# SAFETY ASSESSMENT METHODOLOGY IN THE EVALUATION OF REMEDIATION PHASE

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**Abstract:** Remediation is a major problem faces the nuclear and radiological industries. The range of contamination levels and contaminants is wide and varied. There are many technologies that offer the potential for remediation but few processes that deal with all or most of the contaminants and even fewer that have been applied with confidence. The remediation technique selected in each case shall be assessed regarding environmental safety. Therefore, policy decisions should be based on an understanding of the potential effectiveness of remediation technique according to the type and level of contamination. Certain situation required an urgent remediation technique. Time, in this case, is considered very important factor that may increase the contamination problem. Therefore, the preparedness remediation phase is a needed process. Herein the present work evaluates the remediation phase through a safety assessment methodology. The safety assessment methodology of radioactive waste disposal is modified and adapted to be appropriate to the remediation phase.

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**Key words:** Contamination; Safety assessment; Radio active waste; Remediation.

## Introduction

Radioactive contamination, in soil/water or air, can be resulted from various activities such as; nuclear fuel cycles facilities, nuclear weapons production, radioisotope production facility, radioactive waste disposal facilities, and finally decommissioning of any of these facilities. Additionally, soil and air contamination can be resulted from mining and milling of uranium, nuclear fuel cycles facilities, mining of minerals, metal industries. The contamination risks associated with nuclear and radiological activities has important effects on policy and commercial decisions in the last few decades. A variety of activities and accidents may result in dispersed (non-point) sources of radioactive contamination. The relationships between radioactive contamination and the risks to human health have scientific and regulatory dimensions. From the scientific perspective, the risks associated with radioactive contamination depend systematically on the magnitude of the source, the type of radiation, exposure routes and biological susceptibility to the effects of radiation damage [1]. Whether the contamination remains dispersed over time will depend on the chemical and mineralogical characteristics of the contaminant, environmental transport processes and receptors [2].

The range of chemistry is large, and the range of the level of contamination is broad, and it also difficult to predict the volumes of contaminated soils that might be encountered during site remediation. Consequently the time and the cost required for remediation decisions increase. On the other hand, the pollution or the contamination problem may become from small to severe situation. From here, this work tries to found a way to predict the contamination and its possible remediation to limit as possible the consequence of environmental pollution [3]. It is important to note that the present work is directed to environmental contamination and not the contamination inside any facility.

## Appraisal of the present situation.

Before the construction of facility operates or generates radioactive materials, two essential documents were prepared namely environmental impact assessment (EIA) and safety analysis report (SAR). The first document EIA, according to the International Association for Impact Assessment (IAIA), is "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made [4]. The second document SAR, according to the international atomic energy agency (IAEA), this report shall be prepared by the operating organization for the justification of the facility design that shall be the basis for the safe operation [5].

Safety assessments, as a chapter in the safety analysis report, are undertaken as a means of evaluating compliance with safety requirements (and thereby the application of the fundamental safety principles) for all facilities and activities and to determine the measures that need to be taken to ensure safety [6]. Safety assessment involves the systematic analysis of normal operation and its effects, of the ways in which failures might occur and of the consequences of such failures. Safety assessments cover the safety measures necessary to control the hazard, and the design and engineered safety features are assessed to demonstrate that they fulfill the safety functions required of them [6]. Where control measures or operator actions are called on to maintain safety, an initial safety assessment has to be carried out to demonstrate that the arrangements made are robust and that they can be relied on. A facility may only be constructed and commissioned or an activity may only be commenced once it has been demonstrated to the satisfaction of the regulatory body that the proposed safety measures are adequate [7].

For that purposes, the IAEA organized a co-ordinated research project on Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities (ISAM) to improve and harmonize the approach to such safety assessment, which has resulted in development of the ISAM project methodology [8]. This methodology has a very organized steps help the operator of disposal facility to conduct the safety assessment and help the regulatory to evaluate this assessment as shown in Figure 1.

