Summary of work and recommendations by the "Tritium: Defence in Depth" working group

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1. Sources of tritium releases

The natural balance of tritium was profoundly altered by atmospheric atomic weapons testing between 1945 and 1963, releasing approximately 240 EBq (650 kg) of tritium into the environment. These emissions increased the concentration in rainwater to several hundred Bq.L^{-1} in the Northern hemisphere. It has now fallen back to approximately 1 Bq.L^{-1}. The oceans form the receiving destination for all tritium releases. In 1998, surface-level concentration in seawater at the equator was 0.1 Bq.L^{-1}. Average concentration is of the order of 10 Bq.L^{-1} in the Channel, and is locally several hundred Bq.L^{-1}, which is generally related to discharges from nuclear facilities. In some rivers, the value can get as high as several hundred Bq.L^{-1} locally.

The world's nuclear reactors discharge 12,000 TBq (0.035 kg) of tritium on an annual basis, chiefly in liquid form as tritiated water and 6,000 TBq (0.018 kg) as tritium gas. Fuel reprocessing plants, chiefly the La Hague plant, discharge 12,000 TBq (0.035 kg) of tritium in liquid form and 70 TBq (0.0002 kg) as tritium gas.

In France, tritium releases from military facilities have significantly fallen in the last 20 years. The overall trend is also decreasing, but this is a result of the gradual disappearance of the tritium inventory formed due to atmospheric testing (of which approximately 10.5 EBq (30 kg) remained in 2010).

Developments in civilian industrial technologies and the implementation of optimisation principles have led to significant reductions in discharges of most radioactive elements into the environment over the last few decades. This does not however apply to tritium, the noble gases and carbon 14. Industrial sources of tritium releases have, for instance, doubled over the last twenty years at the La Hague reprocessing centre (because the electricity generated by the reprocessed fuel doubled over the same period) and also due to:

- a growing fleet of operating NPPs,
- changes both in fuels used and reactivity controls in PWR plants,
- the potential commissioning of fusion reactors in the future, which suggests that the trend will be lasting, even though the use of fusion energy will initially give tritium a high added-value, which will have the effect of reducing losses.

2. The issue of reducing tritium's impact

The OSPAR Convention recommends that the aim should be to bring radionuclide concentrations towards their natural levels, taking into account their impact and the possible reduction techniques (Sintra accords). It is therefore legitimate to seek to reduce the impact of tritium, even if it is already low. This goal should be set within an overall radiation protection framework, because planned solutions to reduce the impact of tritium should not hinder the overall policy of reducing collective doses or lead to an inequitable increase in dose for workers.

The need to refer to an assessment of the overall radiological impact of practices highlights the relatively low radiotoxic potential of tritium (although this is disputed) and the differentiated potential of tritium gas, tritiated water and organic compounds (OBT: organically bound tritium) with respect to other sources of human exposure. Using the dose conversion factors specified in current legislation, tritium exposure causes an annual dose of less than 0.1 µSv for the reference groups at La Hague (contribution less than 1% of the impact over and above natural background radiation) and 0.4 µSv for the reference groups in villages close to Valduc. These conversion factors could be increased (see the conclusions of the

"Radiological Impact" working group), but whatever the final values, the expected result does not seem likely to alter the order of magnitude of the impact or the optimisation of practices.

The initial source of tritium production in France is the operation of PWR nuclear power plants. Tritium production in the fuel remains sequestered and only makes a marginal contribution to human exposure. The main source of tritiated discharges is due to neutron activation within the reactor coolant system. Tritium production could be reduced by increasing the isotopic concentration of boron 10 and lithium 7, but the benefit would only be slight. The boron in the reactor coolant system of PWR plants cannot be replaced. The secondary source rods add a further contribution to the discharges, which can be slightly reduced, but the figures for this are not available. Approximately 98% of discharges from PWR plants occur in liquid form. Given the relative radiological impact, which is on average 100 times higher for gaseous emissions than liquid discharges at sea-shore sites, it may be useful to look at further increasing the ratio of liquid emissions. However, this solution assumes appropriate outlet channels, which have already been taken into account in the impact studies. Given the low radiological impacts and the volume of effluent to be treated, detritiation is not realistic.

EDF has a fuel development programme whose aim is to increase the electricity generated by each tonne of uranium and to reduce the quantity of waste. However these developments have tended to lead to an increase in tritium production. The ARCO association highlighted the fact that at Flamanville, tritium discharges have doubled due to an increase in electricity generation of just 4.5%.

The La Hague fuel reprocessing plant is the main source of tritium releases, mostly in the form of liquid discharges, given the relative impact which is 1,000 times lower than for atmospheric releases. Given the potentially large volumes to be treated (of the order of 40,000 m^3 per year) and the very low activity concentration at the time of discharge, detritiation is not achievable with currently available technologies. Reducing waste volume further up the process would lead to occupational exposure levels that would be incompatible with process optimisation. Various areas for discussion, R&D and process improvement have been identified, in particular:

- the need to assess which process changes or fuel reprocessing options have a genuine industrial future (voloxidation, pyroprocessing, etc.);
- the necessary discussions regarding design of a reprocessing plant with fewer site-specific advantages than La Hague in terms of radiological capacity, which would not therefore be granted the same effluent release permits.

