disposed of in deep underground, at a depth of a few hundred meters, shielded from potential criminal actions and from possible consequences of long term climate change.

With common sense one understands that deep underground disposal would be even safer than shallow depth storage. Yet, it appears that deep underground disposal is felt to be more frightening than surface storage!

HLW Waste Production

Orders of Magnitude

In a 1000 MW electric (MWe) reactor, the spent fuel produced each year amounts to approximately 30 metric tons (about 3 m^3). Its main component is uranium (about 28.7 metric tons, corresponding to the extraction of 120 metric tons of natural uranium). The spent fuel also contains about 1 metric ton of fission products, with 45 kg of nuclides with a half-life of about 30 years (cesium 137 and strontium 90) and 65 kg of nuclides with a longer half-life. And, finally, it contains about 220 kg of plutonium and 18 kg of minor actinides[ii] (americium, curium, and neptunium).

The final quantity of waste to be disposed of depends on the view one has of the future of the nuclear power industry.

In a nuclear power phase-out scenario, the emplacement of the totality of the spent fuel in deep underground disposal repositories has to be considered. The practice of fuel reprocessing[iii] and the use of Mox do not change much since, at the end, the uranium from the reprocessed spent Mox and the waste from the reprocessing will have to go into the disposal facility. Thus, with nuclear phase-out, for each 1 000 MWe reactor, approximately 30 metric tons per year of high level long lived waste (HLW) will have to be placed in geological storage[iv].

In the opposite case, with sustainable nuclear power based on future breeding reactors, both the uranium from the reprocessing and the plutonium have to be considered as resources and the amount of HLW waste to be placed in geological repositories is down to about 1 metric ton per year. Add to that the production of about 20 metric tons of intermediate level long lived waste (ILW-LL) whose global radioactivity is a few per cent of that of the HLW waste, which radiate practically no heat and, as a consequence, whose management is easier.

As we see, a nuclear power phase-out scenario leads to having to manage 30 times as much HLW waste as in a sustainable nuclear power scenario. In addition, a phase out scenario would require that the decision on an underground repository be taken rapidly as it would imply a rapid vanishing of nuclear expertise which, today, ensures the safety of the storage facilities. Such expertise vanishing is already noticeable in countries such as Italy. Unlike what happened in Germany and in Belgium, a nuclear power phase-out decision should not be made before a geological repository is established. To demand nuclear power phase-out and at the same time oppose the development of a geological repository is irresponsible.

Comparisons

Today, 37% of electricity worldwide is produced by coal-fueled plants. A 1 000 MWe coal-fueled power plant consumes about 4 million metric tons of coal per year. On average, it produces about 300 000 metric tons of ashes; of these, 400 metric tons are heavy metals (cadmium, nickel mercury, lead,...) and other toxic products (antimony, arsenic, beryllium, fluorine,...) and radioactive nuclides among which 5 metric tons of uranium and 13 metric tons of thorium and their daughter isotopes (radium, radon, polonium,...). Note that these radioelements are not managed as opposed, obviously, to those produced in the nuclear power industry. In addition, such a coal-fueled power plant releases 10 million tons of carbon dioxide to the atmosphere each year and tens of thousands of metric tons of floating ash and fine particles.

It is interesting also to compare the volume of nuclear waste to that of toxic industrial waste. In the European Union in 1998, the total volume of HLW waste, including its containers, was 150 m^3 (a cube with 5.5m sides). The total nuclear waste volume, including intermediate level (ILW) and low level waste (LLW) was 80 000 m^3 (a cube with less than 45m sides) while the volume of toxic industrial waste was 10 million m^3 (a cube with 215m sides) and that of all the industrial waste was 1 billion m^3 (a cube with 1 km sides).

The management of toxic industrial waste and of nuclear waste, whether in the short term or in the long term is hardly comparable but note that severe lead or mercury intoxications have been observed even in developed countries while, in these same countries, there have been no reports of radiation exposure leading to significant consequences to the population, thanks to the careful management of the spent fuel and of the waste from the reprocessing.

