Management of industrial sites contaminated with radionuclides in France

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Abstract

The method to be used for the assessment and management of the radiation risks associated with sites contaminated by radionuclides is being developed in France at the request of the authorities. The aim is to provide all the stakeholders (administrations, elected representatives, engineering companies, operators, residents' associations and environmental protection organizations) with a guide describing how to proceed. There are six stages: the removal of doubt, the pre-diagnosis, the initial diagnosis, the simplified risk study, the detailed risk study and the assistance in the selection of the remediation strategy. Each stage of risk assessment involves the stakeholders to a greater or lesser degree depending on the complexity of the site in question.

The guide outlines the criteria which enable the assessment sequence to be interrupted and the appropriate decisions to be taken. For example, one can stop at the stage of the simplified risk study when the site is small and if it is relatively easy to remove and store the contaminated soil. However, in many cases will be needed. The selection of the appropriate strategy presupposes the identification of several alternate options which must be characterized in terms of reduction of dosimetric impact, reduction of contamination, costs and associated nuisances. The choice of strategy requires the close involvement of the stakeholders. The radiological aspect is generally only one of the elements of the choice, and the conditions have to be created to enable the stakeholders to discuss all the relevant aspects in the site's specific context.

I Context of the study

I-1 Background

France has known about the existence of industrial sites contaminated with long-lived radionuclides such as radium for a long time and the clean-up of the first sites dates back to the 1960s. During the 1990s, an increasing number of such contaminated sites came to light. They are the legacy of earlier activities that involved the use of radionuclides for their radioactive properties, such as radium paint, the watch-making industry and uranium metallurgy. In other cases, the radionuclides were byproducts of activities, as in the flint industry (crushing and processing of monazite, production of cerium oxides) or the radium-226 extraction industry.

Uranium-238, thorium-232, radium-226 and their daughters are therefore particularly prevalent at such sites. Other industrial or laboratory activities have also led to the contamination of sites by, inter alia, strontium-90, caesium-137, tritium and carbon-14.

I-2 Past policy with respect to sites contaminated with radionuclides

In the mid 1990s, the authorities responded to the needs of the operators responsible for the clean-up of sites by establishing operational objectives for the decontamination of soil and buildings on a case-by-case basis. Thus, for example, for certain sites contaminated with radium-226, the decontamination objectives are as follows [1]:

- Outdoor, the levels for hot points are 5 Bq/g of soil and 1 ÌGy per hour;
- Indoor, the levels are 1 Bq/g of material and 0.2 ÌGy per hour;
- For all surfaces where there is non-fixed contamination, the level is 1 Bq/cm^3 of material collected (sampling of 10 cm by 10 cm by 0.1 mm).

These levels are based on the hypothesis of 1000 hours spent outside per year and 5000 hours spent inside per year. They were established to satisfy implicitly an equivalent dose of some tenths of a mSv per year, barring an exceptional case (someone staying permanently in the immediate vicinity of the hot points). Such levels were effectively applied for the remediation of certain sites.

There are similar levels for thorium-232 and for caesium-137 based on the same hypotheses.

All these levels are applicable for any present or future use of the sites.

Moreover in 1997, a legal framework defined the administrative procedures for the remediation of radioactively contaminated sites. A circular [2] specified the missions of those involved, in particular: the Prefet, who is the State representative responsible for the site remediation, the Office for Protection against Ionizing Radiation (OPRI), which provides the Prefet with radiation expertise and the National Agency for Radioactive Waste Management (ANDRA). This agency has a dual role: it performs a technical and financial assessment of the remediation work and, when the site has no identified or solvent responsible officer, it takes on the role of project manager.

Since 1993, ANDRA has published each year an inventory of radioactive waste in France, including a list of sites contaminated with radioactive substances [3].

I-3 Current policy with respect to sites contaminated with chemicals

In parallel, the authorities established the policy for the remediation of sites contaminated with chemicals [4] (1993 onwards). This was based on:

- A census of the sites;
- The categorization of sites, on the basis of a simplified risk study, in three groups: the so-called "insignificant" sites, those "to be monitored" and thoses requiring in-depth investigation;
- The treatment of the sites, the scale of which depends on the objectives of decontamination established by the authorities (see section III-2).