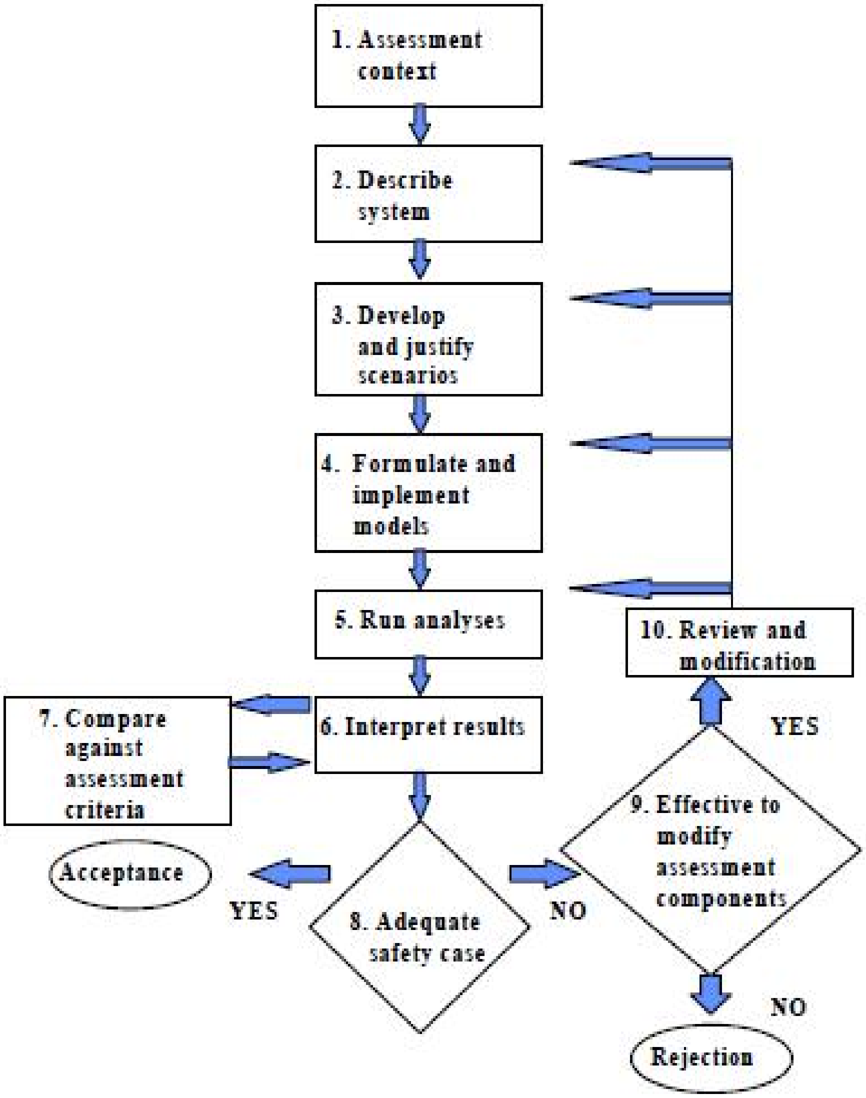

**Figure 1. The ISAM Project Methodology [18].**

Whilst there are differences in the detail of the approaches used, many of the more recent safety assessment methods, such as ISAM, have the following key components [8]:

— The specification of the assessment context;
— The description of the disposal system;
— The development and justification of scenarios;
— The formulation and implementation of models; and
— The analysis of results and building of confidence.

In the present work, as a previous work [9], the steps of the safety assessment methodologies of radioactive waste disposal are adapted to the assessment methodologies for remediation phase. The safety assessment methodologies for disposal of radioactive wastes are tailored to accommodate the procedures required for the expected remediation phase. Each item of safety methodology has be redesigned to agree with the purpose of remediation phase

### Proposed Safety assessment Methodology for Remediation Phase.

The safety methodology of radioactive waste disposal phase is adapted as shown in Figure 2. Each item is discussed as follows:

