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DESIGN BASIS OF OFF-SITE EMERGENCY RESPONSE PLANS FOR FUEL CYCLE INSTALLATIONS

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DESIGN BASIS OF OFF-SITE EMERGENCY RESPONSE PLANS FOR FUEL CYCLE INSTALLATIONS

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1. Introduction

In France, the term "off-site emergency response plan" (French abbreviation PPI) refers to all the arrangements which should be made by the government authorities to protect the population in the event of an accident affecting the installations of the site considered.
Management of the medium- and long-term consequences of the accident is covered in the post-accident action plan (French abbreviation PPA) which is intended to set out the provisions for a subsequent return to normal living conditions in the areas affected by the accident. It should also be borne in mind that management of the accident situation on site is covered in the on-site emergency response plan (French abbreviation PUI) implemented by the operator.

To determine the nature of the counter-measures which could be taken, it is necessary in the event of an accident to determine the upper bound case for releases of radioactive materials or chemicals. Several "typical accidents" have thus to be defined together with associated "source terms" representing releases which may arise from the different installations of the site.

The approach adopted in France consists in drawing up a list, as exhaustive as possible, of conceivable beyond-design basis accident situations which may affect the installations of the site considered.

These accident situations can be sought on the basis of reference accident situations dealt with in the safety reports of the installations involved. The most selected case consists in considering one or more aggravating factors with regard to these reference accidents (e.g. containment damage, filtration failure).

After identifying all the installations which could be at the origin of a significant release of radioactive or toxic products, the associated risks (fire, explosion, criticality etc.) are assessed as realistically as possible for each of them. This evaluation leads to the adoption of upper bound accident situations characterised in particular by a "release level" and kinetics derived from this assessment.

The "source terms" expressed in terms of quantities released with associated kinetics make it possible to calculate dose equivalents which could be received by members of the public or concentrations in toxic elements, according to the distance from the damaged installation.

The counter-measures to be provided in the off-site emergency response plan are based on the assessment on the one hand of the atmospheric dispersion of dangerous products corresponding to "source terms" and, on the other hand, of health effects which may arise, quantified on the basis of radiological and/or toxic data.

Based on these results, distances are suggested for the government authorities to take into account for the operational part of the off-site emergency response plan. The counter-measures put forward are essentially confinement and evacuation.

The distances relative to these two sorts of counter-measures are calculated in part on the basis of numerical values of intervention levels recommended by the International Commission on Radiological Protection (ICRP), in part on the basis of available toxicological data.

Two cases for the application of the methodology are put forward : one relates to front-end fuel cycle installations (Tricastin nuclear site), and the other to spent fuel reprocessing installations (COGEMA's La Hague plant).

2. Outline of the method

2.1. Definition of typical accidents

An identification of all the risks encountered in each installation leads to a consideration of the risks represented by the equipment and processes used, those represented by goods received, stored, used and produced, those provoked by human failure, and those provoked by events of an external origin.

In normal operation or during transients in the installations at the sites considered, the main probable accident situations are as follows:

- critical excursion,
- irradiation,
- dispersal of radioactive and/or toxic substances.

Possible sources of these risks include:

- process or equipment failure: fires, explosions, loss of radiation shielding, leakage from equipment, build-up of explosive gas or dust, dropped loads, modification to the sub-criticality parameters, pipe or valve rupture, corrosion, wear, flames or fire used during work;
- events of external origin: aircraft crashes, overpressure caused by explosion of an oil tanker, a barge, an explosive gas storage tank, a heating system or gas line. Any overpressure calculations are performed under the same atmospheric conditions as the estimate of the consequences of the resulting release;
- human failures.

It should be borne in mind that the approach adopted has to ensure a certain amount of realism, especially regarding the hypotheses to be taken into account when drawing up the accident scenarios; the nuclear operator's means of prevention, detection and action can be taken into account when estimating the duration of the release.

These accident scenarios can be drawn up on the basis of existing scenarios already dealt with in the safety reports and on-site emergency response plans (PUIs) for the installations in question. Indeed, the accidents set out in Level 3 of the on-site emergency response plans (accident situations which are radiological or toxicological in nature with off-site consequences) should be consistent with the typical accidents adopted in the technical bases for the off-site emergency response plans. Generally speaking, one or more aggravating factors are added to the design basis accidents set out in the safety reports, to wit damage, failure or additional loss of confinement.

Usually, an initial, mainly qualitative approach is used to dismiss, *a priori*, certain accident scenarios which do not appear to have significant off-site consequences or those with a very low probability. A more detailed analysis (quantitative) is then used to determine accidents with insignificant off-site consequences (accidents dismissed *a posteriori*) and to adopt upper bound accident situations with release levels and kinetics : the "source term".