In order to facilitate the work of the operators and administrations, guides were drawn up for sites contaminated solely by chemical substances. The guides covered the initial diagnosis, the simplified risk study (1995, revised in 1997) [5] and the detailed risk study (to be published in 1999).

II The request to the Nuclear Safety and Radiation Protection Institute (IRSN)

The authorities assigned the task of preparing a guide for sites potentially contaminated by radioactive substances[1] to the Nuclear Safety and Radiation Protection Institute, formerly Nuclear Safety and Protection Institute, IPSN). For the sake of consistency, they requested that the guide be based, as far as possible, on the approach adopted for sites contaminated by chemicals. The study completed by the end of 1999 will be made public once it has been approved by the two ministries (Health and Environment) that commissioned it.

The aim of the guide is to provide an operational framework for the management of radioactively contaminated sites, which will replace the current case-by-case approach by a set of recognized procedures that will ensure the "traceability" of the whole process from assessment to decision. It will provide a system of reference for all the stakeholders involved and will permit dialogue on a common basis.

III The objectives to be met

In order to comply with the request, the IRSN considered that the following objectives should be met.

III-1 Consistency with the french regulatory framework

The current regulatory framework for the management of sites contaminated by radionuclides may change with the transposition into French law of the European directive on Basic Safety Standards (96/29) of May 1996. Since the European directive itself is based on the ICRP Publication 60 [6], this latter publication provided the conceptual framework for the preparation of the guide.

III-2 Consistency with the approach adopted for the chemical sites

The approach adopted for the assessment of risks in the case of chemical sites involves carrying out an increasingly detailed analysis:

1. By starting with purely documentary criteria;
2. By carrying out an initial diagnosis leading to a "conceptual overview[2]" of the sources of contamination found at the site in question;
3. By carrying out a simplified risk study; and
4. For sites where the management cannot be guaranteed on the basis of the previous stages, by carrying out a detailed risk study.

[1] Sites at which industrial activity or research involving radioactive substances was carried out in the past. The sites of nuclear facilities in operation or in the process of decommissioning are excluded from the scope of the guide.

[2] Discursive and graphic representation of the situation, providing a synthesis of the knowledge acquired at that stage.

The risks are assessed taking into account the future use of the site. In the case of carcinogenic pollutants, the decontamination objectives (expressed, for example, in mg of pollutant per kg of soil) are established for a maximum risk[3] of 10^{-5}. If the available remediation techniques do not make it possible to reach this level realistically, a higher level may be tolerated, provided the risk does not exceed 10^{-4}, upon submission of a detailed technical and economic study[4].

III-3 Pragmatic approach to meet the stakeholders expectations

In view of the operational nature of the guide for sites potentially contaminated with radioactive substances, a pragmatic approach had to be adopted that meets, as far as possible, the expectations of the various stakeholders. The guide is intended to be used by administrations, local and regional communities, engineering companies, insurance companies, operators, various organizations, etc., involved in the preparation, implementation or control of site management studies.

It was thus necessary to provide not only site management principles, but also precise descriptions of each assessment stage (radioactivity measuring equipment, mapping of soils and buildings, etc.).

It was also necessary to present the hypotheses adopted in the simplified risk study model as clearly as possible with a view to ensuring transparency.

Since the guide is intended to deal with the various situations that might be encountered in practice, the approach involves several stages. It may not be necessary to implement all the stages. Indeed, the assessment effort, which is often very costly and lengthy, should take into account the characteristics of the situation encountered. In some cases, it should be possible to stop the process very quickly when it is relatively easy to prove that the suspected contamination at a site does not in fact exist. In other cases, the site is indeed contaminated, but on a small scale and its contamination profile is relatively easy to grasp. In such cases, a simplified risk study can be carried out and a satisfactory remediation strategy or use advocated. Finally, in the most complex cases, all the assessment stages will have to be implemented and several remediation strategies compared before the most suitable one is selected. However, even if all the stages have to be implemented, the effort devoted to each one of them should be commensurate with the level of the radiation risk and take into account the economic, social and cultural context of the site considered.