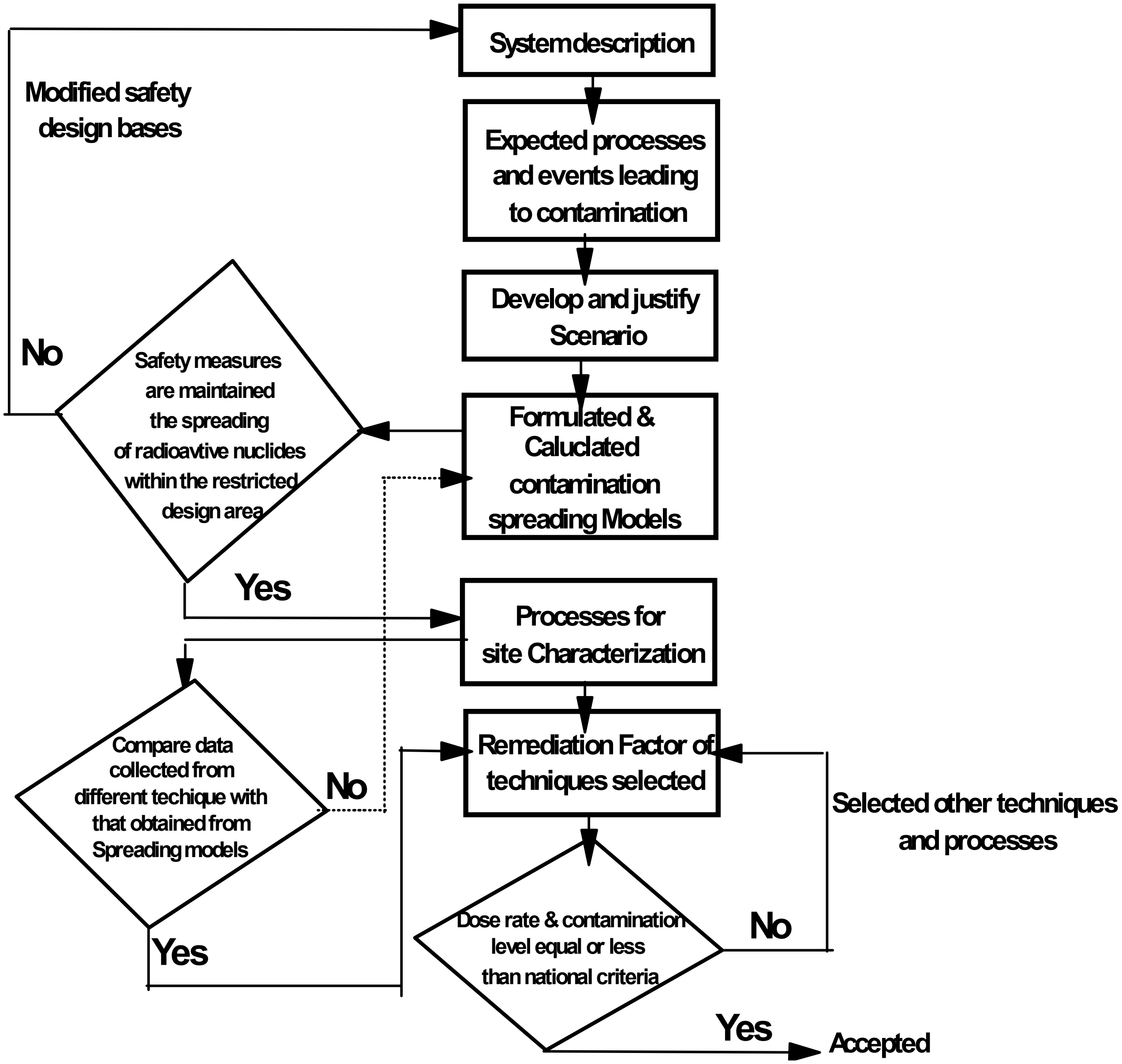

Figure 2. The safety methodology of radioactive waste disposal phase

### 1. System Description.

The safety assessment methodology of radioactive waste disposal started with the assessment context. This step represents the factors that the analyst will consider to determine the scope of the analysis, and which describe the domain of concern; in other words the boundary conditions of the iteration system, which reflects known facts present in the system considered. Referring to the safety assessment of remediation phase, the methodology shall be started with the system description. The system description shall consider the following elements:

a- **Facility in consideration:** the design of the facility shall be described, site characterization, density of population around and its work purposes.

b- **The safety regulation:** the regulations followed during construction, operation and decommissioning shall be cited. The restricted area designed around the facility shall be specified.

c- **Work places description:** not all work places in the facility can be a source of contamination. Therefore, the operator shall describe the work places which are under safety control. The description shall consider safety design barriers and monitors, staff, type of activity and characteristics of radionuclides involved**.**

### 2. Expected processes and events leading to contamination.

The probable processes, human errors, natural events and decommissioning of the facility that leading to environmental contamination shall be considered in the light of the site, and climatic characteristics. Previous contamination cases in different facility can be source of data that help the operator in his expectation; Three Mile Island, Chernobyl, Goiania, Fukushima, and others [10]. Additionally, safety measures presented in the facility shall be evaluated. Screening of these processes should be performed to select the most probable processes.

