The impact of nuclear **power plants under normal operation on health and the environment**

Conversation[a] with **Claude Stéphan,** physicist, CNRS, and **Pierre Barbey,** biologist, University of Caen

What is the impact of a functioning nuclear power plant on the surrounding environment, land and people? Which industrial stages of the process, from ore extraction to plant operation, are the most controversial in terms of their perceived effects? Two researchers answer our questions from opposing sides of the debate.

From ore extraction to reactor

When we think of the environmental impact of civil nuclear power, we immediately think of the reactor, its emissions and its potential danger to the surrounding population. However, it is also important to consider the issues upstream and to look at the journey of the nuclear fuel before it is loaded into the reactor. Although it is the case that a few thousand tons[b] of natural uranium are sufficient to power all of France's nuclear reactors for one year, the process of ore extraction has consequences for the environment and the local population.

Firstly, there is the radioactive decay of uranium which leads to, among other things, the formation of radon, a radioactive gas which is present in large amounts in mines; the radioactivity level in a uranium mine is between ten and one hundred times greater than the background level[c]. Secondly, both these radioactive elements are released from the mineral texture in which they are contained and readily mobilized in water through the mechanical processing (crushing and grinding) involved in uranium extraction.

Uranium mining on French soil began in 1949 and was largely abandoned in the 1990s. During this time, some 250 mining sites in 27 departments produced 76,000 tons of uranium. Although all the uranium used by France is now imported (mainly from Niger, Canada, Australia and Kazakhstan), this has not always been the case and the environmental impact hasn't gone away. For example, the choice of importing raw materials from foreign countries only shifts the impact of the mining industry away from France. Furthermore, ongoing monitoring is still required even though the French mines are now closed[d].

Claude Stéphan acknowledges that the conditions under which the first mines were established and the working practices at the time fueled the negative image of ›››

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uranium mining. Public perception is largely based on the health and environmental impacts resulting from practices applied in a bygone era when there was little regulation. Indeed, in the early days, workers were exposed to levels of radiation that are now considered dangerous, in particular as a cause of lung cancer.

Following the closure of most French mining sites, the mobilization of community action groups in response to radioactive pollution and handling of mining waste and slag heaps has led the public authorities to take action. They responded by initiating a major multi-stakeholder consultation process between 2006 and 2010, by setting up local "monitoring bodies for former mining sites", and also by strengthening the regulatory framework for the management of these former sites.

The necessary controls are now in place, with a system of regulatory and administrative inspections and controls carried out by the Regional Environment Directorates under the authority of the prefects (government representatives at the regional level). The system reduces the possibility of regulatory decisions being influenced by a political or an economic agenda. This has led to a shift from virtually non-existent planning to multi-stage effluent treatment processes and management systems designed specifically for the sector.

Although the radiological impact seems to be under control in the former French mining sites, which are now closed, Pierre Barbey reminds us that the impact on the environment is also of a chemical nature. Uranium, as well as being radioactive, is first and foremost a highly toxic chemical element. It is on the basis of this toxicity that the World Health Organization (WHO) set the uranium concentration limit for drinking water at 15 µg/l. It should be noted, however, that setting limits and making recommendations based on toxicity is not straightforward. One of the difficulties, in the context of former uranium mine sites, is that the toxic substances extracted or produced are of natural origin and that anthropogenic activity adds to a natural background noise, which itself fluctuates. In order to assess the dose-dependent impact and to help set limits, WHO opted to estimate the transfers of toxic pollutants into the environment and to take into account all routes of human health damages using exposure scenarios based on lifestyles.

A further point to stress, with regard to the environmental impact, is that the restoration of former mining sites is a major industrial undertaking. The French government assigned Areva (now Orano) to manage and monitor all former French sites, including those that were not under its jurisdiction. The aim of redevelopment is to minimize any environmental effects by making the sites safe for the public, by providing radiological and environmental monitoring, and by providing water treatment should that be required. Some 100 specialists are deployed each year to carry out nearly 7,000 environmental, geological, radiological and health analyses.