IV The proposed methodological options

IV-1 The stages of the assessment procedure

The chapters of the guide describe the various stages that make it possible to assess the risks and to identify the appropriate remediation actions. A distinction is made between:

1. Removal of doubt. This is based on a rapid investigation in which measurements are made of the radioactivity in the buildings and the areas that are believed to be contaminated: gamma radiation and associated dose rate, use of specific alpha, beta and X-ray monitors if necessary;

2. Pre-diagnosis. The main objective of this stage is to identify and assess the real or potential risks of radiation exposure of persons at the site or in the vicinity of the site so that the necessary protection actions required in the short term can be taken. To this end, a preliminary survey and a visit should be made of the site (including the buildings) and the vicinity of the site;

3. Initial diagnosis. The aim of this stage is to establish a site status report in terms of past activities (historical analysis), vulnerability of the environment (soil, groundwater, surface water, air) and radiological characterization (mapping of the surface and initial studies at depth, radioactivity measurements of water, plants and animal products). These data are essential in order to carry out the simplified risk study, which will generally be necessary;

4. Simplified risk study. This involves a calculation of the potential dosimetric impact associated with various scenarios for the use of the site based on the results of the radioactivity measurements of the soil and buildings of the site. In order to facilitate this calculation, generic scenarios (residence, offices, primary school, car park, etc.) have been elaborated and assessed by the IRSN using a model [7]. The model makes it possible to determine the individual effective dose (in mSv/year) associated with the specific unit contamination of the soil (1 Bq/g of soil) for several radionuclides[5].

[3] Probability of a cancer attributable to contamination of the site occurring during the life of an exposed person.
[4] Ministry of the Environment, circular to be published.
[5] Tritium, carbon-14, strontium-90 with its daughter product (^{90}Y), caesium-137 with its daughter product (^{137}Ba^{m}), thorium-232, radium-228 with its daughter product (^{228}Ac), thorium-228 with its daughter products (^{224}Ra, ^{220}Rn, ^{216}Po

The model takes into account the highest specific activities measured in the zone studied or the most pessimistic contamination hypotheses, realizing that the maxima may be found at depth rather than at the surface. The corresponding individual dose is considered as the dose received by the reference group.

The dosimetric impact is assessed for the several decades to come in accordance with the prevailing practices in the context of sites contaminated with chemicals. In the case of a new use of the site, the impact is evaluated for the probable duration of that use. A subsequent change in its use would require a new assessment. Such a requirement is included in the easement attached to the site after its remediation.

5. Detailed risk study. This involves first of all in-depth sampling of the site, focusing on mapping at depth, which was deliberately succinct during the initial diagnostic stage. The detailed risk study needs the identification of the hydrogeological characteristics of the site and its environment. The scenario of future use must be clarified by carrying out, if necessary, a site analysis to provide the most realistic model possible for the subsequent utilization of the site.

   The radiological impact is determined using several indicators depending on the specific situations:

   - The individual dose to the reference group and the numbers involved;
   - The average dose at the site and the numbers involved;
   - The average dose at contaminated zones in the vicinity of the site and the numbers involved;
   - The specific activity in the soil, agricultural products, forestry products, meat of domestic animals, milk, etc.

6. Assistance in the selection of the remediation strategy. It should be noted that the remediation strategy depends on the future use of the site. A change in use may often facilitate the clean-up or obviate the need for it. In the majority of cases, however, clean-up techniques should be envisaged. The available techniques should therefore be examined (removal of soil, in situ confinement, installation of shielding, etc.). These techniques should be combined with the available interim storage or disposal for the generated waste in order to determine the different possible remediation strategies. The latter should be characterized in terms of the radiological impact (doses avoided, contamination of fauna and flora avoided, doses to intervention personnel) and in terms of economic costs, of associated nuisances, of duration of remediation efficiency, of potential reversibility, and of potential need for long term monitoring of the site. A summary of the preceding characteristics must be presented clearly identifying the uncertainties in the assessment so that the strategies can be compared.

IV-2 The decision-making framework adopted

If the measures carried out during the removal of doubt do not reveal any radioactive contamination, the experts advise the stakeholders to consider the site as not radioactively contaminated[6]. When contamination is confirmed and it is possible to remove all the sources of radioactive contamination easily, the process comes to an end. Otherwise, it is necessary to proceed to the pre-diagnostic stage.

At the end of the pre-diagnosis, short-term actions may be taken, including restriction of access, marking off of areas and the removal of hot points. In some simple cases, after removal of the contamination, the experts may advise the stakeholders to consider the site as not radioactively contaminated. In the other cases, it is necessary to proceed to the initial diagnosis stage.