### 3. Development and justification of scenarios.

The contamination scenario shall start with the cause of accident. The scenario considered shall describe the sequential events lead to environmental contamination. The factors (human, safety measures, and/or others), which can control the degree of pollution shall be evaluated. A scenario describing such accident will require consideration dealing with the various pathways leading to human exposure both internal and external [9]. The choice of appropriate scenarios and the justification of their events should be based on lessons learned from previous contamination cases [10]. Accurate knowledge of the events of previous accidents provides suitable logistic information to help formulate intelligent justified scenarios. The development of suitable scenarios and its consequences are considered of major importance in safety assessment methodology [9].

### 4. Formulation and calculation of contamination spreading models.

Similar as the safety assessment methodology, the operator shall expressed the modes of radionuclides migration, dispersion and contamination in environment (air, soil and water) shall be expressed into mathematical formulations. Additionally modes of human exposure should be modeled. These models shall be based on scenarios selected. The physical, chemical and biological effect of environment shall be mathematically considered with the behavior of contaminant. Meanwhile, behavior of contaminants in soil is a complex topic that has challenged the scientific community over a number of years. There are a number of processes in which the contaminants might interact with soils. These include, but are by no means limited to, the following mechanisms [11]:

- Dissolution in pore water in soils
- Physical sorption of charged species (e.g. double layer systems)
- Chemical sorption of charged species (e.g. ion exchange)
- Physical sorption of particulates or neutral species by electrostatic forces
- Inclusion in mineral matrices (mineralization)
- Co-precipitation with other species (e.g. natural flocculation by ferric oxyhydroxides)
- Complexation with natural organic species (e.g. humic acids)
- Precipitation or sorption by indigenous bacteria

It is also notoriously difficult to predict the volumes of contaminated soils that might be encountered during site remediation. This will depend on factors such as [11]:

- Amount of material spilled or leaked to the soil (often this can only be inferred).
- Chemical form of the contaminant and the chemistry of the soil system. Again, this can often only be estimated.
- Mobility of the contaminants. This again is difficult to determine because of the variety of mechanisms for transport of contaminants.

Additionally, behavior of different radionuclides involved shall be undertaken. Naturally analogues can be an important source of information on the long-term behavior of radionuclides products in the environment. Of special interest are the Oklo and Bangombe deposits of Gabon, which hosted natural fission reactors about two billion years ago [12,13] (Pourcelot and Gauthier-Lafaye, 1999; Jensen and Ewing, 2001). Abstraction of the hydrogeochemical properties of real systems into simple models is required for risk assessment. Heterogeneities in geochemical properties along potential flow paths, uncertainties in or lack of thermodynamic and kinetic parameter values, and the lack of understanding of geochemical processes all necessitate the use of a probabilistic approach to risk assessment. System complexity and limitations in computer technology preclude precise representation of geochemical processes in risk assessment calculations. Uncertainties in properties of the engineered and natural barriers are incorporated into the risk assessment by using ranges and probability distributions for the parameter values in Monte Carlo simulations, by regression equations to calculate sorption and solubility limits from sampled geochemical parameter ranges, and by the use of alternative conceptual models [1].

The representation of selected scenarios in mathematical formulations usually involves sets of coupled algebraic, differential and/or integral equations. These equations should be solved through analytical or numerical mode. Data required and boundaries conditions are considered from system description step. The calculations shall performed to calculate the dose received to individual/workers from the contaminated land from all possible pathways.