2.2. Evaluation of the "source terms" associated with the accident situations considered

Mention is made of the hypotheses needed to assess the "source terms" (quantities involved, suspension coefficients in the installation, routing of substances through the installation, deposition coefficients, filtration coefficients).

- Quantities involved.

- Firstly, the quantities present in the unit in question are set in terms of an upper bound figure valid for any given moment (maximum authorised quantities, maximum vessel fill-up level
- Secondly, the part (or number of units) affected by the accident is selected according to the type of confinement used to keep substances in the installation and the presence of high-risk equipment.
- Thirdly, the nature and physical and chemical properties of the substances involved are considered in such a manner as to estimate their leakage state (solid, gaseous or liquid) and any reactions they may undergo with the different environments they pass through (in particular UF_6).
- Fourthly, the leak rates (single phase or two phase depending on the situation), the instantaneous vaporisation rate, pool evaporation rate and suspension factors are evaluated.
- In the meantime, the associated durations are estimated in the light of certain operator intervention equipment (bunds, remotely controlled valves, spreading of neutralising products, water curtains, emplacement of lids etc.).

- Height and release paths.

Radioactive and/or toxic material can migrate directly if their sole containment has been damaged (containers stored outside, for instance).

In all other cases, migration, filtration and deposition coefficients can be adopted to take account of the various containment barriers, passage through intermediate rooms (estimation of any involvement in a fire according to their heat load density), and filtration (estimate of the number of floors spared in the event of a fire).

Releases are characterised in terms of the height at which they are released into the open air. Natural leaks from the building (windows, doors) or releases at a height taking into account the height of stacks and any buildings in the vicinity are considered as ground-level releases.

Furthermore, a rise in the height of the plume resulting from the large amount of heat energy at the source during a fire can be taken into account when estimating the height of the release.

- Release kinetics.

An estimate of the kinetics (slow or fast) is essential when evaluating consequences and depends on the many hypotheses set out above.
The "source term" is therefore characterised by a quantity (activity or mass) of substances (physical and chemical nature, composition) released at a specific height above ground for a specific period.

2.3. Evaluation of health consequences

Public health consequences are expressed in terms of effective committed dose equivalents to the whole body and to the critical organ in the case of radiological consequences, and in terms of concentration couples of toxic elements/exposure periods (corresponding to the toxic load) in the case of toxicological consequences, which can be received by members of the public at different distances from the installation in question.

- Atmospheric dispersion.

The most critical contamination path to man in the short term is the atmospheric path. Atmospheric dispersion calculations are performed, taking into account adverse meteorological conditions to ensure that the counter-measures proposed for protecting the public cover the worst-case scenario.

The meteorological conditions chosen depend on the site in question so that any calculation of health consequences will remain realistic (dry weather and the Mistral wind in the Rhône valley for instance).

All calculations performed take account of Doury atmospheric dissemination parameters using the codes developed at the Institute for Nuclear Safety and Protection (IPSN), adapting them to the different types of release (products, kinetic) and to the geometry of the source.

For releases lasting longer than thirty minutes, a corrective factor can be applied to the dispersion calculation to take account of the gusts of wind over time (variations in the direction of the wind for the duration of the release).

- **The radiological viewpoint**

In Publication 63, the International Commission on Radiological Protection (ICRP) recommended a certain degree of flexibility in ascribing numerical values to the intervention levels for applying measures to protect the public in the event of a nuclear accident.

In France, distances around the site in question where counter-measures must be put into effect as part of the off-site emergency response plan are evaluated for each of the "justified" intervention levels relating to evacuation and confinement counter-measures. The values of these levels, recommended by the ICRP, are:

	confinement	evacuation
committed dose equivalent to the whole body	50 mSv	500 mSv
committed dose equivalent to the critical organ	500 mSv	5 Sv

- **Chemical toxicity**

Two types of data are currently used for health effects following the dissemination of chemical products :

* toxicity graphs (of the DANDRES type for chlorine), the use of which is recommended by the Institute for Nuclear Safety and Protection. This is a compilation of charts showing the various levels at which toxic effects appear in humans (irritation, illness, danger, lethal) in terms of concentration in air and the length of exposure at this concentration. These curves were plotted

specifically for hydrofluoric acid, ammonia and chlorine. The concentration adopted for implementing counter-measures corresponds to the level at which the "illness" effect appears ;

* IDLH. This is a bearable exposure level, for an exposure of thirty minutes, with no irreversible effect on the organism. These values were obtained from tests to qualify protective masks for workers. If the length of exposure is not equal to thirty minutes, the IDLH concentration is extrapolated back, taking account of the toxicity factor for the chemical in question when this is known.

- **Uranium toxicity**

By virtue of the chemical toxicity of uranium, its dissemination provokes certain toxicological consequences, in addition to the consequences arising out of its radioactive nature. The atmospheric concentration adopted when determining the distances at which counter-measures must be implemented to protect the population corresponds to the level at which the "renal lesion" effect arises.