Transportation of the uranium is the second major issue after mining. The main difficulties associated with transporting radioactive substances are the risk of inhalation or ingestion of radioactive particles, the risk of external irradiation, and the risk of radionucleotide release to the environment. About 10% of the nuclear packages transported in France are connected to the nuclear power industry and this represents about 19,000 annual journeys, for 114,000 packages(e). The movement of dangerous goods by road, rail or sea is regulated by the national authorities. The package itself must provide sufficient protection to avoid any harmful consequences on people or the environment. The radioactive material is enclosed in leakproof steel drums loaded into containers certified by the International Organization for Standardization (ISO) with appropriate marking and placarding. Therefore, in a non-accident situation, transporting nuclear materials does not appear to have a significant impact on the environment or the general population.

From reactor to waste

The impact of a normally-functioning nuclear power plant on the environment is essentially due to exposure of nuclear workers and the public to thermal, chemical and radioactive discharges. Nuclear-related industrial discharges are not very different from those produced by any other thermal power plant. However, the post-Chernobyl era saw the creation, under public pressure, of two independent regulatory bodies, the French Nuclear Safety Authority (ASN) and the Institute for Radiological Protection and Nuclear Safety (IRSN), to manage all nuclear risks (electronuclear, medical, etc.). The ASN contributes to the drafting of regulations relating to nuclear energy and overseeing their compliance, while the IRSN coordinates research in connection with nuclear safety and keeps a record of any feedback from the plants. Both organizations, together with the operator, also participate in ten-yearly inspections designed to assess whether or not a power plant can continue to operate and to carry out checks and confirm the necessary safety requirements are met.

Finally, the ASN sets the regulatory limits for all emissions that a nuclear power plant is authorized to produce during operation, the main ones being production of water, waste gases and heat. In France, regulatory limits prevent excessive local heating of the cold source (river, sea) due to water being returned at a temperature slightly higher than the temperature at which it was taken. Consequently, production must be reduced or suspended if the water returned is too hot compared to the cold source (dilution effect).

With regard to radioactive emissions, Claude Stéphan points out that over the last twenty years, EDF's nuclear fleet has reduced the level of its radioactive emissions 100-fold except for the noble gases, tritium and carbon-14. In the latter case, the release of this isotope into the environment is extremely low and, as it is essentially in a form (methane) that cannot be assimilated by plants, it represents only about 1% of the average background level. The epidemiological impact on populations living near French nuclear power plants is considered insignificant. However, many local residents' groups are concerned and closely monitor changes in radioactivity levels in the soil and groundwater(f).

The maximum permissible annual radiation dose for nuclear energy workers is 20 millisieverts(g), which is just over four times the natural background radiation dose. In practice, the level of radiation received is much lower and the number of times this threshold is exceeded is decreasing year on year. Is this radiation dose dangerous? The question remains open. The available studies show no effects at doses below 100 millisieverts, either because there are none or because the statistical significance of the surveys was insufficient to detect them[h]. The public in the immediate vicinity of a nuclear power plant receives ten thousand times less, or 0.002 millisieverts per year, which is negligible compared to what is received from natural background radiation (especially radon) and medical examinations.

The reprocessing of spent fuel like plutonium from EDF's nuclear power stations, as well as from other countries, is more controversial. Pierre Barbey points out that, compared to other processes in the industry, reprocessing is a particularly polluting step. An inventory carried out in the second half of the 1990s by a multidisciplinary group of experts, the North-Cotentin Radioecology group (Groupe Radioécologie Nord-Cotentin, GRNC), led to the identification of 73 radioactive elements (excluding elements with short half-lives) from reprocessing operations, i.e. double the radioelements declared by the operator at that time. The La Hague site currently benefits from ASN an authorization to release radioactive and chemical pollutants into the environment. Commissioned in 1966, the La Hague reprocessing facilities generated increasing discharges, due to the increase in activity, until the mid-1980s. It was at that time that the operator introduced a new effluent management system and, since then, a gradual decrease in discharges has been observed. However, this new system does not address certain non-retained radioelements (tritium, noble gases, etc.) which continue to increase in proportion to the amount of reprocessed fuel. It should be noted that, unlike nuclear power plants, the carbon-14 released is mainly in the form of CO_2, which can be assimilated by plants, and is the main contributor to the dose received by the local population.