Disposal In Geological Repositories

As long as they remain confined underground in the deep underground repository, nuclear waste represent no danger whatsoever to the population. A contamination of surface water by long lived radionuclides could possibly represent a risk in the future. For this contamination to occur, the following would have to happen:

- First, the containers in which the waste are stored would have to be damaged by aqueous corrosion; this should take at least 10 000 years.
- The radioactive elements would have to progressively dissolve in water. For those enclosed in glass, this would take several hundreds of thousands of years. Some elements like plutonium americium, curium and neptunium are not easily soluble in water, so that dissolving them takes even longer.
- The dissolved radioactive elements would have to be conveyed by water so as to escape the storage geological layer. In clay, this implies a diffusion process which is very slow. Typically, for a site such as Bure, this would take some hundreds of thousands of years for the most mobile elements (iodine 129, technetium 99, niobium 94, chlorine 36) and much longer for the less mobile elements (plutonium, uranium, neptunium...).
- The radioactive elements would have to reach the groundwater table, a process that would be rapid compared to the previous ones. At this stage, the most radioactive radionuclides, cesium 137, strontium 90 and the main actinides (plutonium, americium, and curium) will all have decayed and disappeared a long time ago! Neptunium, with its very low radioactivity, is poorly soluble in water and not mobile. A small layer of clay a few meters thick would be enough to keep it from ever reaching the surface. Practically, only iodine 129 and chlorine 36, both weakly radiotoxic elements could end up in the underground water neighboring the repository, after some hundreds of thousands of years.

Hazard to the Population

The fundamental safety rule decreed by the safety authorities for geological disposal recommends that the exposure increase to the most exposed populations at any time in the future be at most one tenth of the level of natural radioactivity. For a well designed disposal, all the calculations done to simulate a return of the nuclides to the biosphere show that this limit should never be reached except in the event of deliberate intrusion in the disposal repository and in that case, the hazard is undergone by the intruding agents themselves.

In ANDRA's "Dossier Argile 2005" (Clay file 2005) an estimation of the maximum doses that could be received by the most exposed populations for the various types of waste stored[v] is provided.

Type of waste	Maximum dose (mSv/yr)	Time frame of maximum (years)
All B	0.00047	370 000
All C	0.0008	550 000
CU1 + CU2	0.022	410 000
CU3	0.000073	400 000

Table 1
ANDRA's estimation of the maximum doses potentially received by the most exposed populations

The Basic Safety Rule (BSR) in France limits the acceptable dose to 0.25mSv/year. We see that in the worst case, the dose anticipated by ANDRA would not exceed one tenth of the BSR. Note that no effect from natural radiation under 50 mSv has ever been observed.

Neither the present residents in the vicinity of these geological disposal repositories nor their remote descendants are exposed to any hazard, except in the event of accidents related to the various transport operations in connection with the disposal facility's operation. Why so much doubt is expressed in the media and among the population regarding the innocuousness of this geological disposal remains to be understood. In all likelihood, institutional organizations have not informed the population sufficiently, arguing that they did not have the definitive risk evaluations.

Hazard to the Environment

While there is no longer any doubt that human action is responsible for the disappearance of a number of animal species, there is no indication that such a disappearance can be attributed to the exploitation of nuclear power. On the contrary, in the extreme cases of radioactive contamination, such as with atmospheric nuclear weapons testing or the Chernobyl catastrophe, the biotopes rapidly returned to their initial state even if the residual radioactivity remained significantly high.

More generally, any impact on the biosphere due to the production of electricity by nuclear power could be envisioned only if the average radioactivity increase were to overshoot significantly the level of natural radioactivity. This said, the activity of the total amount of waste produced in the operation of the entire French reactor fleet during 50 years without any reprocessing would represent, after 1000 years, only about one ten thousandth of the radioactivity of the French earth crust[vi], which means that, in the very unlikely event where all the activity of the disposed waste were to be released to the environment, the mean radioactivity increase would remain very small.

Other Geological Options

- The Bure site that was chosen by ANDRA for its underground laboratory is characterized by a thick argilite layer. This argilite is saturated with quasi stationary water.
- The sites hollowed out in salt layers such as those being tested in the USA and in Germany are anhydrous and totally dry. However, if for some reason or another, such as a poor conception of the access routes or future exploitation of the salt, water were to penetrate in the site, it would saturate with salt and become very corrosive, thus accelerating the dissolution of the fuel components.
- Granitic sites, such as those foreseen in Sweden and Finland are characterized by a total absence of water in so far as the granite is homogeneous and weakly cracked as in the Baltic Shield.