In the case of accidents with both toxicological (chemical and/or due to uranium) and radiological consequences, the distances at which counter-measures must be taken to protect the population would be the largest distances calculated for one of the types of consequences.

The practical conditions and resources needed to implement counter-measures are to be laid down by the competent government authority. However, it may be recommended to take certain actions in this area, particularly in view of the short response times required for certain accident situations with fast kinetics: these are mainly precise local counter-measures, specific to the site, that the operator may have to implement on behalf of the government authorities before they actually intervene.

3. Application to installations from the front-end of the fuel cycle : the Tricastin site

The Tricastin site houses many installations from the front-end of the fuel cycle :

- the COMURHEX plant for converting uranium into uranium hexafluoride (UF_6),
- the EURODIF plant for the enrichment of uranium isotopes by gaseous diffusion,
- the FBFC plant for the fabrication of uranium-based fuel for pressurised water reactors,
- installations for uranium chemistry and for alternative uses of UF_6 run by the *Compagnie Générale des Matières Nucléaires* (COGEMA), including the W plant for the defluorination of uranium with a low concentration of the 235 isotope from the EURODIF plant and from the UF_6 transfer and sampling units,
- the SOCATRI plant for decontaminating equipment and for processing solutions containing uranium,
- installations run by the Commissariat à l'Energie Atomique (CEA) carrying out research and development into enrichment processes.

One of the main features of all of these installations, from the point of view of risks, is the use of uranium with varying concentrations of the 235 isotope, especially in the form of UF_6, and various chemical reagents (especially hydrofluoric acid (both anhydrous and in solution, chlorine and ammonia).

As part of the approach outlined earlier, a tentative list of accident situations was drawn up on the basis of installation characteristics, especially from the point of view of confinement and the conditions in which the various products are used, whether chemical or radioactive, the quantities and physical and chemical forms of the products and any possible events which could arise out of the environment of the site.

The main accidents listed are as follows:

- criticality accident (generation of 5×10^{18} fission reactions in 10 minutes),
- release of UF_6,
- explosion involving hydrogen arising in furnaces used for the production of products containing uranium,
- fire involving contaminated solvents or oils pending incineration,
- release of chlorine,
- release of chlorine trifluoride,
- release of ammonia,
- release of hydrofluoric acid.

As regards chemical reagents. account is taken of events which could affect storage installations, especially when filling storage tanks, either for feeding in reagents or for removing products after production, distribution installations and transport operations carried out on the site.

The main probable scenarios were drawn up for each of these accident situations and studied with a view to adopting typical accidents for the production of technical bases for performing the sizing calculations for the site off-site emergency response plan.

The following typical accidents were adopted for the purposes of the sizing calculations.

1. A leak of UF_6 from a cask holding natural UF_6 being cooled in an outdoor yard. This container contains the largest quantity of UF_6 in a form which can easily be spread outside a building (liquid form), the loss of the confinement function of such a container was assumed. To retain some degree of realism, it was decided to assume a leak from a broken valve.

2. An aircraft crashes onto a storage yard for casks containing UF_6 at ambient temperature. In view of the fuel fire likely to break out after the accident ; a release of gaseous UF_6 into the atmosphere is adopted.

3. An aircraft crashes onto the EURODIF gaseous diffusion plant, followed by the fuel in the plant's fuel tanks catching fire ; a release of gaseous UF_6 is assumed.

4. A leak of UF_6 from a cask, assumed to have been over-filled and to be undergoing heating in an oven. In view of the characteristics of the building housing the oven, this accident would result in different releases, depending on whether or not one accepts the hypothesis of redeposition of most of the uranium in the immediate vicinity (in or around the building), in the case of a leak of liquid UF_6.

5. A leak of anhydrous hydrofluoric acid from a distribution pipe from the cold store for this reagent or when filling a delivery tanker.

6. A leak affecting a store for a 70% solution of hydrofluoric acid attached to the W defluorination plant, following the loss of confinement of a vessel combined with the failure of devices for limiting existing consequences to act immediately.

7. A handling accident involving a container of one tonne of liquid chlorine resulting, following the rupture of a valve, resulting in a release of gaseous chlorine.

8. A leak at an ammonia tank following a pipe break, resulting in a gaseous release.

9. A leak when filling up an ammonia delivery tanker resulting in a gaseous release.

The environmental consequences of these scenarios were evaluated using the methodology set out above, taking into account the different adverse meteorological conditions at the various release heights adopted (at ground level for the majority of postulated accidents, except in the case of aircraft crashes where an increase in the height was assumed as a result of the heat given off by the fire).