PHENIX, SUPERPHENIX and fast breeder reactor designs were not extensively discussed, despite the fact that the forthcoming GEN IV programme will soon be making the headlines. Tritium production is higher than in PWR plants and 95% of the tritium formed in the fuel passes into the molten sodium in the reactor coolant system. The borated control rods add a significant contribution and tritiated methane is formed. Tritium releases, standardised for one GWe, are overall twice as high as in the PWR design. The tritium could be recovered and reused from the molten sodium in the SUPERPHENIX reactor. The radiological impact of this operation needs to be more closely analysed.

A small fraction of the tritium produced in nuclear reactors is recycled by small producers in order to create synthetic tritium-labelled molecules for industrial uses (luminescence) and for research. Although these sources only represent a small volume of waste, they can cause significant inadvertent environmental marking. The radiological impact of this is difficult to identify and depends largely in speciation. An appropriate outlet channel should be provided in order to manage these sources.

Tritiated waste is stored in various centres run by the French National Radioactive Waste Management Agency (ANDRA). Some tritium-marking in ground water has been traced to the "Centre Manche" (CSM), in places reaching values of several hundred Bq/L, leading to various assessments of potential developments over time. Work to characterise the source and the transfers to outlet routes needs to be continued and the predictions need to be reinforced by taking appropriate measurements. The Soulaines and Morvilliers centres have been subject to prudent management of the tritium radiological capacity and to tough rules as to the intake of waste packages. This situation has meant that environmental marking has remained low. However, ANDRA does not have actual authorisations for tritiated waste, which leaves many sources of tritiated waste without a permanent home. The solution described in the CEA report drafted under the 2006 Act is 50 years interim storage, until a new disposal site is opened, with the appropriate authorisations.

Some defence sites have nuclear purification, recycling and storage facilities, for manufacturing weapons subassemblies and for reprocessing or neutralising waste. This is the case at the CEA centres at Valduc, Marcoule and Bruyères-le-Châtel. Monitoring of these facilities has shown a hundred-fold decrease in releases since the 1970s and 1980s, with gaseous releases of 95 TBq (0.3 g) at Valduc in 2007, for instance. This reduction in releases has been achieved by detritiation of highly tritiated waste by using heat treated to separate tritiated water from a solid substrate. The tritiated water is then trapped on zeolite. The resulting volumes are low and the waste is stored at the Valduc centre. The practice is optimised and research is continuing into the recovery and use of the tritiated water. The working group noted a lack of data about certain facilities that are the exclusive responsibility of the French Ministry of Defence (reactors on sea-going vessels).

Fusion reactors are seen as a possible energy-generation option in the future (unclear exactly when). The ITER research facility which will provide data for the design of a prototype fusion production reactor is due to be commissioned in 2019 for the non-nuclear phase and to enter nuclear phase in approximately 2025. It will have a process inventory of approximately 1 kg of tritium (358 PBq). No tritium release permits have yet been issued. The ITER design incorporates the notion of defence in depth in its operating methods, with respect to tritium, which is the fuel in the machine. This means that multiple static confinement barriers and dynamic confinement systems are planned, including detritiation and atmosphere treatment at source, limits on the water quantities allowed and water recycling and detritiation. One whole facility is entirely dedicated to tritium, to injecting the deuterium-tritium mixture into the tokamak, and to extracting, recovering and purifying the tritium for reuse. The feasibility of decommissioning was incorporated at design phase. It takes into account the classification of the waste generated – VLLW, L/ILW and LLILW, the outlet channels available and the availability of the site for interim storage of its operational waste. The facility follows the guidelines of the French National Plan for the management of radioactive substances and waste (PNGMDR).

3. Recommendations from the "Tritium Impact" working group

In conclusion, the working group puts forward the following recommendations and observations.

- Management of the current processes enables discharges from all facilities to be recorded and calculated; for the La Manche storage centre, work to characterise the source and the transfers to outlet sources should be improved and these predictions need to be reinforced with measurement data.
- Detritiation in PWR reactors in NPPs would only have a limited effect on the radiological impact is not currently achievable at an acceptable cost. The associations ACRO and ANCLI are opposed to the use of new fuels, on the basis of the precautionary principle, for as long as doubts remain as to the tritium impact.
- Detritiation is not achievable in the La Hague plant with the best technologies currently available and in any case it would only have a limited effect on the radiological impact. The discharge/waste strategy to promote tritium storage and recovery at an acceptable cost could only be considered for materials with high-level tritium activity. The associations ACRO and ANCLI are requesting that the oldest fuels be prioritised for reprocessing in order to limit releases, but AREVA and EDF consider that the practice is optimised in this respect.
- In the view of ACRO and ANCLI, a reduction in tritium production from civilian and military facilities is required.

- Absolute containment of tritium is an issue that is both technical and financial and determines the development of containers.
- Tritiated waste management in future repositories will require specific permits, enabling the tritium to be appropriately accounted. Specific management schemes should be accessible for small producers.
- Assessment of the tritium impact of above-ground repositories requires continuous improvement of the knowledge of source terms, the various transfer pathways from the waste and the associated transfer processes, and also requires the relative weight of the various transfer pathways to be quantified according to the technical solutions selected.
- Dedicated interim storage facilities to allow tritiated waste from various sources to decay should be put into service, in accordance with the Decree pursuant to the French National Plan for the management of radioactive substances and waste (PNGMDR 2007-2009).
- The development of detritiation work carried out on behalf of ITER should be monitored.