

# **A Brief Discussion on the Decision Aiding Techniques Applied to a Laboratory of Radioactive Decontamination: a General Case**

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**Abstract.** In the Laboratory of Radioactive Decontamination ( RDL ) at the Instituto de Pesquisas Energéticas e Nucleares – IPEN it has been received objects and equipments from the various installations, each one processing different kinds of radioisotopes. These radioactive materials can range from nuclear fuel fabrication and processing, research reactor utilization or radiopharmaceuticals production. This means many different physical and chemical properties of the contaminants and composition of the contaminated surface. It is difficult to decide whether to decontaminate or not the objects and equipment that were used on the processing of these radioactive materials. Most of the radioactive contamination are transferable ones but some are fixed that would imply in more effort to reduce the contamination levels. Depending on the reuse or on the repairing need, for instance, of equipments, tools or objects, the permissible levels of remaining contamination varies and for so the decontamination process shall be more severe. Several parameters must be considered to make a decision, not only their cost to buy new ones compared to the cost of the materials and personnel those will execute the decontamination, but also the installation budget to buy new equipments, collective dose of the workers, readiness for reuse and so on. In this work we discuss how the parameters influence on the decision about decontaminate or not and if so, up to where to proceed. We also compare the decision aiding techniques applied to a general case considering some parameters those are fundamental and others that are not so important all the time but can affect in a significant way the decontamination choice and the way they can affect the decision maker to choose the best option.

## **1. Introduction**

Economic considerations are an important aspect of any human activity. Therefore it is necessary to estimate the decontamination costs in the overall budget of a radioactive installation or a nuclear plant [1].

In the Laboratory of Radioactive Decontamination, RDL, it has been received objects and equipments from the different installations of IPEN, each one processing different kinds of radioisotopes. These radioactive materials can range from nuclear fuel fabrication and processing, research reactor utilization or radiopharmaceuticals production. This means many different physical and chemical properties of the contaminants and composition of the contaminated surface. It is difficult to decide whether to decontaminate or not the objects and equipment that were used on the processing of these radioactive materials. The economic analysis of decontamination must consider as case basis the costs of any particular decontamination operation against the benefit resulting from it [1]. The simplest kind of decision is that in which reductions in radiation doses are accompanied by savings of resources. More often, the reduction of dose can only be achieved by the expenditure of some effort and by allocating additional resources. In this case, even in the simplest situation, it is necessary to decide whether the dose saving that is likely to result is worth the effort of achieving that saving. The effort needed may include financial expenditure, efforts in training or reorganization of working procedures [2].

Most of the radioactive contamination are transferable ones but some are fixed that would imply in more effort to reduce the contamination levels. Depending on the reuse or on the repairing need, for instance, of equipments, tools or objects, the permissible levels of remaining contamination varies and for so the decontamination process shall be more severe. Preceding a decontamination process, it is necessary to consider carefully the safety and economic aspects of the action, and to decide whether or

not the decontamination is at all necessary. The criterion of safety prevails on any economic arguments. The safety aspects are defined by the limits of the maximum permissible surface contamination [1].

Several parameters must be considered to make a decision, not only their cost to buy new ones compared to the cost of the materials and personnel those will execute the decontamination, but also the installation budget to buy new equipments, collective dose of the workers, readiness for reuse and so on. Whenever a decision to proceed with decontamination has been made for the purpose of health protection rather than for technological reasons. It is prudent to aim always at achieving the maximum decontamination results. There may be sometimes a case where the value of a contaminated item is less than the costs of its decontamination. On the other hand, the object may be so bulky that the expenses related with its disposal as a solid radioactive waste might be higher than the costs of its decontamination [1,3].

Supposing that the only available decontamination procedure involves the utilization of decontaminating solutions, an analysis made before must conclude that the costs of the means needed to manage and dispose safely of the resulting liquid wastes would exceed the those which are related to the disposal of the entire object as a solid contaminated item. That would logically induce to safe disposal. Another possibility that must be considered, is whether it would not be feasible to partially decrease the contamination level by a simple and cheap decontamination procedure and therefore to reduce the costs of the disposal [1].

In this paper we discuss how the parameters influence on the decision about decontaminate or not and if so, up to where to proceed. We also compare the decision aiding techniques applied to a general case considering some parameters those are fundamental and others that are not so important all the time but can affect in a significant way the decontamination choice and the way they can affect the decision maker to choose the best option.