## 5. Performance of safety measures in the facility

The occurrence of accidents and natural can not be prevented. Meanwhile, safety measures, provisions and barriers shall have the function to limit the consequences of any event. Therefore all workers (operators and regulators) must have the objectives to control the accident within the designed restricted area around the facility. Once mathematical calculations are resolved, the results shall approve the capability of safety measures and barriers to maintain the contamination within the restricted area. If yes, the operator will continue the next step in the safety assessment process. If not the operator, through the responsible committee, shall modify and improve the system description and repeat the same procedure until he reaches this condition.

## 6- Processes for site characterization

Characterization of the contaminated site is essential before embarking on a program for its remediation and ultimate restoration. Reliable and suitable data must be obtained regarding the distribution and physical, chemical and nuclear properties of all radioactive contaminants. Characterization data is necessary for assessing the associated radiation risks and is used in support of the required engineering design and project planning for the environmental restoration. In addition, continuing characterization can provide information regarding efficiency of the cleanup methods and influence possible redirection of work efforts. Similarly, at the end of the remediation phase, characterization and ongoing monitoring can be used to demonstrate completion and success of the cleanup process [14]. The process of characterizing site involves first determining what contamination is present and where. Complete soil and water characterization in the whole site area is essential to know; 1) what's the extent of soil and water contamination; 2) are there other contaminants; 3) what are the pollutant migration pathways towards the receptors; and 4) is there any impact in the vicinity areas such as the water sources, residential areas, etc.[15].

Once it is clear what wastes are present and at what locations, a selection of treatment and/or management alternatives can be evaluated to identify a preferred remedial approach. General predictions of radionuclide mobility are difficult to make; instead, site-specific measurements and thermodynamic calculations for the site-specific conditions are needed to make meaningful statements about radionuclide behavior [16]. There is also an understandable tendency to produce conservative estimates of contamination levels that are often not found in practice when the remediation task is underway the current standards for waste management or are past their design lives. To evaluate the environmental impact of old radioactive waste sites and to predict the spread of radioactive contamination through groundwater, monitoring boreholes were drilled at the waste disposal site and areas adjoining it on the south and west. Equipped with filter columns, these boreholes were designed to permit observation of the level, chemical composition, and radionuclide content of the groundwater.

A wide range of site characterization techniques exist, some of which will require changes in methodology depending on the particular site and contaminant [17]. The operators shall cite all available techniques for site characterization in case of selected contamination scenarios. Characterizing contaminated sites involves conducting investigations (surveys, piezometer-readings, chemical analyses, etc.) in a contaminated site or in a site that is potentially considered as such with the main aim of defining the geological and hydrogeological structure, verifying whether the land and water is contaminated and developing a conceptual model of the site. Below is a list of documents that can be useful in this first stage of analysis, both for planning characterization surveys and for analyzing results achieved.

**7- Compare data collected from site characterization processes with the data obtained from the calculation of the scenarios.**

The data collected by the techniques selected shall give comparable contamination map with the modeling formulated. Then, the assessor goes the next step. On the other hand, when the available techniques for site characterization can not give a similar contamination map, the assessor shall select another set of suitable models. This can be achieved by conservative assumptions, by reduction of uncertainty, and by analysis the sensitive parameters. Unfortunately, the other option of changed the existed techniques for site characterization is not an option because it depends on the available financial of the facility.

**8- Remediation factor of techniques and processes selected**

There exist numerous remediation technologies although they all fall within three of broad categories, namely: immobilization, extraction, destruction [18-23]. In many current remediation programs, simple excavation of contaminated soil and removal of contaminated groundwater by pumping are the preferred techniques. These techniques may be practical for removal of relatively small volumes of contaminated soils and water; however, after these source terms have been removed, large volumes of soil and water with low but potentially hazardous levels of contamination may remain. For poorly-sorbing radionuclides, capture of contaminated water and removal of radionuclides may be possible using permeable reactive barriers and bioremediation. Alternatively, radionuclides could be immobilized in place by injecting agents that lead to reductive precipitation or irreversible sorption. For strongly sorbing radionuclides, contaminant plumes will move very slowly and likely pose no potential hazards to current populations [24]. However, regulations may require cleanup of sites to protect present and future populations under a variety of future-use scenarios. In these cases, it may be necessary to use soil-flushing techniques to mobilize the radionuclides and then to collect them. Alternatively, it may be possible to demonstrate that contaminant plumes will not reach populations and that monitoring networks and contingency remedial plans are in place to protect populations if the plume moves more rapidly than predicted [1]. Over the past few years, few areas have excited as much interest as soil remediation [25]. Also, there is a multitude of techniques for remediation soils contaminated with organic materials [26]. There are however, fewer that can be deployed against inorganic contaminants, including radionuclides as unlike organic contaminants, inorganic contaminants cannot be degraded or destroyed and therefore pose a more difficult problem for remediation.