At the end of the initial diagnosis, if it is confirmed that the site is not radioactively contaminated, the experts advise the stakeholders to consider the site as not contaminated. In general, this is not the case and it is necessary to proceed to the simplified risk study.

The simplified risk study makes it possible in some cases to halt the assessment process and decide on the steps to be taken. The simplified risk study is based, as seen before, on a procedure involving generic scenarios characterized by simple, worst-case hypotheses. It presupposes also the establishment by the authorities of an individual effective dose, the so-called "selection level[7]" expressed in mSv/year that is unique and applicable to all uses. When, for certain uses, the doses associated with the contamination measured at the site are below the selection level, the experts advise that the site should be used for one of these uses without remediation, but with an easement applying to subsequent change of use. If the selection level is exceeded for the use desired by the stakeholders, a detailed risk study generally has to be carried out, except in the special case of a "small" site

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^{212}Pb, ^{212}Bi, ^{208}Tl and ^{212}Po), americium-241, uranium-238 with its daughter products (^{234}Th and ^{234}Pa^{m}), uranium-234, thorium-230, radium-226 with its daughter products (^{222}Rn, ^{218}Po, ^{214}Pb , ^{214}Bi and ^{214}Po), lead-210 and its daughter product (^{210}Bi), and polonium-210.

[6] The guide only deals with radioactive contamination. If there is chemical contamination, the relevant guides should be consulted.

[7] Individual dose (received in the reference group) above which the need for remediation has to be studied.

for which it would be relatively easy to remove the contaminated soil and thus reduce the doses to a level below the selection level. After clean-up, the site can then be used without the application of any easement.

The detailed risk study makes it possible to refine the hypotheses and to select realistic data for the desired use. It thus helps to reduce the conservative margins and may sometimes lead to the conclusion that the site can be used as it is, with a possible servitude applying to a subsequent change in use. This is the case if the detailed risk study indicates that the calculated doses are lower than the selection level. If this is not the case, it is necessary to proceed to the stage of assistance in the selection of a remediation strategy.

Assistance in the selection of remediation strategies. Two situations must be distinguished:

- Remediation within the context of maintaining the current use of the site, which pertains to the category of "interventions";
- Remediation within the context of changing the use of the site, which is interpreted by some as belonging to the category of "practices" [8].

In the first situation, the concern for the radiation protection of the populations exposed must be balanced with the need to preserve, as far as possible, the private estate (buildings and land) that needs remediation. A dose that is higher than the selection level may be tolerated following remediation; the residual dose will be assessed on a case-by-case basis by the authorities in close co-operation with the owners or occupants concerned.

In the second situation, the dose after remediation will generally be higher than the selection level. However, it should not exceed a certain value established by the authorities. Such a procedure, based on two reference doses, is similar to the approach adopted in France for sites contaminated with chemicals (cf. III-2).

How to define the needs for remediation? Is remediation really necessary and if so, how far should it be taken? The answer is related to risk "governance" (IV-3.1).

IV-3 Risk management, stakeholders involvement and optimization

IV-3.1 Risk management

For "simple" sites, i.e. when the radioactively contaminated sites are small and when the clean-up of these sites does not create any difficulties of a technical, administrative or financial nature, the management rests essentially on the technical expertise. The doses and contamination of the soil and buildings have to be assessed and then the clean-up methods selected to reduce the radiological impact at an economically acceptable cost.

Sometimes on the contrary the management of a contaminated site is quite more complex because:

- The site is large;
- The radiological impact affects several subgroups of the population to differing degrees;
- The clean-up operation appears difficult and costly;
- Keeping all or some of the radioactive substances at the site creates a potential long-term radiological impact;
- Several uses can be envisaged that have different stakes for the community concerned.

For these "complex" sites, the management is governed by numerous considerations, among which the radiation risk admittedly plays an important role, but not necessarily a central role. It therefore seems appropriate to tackle the question of risk management (selection of remediation strategy) in terms of risk “governance[8]” [9].

Any discussion of the radiation risk cannot be dissociated from the discussion of the use of the site causing the risk. The "accepted" risk more realistic approach is preferred to the "acceptable" risk approach. The appropriate mode of management is that which leads the stakeholders to indicate the remediation strategy (and often the use of the site) that they are ready to accept. The preferred solution thus results from a compromise taking into account various factors depending on the specific context in question.