There is currently no simple solution when it comes to managing spent fuel end-of-life and hence produced waste[i]. Claude Stéphan begins by reminding us that fission fragments account for almost all the radioactivity produced and the vast majority of them have a half-life that does not exceed 30 years. This category of waste is stored in metal casks contained in concrete overpacks at the Aube Storage Center (Centre de Stockage de l'Aube, CSA) and is the responsibility of the National Agency for Radioactive Waste Management (ANDRA). The radioactivity of these materials, known as short-lived low and intermediate-level radioactive waste, will have decreased by a factor of 1,000 after about 300 years, and their storage above-ground is currently considered a solution that significantly limits the impact on the environment.

On the other hand, the rest of the spent fuel, which constitutes the ultimate waste (other fission products and minor actinides such as americium, neptunium, etc.), of intermediate or high activity with a long life, poses greater technological challenges. This waste is nowadays vitrified, i.e. mixed with a glass matrix, a material known for its good resistance to heat and radiation, and stored pending a decision on long-term storage. The solution presently being considered in France, which is the subject of debate, involves deep-layer storage, of the order of 500 m, in the Industrial Center for Geological Storage (Centre Industriel de stockage Géologique, Cigéo), which requires geological and seismic stability on a scale of tens of thousands of years.

Pierre Barbey notes that this and other waste disposal routes are currently only in draft form. At present there are only two surface storage centers: the Aube center and the historic Channel waste-disposal center (Centre de Stockage de la Manche, CSM), the subject of much controversy because of its location in a marshy area that is regularly flooded. Some organizations have disputed whether the radioactivity is actually contained[j], and it is in the process of being closed down. The Industrial Center for Grouping, Warehousing and Storage (Centre industriel de regroupement, d'entreposage et de stockage, CIRES), another waste disposal facility in Aube and managed by ANDRA, is dedicated to very low-level radioactive waste.

In summary, the closure of uranium mines in France appears to have greatly reduced the harmful effects, although there is still a need for constant monitoring of the resulting contamination. Meanwhile the impact has been transferred to the countries that are now producing uranium. The transport of fissile materials appears to be under control. Discharges from operating plants are considered insignificant. Pollution from fuel reprocessing is decreasing but is still detectable. However, the storage of long-lived intermediate or high-level radioactive waste is a considerable problem which is still under debate. ▮

a. See the introduction to the conversations by F. Graner and S. M. Panebianco (p. 18).

b. By way of comparison, this mass is equivalent to only a few percent of the load of a single supertanker.

c. Uranium-238 has been around since the formation of the Earth and has a half-life of around 4.5 billion years and uranium-235 has a half-life of 700 million years, which means that their natural activity is low. Some decay products have short half-lives: the main radioelements of concern to man and the environment are radium-226, polonium-210 and lead-210. By way of comparison, the order of magnitude of natural background radioactivity is 100 Bq/kg for basaltic or sedimentary rocks and 1,000 Bq/kg for granitic rocks. The radioactivity of residual rock (known as "waste rock") from uranium mines is typically 10,000 Bq/kg, that of uranium ore processing tailings is 500,000 Bq/kg, which is strikingly similar to the tailings of lignite power plants operating in Germany or Poland. Uranium ores themselves have a typical activity of 1,000,000 Bq/kg.

d. Since a mine is not considered a Basic Nuclear Installation (BNI), it is not subject to a decommissioning procedure.

e. Other nuclear packages are mainly from nuclear sources used in industry such as food sterilization (60%), or medical uses (30%). In total, these nuclear packages account for a few percent of all hazardous material packages. Source: ASN.

f. See the article by D. Boilley (p. 24).

g. Sievert: unit measuring the impact of radiation on humans.

h. Very small doses may damage one strand of DNA, but not both strands, and in this case the cell can repair it properly. A higher dose is statistically more likely to cut both strands, so it has a much greater effect.

i. On the question of waste, see several articles, in particular those by J.-Y. Le Déaut (p. 13) and B. Romagnan (p. 14).

j. See the criticisms made by the "Nuclear Phase-Out" (« Sortir du Nucléaire ») network, ACRO or Greenpeace e.g. the 2006 ACRO report revised in 2009, www.acro.eu.org/Archives/CSM_GP09.pdf.