The assessor, after calculation the mathematical formulations, shall calculate the remediation percentage and factor acquiring by the techniques selected for remediate the contaminated land. Again, the doses received from remediated soil are recalculated.

**9- Compare dose rate and contamination level with the national criteria.**

The results obtained from the mathematical calculations provide an estimate of the radiological consequences in terms of radiation dose. A radiological event is quantified by the overall consequences of human exposure. On the other hand, human exposures should compare with the dose limit provided by the Safety Series on radiological protection of the IAEA, and the ICRP publications [9]. In case of low dose than dose limit, all process is accepted. The process of safety assessment shall be repeated until reach this convulsion.

## Evaluation of the methodology

Safety assessment, defined by IAEA, is the systematic process that is carried out throughout the lifetime of the facility or activity to ensure that all the relevant safety requirements are met by the proposed (or actual) design. Safety assessment includes, but is not limited to, the formal safety analysis [27]. This reference of IAEA publication, as they mentioned, is intended to provide a consistent and coherent basis for safety assessment across all facilities and activities, which will facilitate the transfer of good practices between organizations conducting safety assessments and will assist in enhancing the confidence of all interested parties that an adequate level of safety has been achieved for facilities and activities.

Safety assessment performed in this work shall be evaluated according to the requirement established by the IAEA. Implementation of the comprehensive set of requirements will ensure that all the safety relevant issues are considered. The safety assessment considered in this work is achieved taken into consideration all the mentioned requirements such as seen in Table 1:

**Table 1. Requirement of IAEA and its corresponding step in the present work**

| IAEA Requirements | Steps of the present work |
|---|---|
| 1: Graded approach | From step 1- to 9 |
| 2: Scope of the safety assessment | Step 1 |
| 3: Responsibility for the safety assessment | Operator or Applicant |
| 4: Purpose of the safety assessment | Preparation of remediation process |
| 5: Preparation for the safety assessment | From step 1- to 9 |
| 6: Assessment of the possible radiation risks | Step 2 |
| 7: Assessment of safety functions | Step 1 |
| 8: Assessment of site characteristics | Step 6 |
| 9: Assessment of the provisions for radiation protection | Step 1 |
| 10: Assessment of engineering aspects | Step 5 |
| 11: Assessment of human factors | Step 2 |
| 12: Assessment of safety over the lifetime of a facility or activity | Step 5 |
| 13: Assessment of defence in depth | Step 5 |
| 14: Scope of the safety analysis | Remediation process |
| 15: Deterministic and probabilistic approaches | Step 4 |
| 16: Criteria for judging safety | Step 9 |
| 17: Uncertainty and sensitivity analysis | Step 4 |
| 18: Use of computer codes | Step 4 |
| 19: Use of operating experience data | Step 6 and step 9 |
| 20: Documentation of the safety assessment | It will documented in the safety analysis report |
| 21: Independent verification | From step 7 to step 9 |
| 22: Management of the safety assessment | It can be applied in the present safety assessment |
| 23: Use of the safety assessment | It can be applied |
| 24: Maintenance of the safety assessment | It can be applied |

## Conclusions

It is not possible to stop events and accidents in nuclear activities that lead to contamination, but limiting its consequences is possible. The time required for remediation decision is an important factor. Therefore preparation for facing such is necessary. Safety assessment of radioactive wastes disposal aims to demonstrate with reasonable assurance that future members of the public and the environment are protected from potential releases from the disposal facility. In this work, the safety assessment methodology is adapted for the evaluation of the safety of remediation phase. The steps of the safety assessment methodology will consist of six processes. The safety assessment developed is considered the IAEA safety requirement for establishing a safety assessment methodology.

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