In the case of "complex" sites belonging to the intervention category, the choice of remediation strategy must, inter alia, take into account:

- The current use of the site and the value (economic, cultural and social) of the premises concerned;
- The perception by the occupants and residents of the radiation risk currently incurred;
- The costs of the clean-up which have to be borne by the various stakeholders;
- The effect on the private estate value;

[8] This expression covers all the social, political, legal, economic, technical and scientific mechanisms that permit, in each context, to take collectively the risk generated by the various social activities.

- Major nuisances of varying duration during the clean-up; and
- Possible conflicts between the owners and tenants, etc.

In the case of "complex" sites, for which a change in use is envisaged, numerous factors are likely to affect the choice of remediation strategy, including:

- The way in which the various stakeholders view the contamination of the site;
- The motives for remediation of the site, which are associated with the radioactive contamination (fears for the health of residents, fear of depreciation of the district, zone, local products, etc.);
- The prospects created by the site remediation project: redeployment for industrial purposes, re-use of the land, tourism, etc.

It should be stressed that these factors can only be taken into account credibly if the stakeholders are involved in an appropriate consultation process.

IV-3.2 Stakeholders involvement

Whether or not the search for the appropriate remediation strategy is accompanied by a discussion on the choice of the future use of the site, there should be in-depth consultations with all the stakeholders. The extent of the consultations will of course depend on the context.

The aim of the consultations is to review and discuss several strategies in order to reach a compromise that appears reasonable to the majority of those involved. The consultations make it possible for those involved to "appropriate" the strategies and therefore to support choices that are likely to modify some of the local habits. They encourage the population to have a more realistic understanding of radioactivity, its nature, its components and risks (radiation culture). They help to maintain the long-term vigilance of the population with respect to a residual risk that is collectively assumed.

In contexts where the subject of contamination is sensitive and induces a polemical climate, consultations may avoid controversies about the validity of solutions which are not analysed in common. In such contexts, lack of consultations is likely to lead to delays, increased costs, and a heightening of local tensions.

The consultation process aims to select a strategy with as many of the following characteristics as possible:

- The strategy provides a level of health protection that both the populations directly concerned and the authorities deem to be acceptable;
- The selected strategy and use of the site take into account the preferences of the local populations in terms of economic and social redeployment and incorporate the cultural characteristics of the community concerned;
- The constraints and possible easements associated with the strategy and use are accepted by the local populations in the light of the prospects that are opened up;
- The strategy should be compatible with an efficient allocation of the national community's financial resources;
- The nuisances caused by the implementation of the strategy, is deemed acceptable by the populations concerned.

IV-3.3 The optimization approach

The optimization approach aims at comparing the strategies in order to help select the one that is most suited to the situation.

In "simple" cases (IV-3.1), the decision process is based essentially on the know-how of the experts that provide technical advice to the competent authorities. The experts may, if they think it is necessary, use decision-making methods such as cost-effectiveness or cost-benefit analysis to compare the strategies and to determine the most suitable one.

In "complex" cases, the guide does not advocate the use of such methods. Why? Indeed it is not a question of proposing the best strategy to the stakeholders. Such methods are difficult for non-specialists to understand. Their use to justify a strategy does not help to create a climate of mutual understanding between the populations concerned and the experts presenting the alternative strategies. Moreover, the use of quantitative techniques involves procedures that make the very heterogeneous elements of choice "commensurable" through monetization or weighing. This quantitative approach has in itself a low degree of credibility for most of those involved.

Rather, the goal is to create the conditions for a debate where the stakeholders can express their point of view based on a proper knowledge of the facts. They must therefore be given the means to appreciate the various

components involved. In particular, it is not a question of favoring one strategy, but of presenting a set of options for discussion. Within this framework, the technical experts have a major role to play: that of providing the technical elements within their sphere of competence clearly and honestly to enable the stakeholders to form their own judgment on the various alternative strategies.

The guide advocates "breaking up" the results and presenting them in the form of tables describing for each strategy (including “do nothing”) the radiation impact, the costs, the effect on exposure of those involved and the associated nuisances.
These tables provide the results obtained within the framework of the detailed risk study and the characterization of the various remediation strategies. They should be accompanied by a detailed description of:

- The necessary hypotheses for the calculations;
- The analyses showing the sensitivity of the results according to the hypotheses adopted; and
- The uncertainties affecting the results.

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