It therefore became possible to determine the distances at which consequences are deemed intolerable in terms of the criteria adopted. These distances are in the region of:
- 4 km for releases of UF_6,
- 2 km for releases of other toxic substances.

The following can be concluded:
- the consequences of the above accident are chemical in nature, the radiological aspects are of only secondary importance in view of the physical-chemical form of the uranium and its enrichment,
- the accidents all display rapid kinetics. It is therefore the operator's responsibility to alert the population (by sirens) ; furthermore, the main probable counter-measure for protecting the population would be rapid confinement following the alert.

4. Application to installations from the back-end of the fuel cycle : the La Hague site

4.1. Typical accidents considered

4.1.1. Events occurring off-site

In the case of COGEMA's La Hague establishment, owing to the specific requirements of site isolation, it is not worthwhile adopting events occurring off-site for the technical bases which will be used to draw up the off-site emergency response plan.

4.1.2. Typical accidents associated with non-nuclear installations

The La Hague site houses the following installations :

- vessels for storing nitric acid and soda in solution (non-flammable toxic products),
- formaldehyde stores (toxic and flammable),
- reagent stores,
- fuel oil stores,
- propane stores,
- hydrogen store.

The consequences of accidents for each installation should not require the implementation of counter-measures to ensure the protection of nearby populations. The accidents associated with non-nuclear installations do not therefore have to be adopted when drawing up the technical bases for the off-site emergency response plan.

4.1.3. Critical excursion

The typical associated accident corresponds to 5×10^{18} fission reactions in 10 minutes and would result in a "source-term" in the order of a few 10^{14} Bq, mainly consisting of rare gases and a little iodine. The radiological consequences of such a release off-site would be low, in the region of a few mSv at most, both in terms of external exposure to the whole body and in terms of equivalent dose committed to the thyroid by inhalation of iodine.

4.1.4 Typical accidents related to releases of fission products

a) The first postulated typical accident corresponds to the prolonged loss of cooling to storage vessels for concentrated solutions of fission products.

b) The second typical accident postulated consists in the failure of the open air scavenging system for a vessel for the storage of solutions with high concentrations of fission products which could, through the accumulation of hydrogen produced by radiolysis, result in an explosion whose consequences would include damage to the vessel itself and also destruction of the cooling system.

The consequences would not require the implementation of counter-measures to protect the population.

4.1.5. Typical accidents associated with releases of plutonium

Plutonium is present in the installations in various forms, particularly in the form of an aqueous or organic solution or as PuO_2 powder. In all cases, the risk to be borne in mind in the installations in question is the dispersion of plutonium following a fire.

Firstly, a solvent fire was adopted as the typical accident, because of the possibility of large quantities of plutonium being involved, also assuming the occurrence of certain containment failures which could lead to rapid releases off-site.

Secondly, it was considered that a fire could also be the root cause of the dispersion of PuO_2 powder.

4.2. Typical accidents adopted for drawing up the technical bases for the off-site emergency response plan for COGEMA's La Hague site

4.2.1. Solvent fire

In the most adverse meteorological conditions, dose equivalents committed to the whole body at the site perimeter, in the first homes (about 1000 m from the release point) and at various distances are such that:

- there is no need to evacuate the population for health reasons;
- populations should be confined to their homes for a distance of about 2600 meters around the accident-hit installation.

4.2.2. Fire involving plutonium oxide powder

Using considerations similar to those developed in the previous scenario, the corresponding radiological consequences are so insignificant that no counter-measures seem necessary to protect the health of the populations.

4.3. Conclusion for the La Hague site

The technical bases, updated after the UP3-A plant was commissioned, and supposed to serve as the basis for the off-site emergency response plan for the La Hague site, are taken from a study of possible accidents likely to affect site installations. The results of this study show that:

- there is absolutely no need to evacuate the population for health reasons,
- populations living within a radius of 2600 m of the site may have to be confined to their homes.

In view of the rapid kinetics of the release (one hour), the alert must be given immediately and is therefore the responsibility of the operator in accordance with conditions and resources to be decided on in collaboration with the government authorities.

Consequently, the 2 km and 5 km zones provided for in the current off-site emergency response plan for the evacuation and sheltering of populations, which were based on former accident studies carried out for the UP2-400 plant, are well in excess of the worst-case scenarios.

5. General conclusion

The process of drawing up off-site emergency response plans for nuclear sites is based on the identification of types of accidents which could arise in the installations and which could lead to releases of radioactive materials in such quantities that it could prove necessary to take measures to protect the population.

The safety provisions made are such that accidents of this sort are of course highly unlikely. The types of accidents considered when drawing up the off-site emergency response plans are therefore one-off situations which are only considered as an additional precaution for protecting the population.

Life-size emergency exercises with the functioning of emergency response centres and involving the authorities and staff are carried out regularly, based on a particular accident hypothesis.