Separation and Transmutation

The dimensions of the geological repository are determined mainly by the amount of heat released by the high level waste packages. Reducing the dimensions of the repository to reduce its cost is one of the reasons for opting for a separation and transmutation strategy. Just extracting the plutonium divides the heat load by a factor two. To reduce the heat load during the first century of disposal it could be economically interesting to separate the cesium and the strontium and store them temporarily during their decay. A separation of the americium and its transmutation in dedicated reactors or in breeder reactors would gain two orders of magnitude on the waste heat load and, as a consequence, a comparable reduction of the repository's surface.

Separation and transmutation are not a prerequisite to establishing a satisfactory management of nuclear waste but it could reduce its cost significantly. On the other hand, extracting the plutonium is a prerequisite to the development of sustainable nuclear power based on breeder reactors.

The Waste Management Financing Issue

Today, the budget of ANDRA, in charge of the definitive disposal of nuclear waste, is fueled by the agents of the nuclear industry, mainly EDF and ORANO (formerly AREVA, industrial group specialized in nuclear fuel processing). The question arises, and it has been raised by the OPECST (Office parlementaire d'évaluation des choix scientifiques et technologiques, the French Parliamentary Office for Scientific and Technological Assessment), whether this solution remains reliable and valid in the context of an open electricity market. Similarly, one can legitimately wonder how the research on separation and transmutation should be financed.

ANDRA's estimate (disputed by EDF) of the cost of the CIGEO disposal repository is 36 billion €. This amount would correspond to the waste disposal of 50 years operation of the present French nuclear reactor fleet which produces about 400 million MWh/year, i.e. a total of 20 000 million MWh. The alternative electricity distributors in France purchase nuclear electricity from EDF at 42 €/MWh. The revenue from 50 years operation of the reactor fleet then amounts to 840 billion €. This waste disposal, then, would represent 4% of the revenue. Incidentally, note that EDF sets aside the sums needed for the management of the waste from its reactors.

Conclusion

There is nothing to justify the statement, however popular, that we don't know how to manage nuclear waste. Really, the problem they pose is socio-political and that of their acceptance by the population. The problem is not technological.

Documents (in French) for Further Information

A. Les déchets nucléaire sont-ils gérables - Cahier d'Acteur SLC (are nuclear waste manageable? SLC contribution to the 2005 debate on nuclear waste.)

https://www.sauvonsleclimat.org/images/articles/pdf_files/debats_publics/dechets-long-final.pdf

B. Physique d'un site géologique de stockage de déchets nucléaires, (The physics of a geological nuclear waste disposal repository) by H. Nifenecker and G. Ouzounian

https://www.sauvonsleclimat.org/fr/base-documentaire/physique-dun-site-geologique-de-stockage-de-dechets-nucleaires

C. ANDRA Dossier Argile 2005

http://www.andra.fr/download/site-principal/document/dossier2005/D05A_266.pdf

D. Le stockage des déchets nucléaires en site profond (deep underground disposal of nuclear waste) by H. Nifenecker and G. Ouzounian.

https://www.sauvonsleclimat.org/images/articles/pdf_files/etudes/dechets.pdf

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i The time required for the amount of a radionuclide to reduce to half its initial value on average.

ii Actinides are the elements whose atomic number is larger than 88. The major actinides are the elements that compose the major part of the spent fuel, namely uranium (92) and plutonium (94). The minor actinides are produced in smaller quantities, they consist in, essentially, neptunium, americium and curium.

iii Reprocessing, done at the Orano factory of La Hague, consists in dissolving the irradiated fuel elements, extracting the plutonium and uranium from the solution and conditioning the remainder in glass packages which, then, contain the fission products and the minor actinides. The recovered uranium and the plutonium are in general used to make Mox (Mixed oxydes) fuel. At present, Mox fuels are not reprocessed. after burn up.

iv The low level waste (from decommissioning) can in general be stored in surface repositories (Soulaines, Morvilliers, Marcoule and the Manche).

v Definition of B waste: intermediate level waste (ILW); C waste: high level waste (HLW); CU waste: irradiated fuel, with CU1: spent Uox fuel from PWRs, CU2: spent Mox fuel from PWRs, CU3: other spent fuels.

vi Assuming the waste are buried at a depth of 500 meters, we calculate the activity of the first kilometer of earth crust. After 1 000 years, the radiotoxicity of the waste is equivalent to that of the uranium that was used to operate the reactors, namely 360 000 metric tons (60 reactors operated during 50 years requiring 120 metric tons per year per reactor). The amount of uranium contained in the first kilometer of earth crust in France with a uranium concentration of 1.7 ppm is about 2 billion metric tons. The radiotoxicity ratio is thus $2*10^{-4}$.