## **2. Surface decontamination**

Radioactive decontamination can be described as any process that either reduce the level of, or completely remove, any radionuclides from a contaminated surface.

The problem of decontamination is made complex because of the large number of possible contaminants, and also the fact that although they all decay in time, many produce a variety of daughter products, which are sometimes isotopes of different elements. The factors that affect decontamination are:

- The chemical, physical and radiochemical nature of the contaminant;
- The material and surface finish of the substrate.

In most cases the contaminants are difficult to remove. They can be classified in soluble ( ionic ), particulate and colloidal. This variation and so, their stronger or weaker interaction to the surface, will make sometimes necessary the use of specific reagents to process the decontamination. Those may not affect or attack the surface, otherwise it will become progressively more prone to contamination and more resistant to subsequent decontamination [3].

### **2.2. Costs of means used for surface decontamination [1]**

Includes:

- Depreciation of machinery and equipment;
- Expendable supplies: raw materials, chemicals, water, decontaminating reagents, supplementary material, energy, etc.;
- Labour

It has to be considered the rate of investment depreciation, the cost of the decontamination facility, the fixed cost, the operational costs of expendable supplies, and the total of salaries of all members of the staff involved.

### **2.3. Other costs associated with a decontamination procedure**

Comprise the costs met in operating the subsidiary linked technologically with the decontamination process:

- Expenses for recovery of expended substances and agents;
- Expenses for treating the resulting radioactive waste;
- Expenses for disposal of the radioactive waste.

To obtain a total cost estimate which would be as close as possible to the real situation, it might be necessary to include also the estimated costs of transportation, personnel protection, health and safety operations, as well as many other items, such as the degree of corrosion damage, the risk of health detriment of the personnel involved, production losses to the temporary interruption of production.

### **3. Benefit resulting from decontamination**

Next to cost estimates, the economic analysis must also include an evaluation of the benefit attributable to decontamination, in order to provide complete information on what procedure is likely to be most profitable.

The criteria of benefit evaluation will vary with different cases of decontamination. As one might well expect, the criteria will be different, if the action involves decontamination of a piece of one equipment, or of large technological systems, or of protective clothing and of others objects for personal protection.

The economic benefit of decontamination ought to be considered from the following viewpoints:

- A decrease in the probability of the health detriment to the personnel;
- Reduction in the purchase costs;
- Savings achieved by economizing the production ( generation of energy or consumer products ) because of shortening the overhaul or repair time periods.

The detriment in a population is defined as the mathematical concept of “expectation” of the harm incurred from irradiation, taking into account not only the probability of each type of deleterious effects but also the severity of the effect. Since there exists a certain relationship between the detriment and the dose equivalent, it is possible, by evaluating the individual or collective dose equivalents, to arrive at a risk estimate, or the probability of harm, resulting from a radiation exposure.

The justification of any activity or practice involving exposure to ionizing radiation must be based on a cost-benefit analysis to ensure that the introduction of a new proposed activity will result in a net gain to the community is also applied for the field of a decontamination.

In an ideal cost-benefit analysis, the net benefit, B, of a decontamination operation involving radiation exposure is expressed by the equation 1:

$$B=V-(P+X+Y) \quad (1)$$

where V is the gross value of decontamination, P the basic cost of decontamination, X the cost of radiation protection and Y the total detriment from radiation exposure caused by the given activity.

The aim is always to maximize the positive value of B so that there is a net benefit from the proposed operation.

#### 4. The optimization procedure

Optimisation of radiation protection in operational situations requires that the complete system be appraised in a systematic manner in order that all factors that have an effect on individual and collective doses are examined objectively to determine if they are appropriate. In the guidance for the construction of Analytical Trees Applied to Radiation Protection in IAEA TECDOC-430 [4] it is developed a branch related to surface contamination. In this branch the decontamination process ended on equipment, clothing and personnel. In the RDL an analytical tree, as seen in Figure 1, can help to appraise an operational decontamination procedure for doing the analysis adding to the specific branches all the phases involved up to the final destination of the object or equipment:

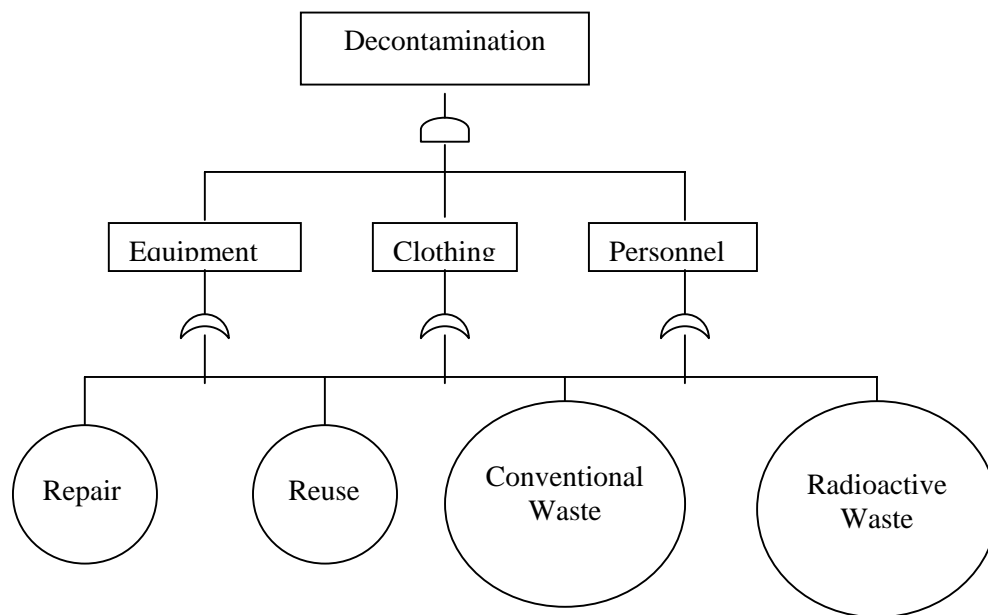


FIG. 1. Analytical tree of RDL decontamination service.

Aids to decision making, particularly those that can deal explicitly with the weighting of different kinds of benefits and harm, will be useful in this process.

The limits are a constraint on optimization and options that do not satisfy the appropriate limits for workers or members of the public are not permitted within the system of dose limitation.

The dose limits, in addition to their role as constraints, may also interact with relevant factors in the decision.

Optimization studies on operations, maintenance and in-service inspection activities should result in standardized that, if implanted, would ensure compliance with the optimization requirement.

The steps of the optimization procedure applied to operations considered in the ICRP 55 [2] are:

- 1) Identification of the need for an optimization study:  
A review is initiated by changes in the levels of individual or collective dose, by changes in costs, by the occurrence of accidents, or simply by the requirement of management or the competent authority to conduct periodic reviews of practice. In the RDL it was identified the necessity of a study on whether decontaminate or not and, if positive, up to where decontaminate.
- 2) Definition of the scope of the study [2,5]:  
The scope of operational studies range from a complete review of the procedures adopted in an organization to a study aimed at optimizing the protection aspects of one specific task. Once defined the scope of the study, it is then necessary to specify the radiological protection factors that are to be included, and the other factors that will affect the final decision. Factors to be included will normally be the collective dose, and the workforce in given periods and its

historical trend, the maximum individual doses, and the numbers of workers receiving doses close to the dose limit or other specified levels such as management objectives. The other factors that will be included for the RDL study are:

- Cost distribution for purchasing objects and equipments;
  - Life span distribution of the objects and equipments;
  - Decontamination cycles previewed to be done during a lifetime;
  - Decontamination factors necessary (below register level). A decontamination factor [6] in radiological protection, is a measure of the effectiveness of a decontamination process. It is the ratio of the original contamination to the remaining radiation after decontamination 1,000 and above is excellent 10 and below is poor;
  - Kinds of decontamination procedures;
  - Decontamination costs;
  - What are the doses involved when receiving the objects ( $<3/10$  AL, Annual Limit );
  - Doses received when performing the decontamination;
  - Time expended by the worker near the object or equipment;
  - The risk of spreading of contamination during normal operation;
  - Costs of the waste generated during decontamination procedures.
- 3) Assessment and quantification the base case:  
A useful step when carrying out an operational study is to perform a detailed assessment of the current situation so that the base case is quantified to the greatest possible extent and the qualitative factors recorded [2]. This quantification can be done by estimating the tangible costs for decontamination and for detriment involved in the actual process of the RDL.
  - 4) Identification of protection options;  
It will be greatly assisted by the study of the current situation, and in most cases it will be clear from that assessment where changes are possible that would lead to modification of some of the radiological protection factors. Thus, in quantifying the collective dose to the workforce the analysis should also identify the modes of operation of the installation and specific jobs leading to the major components of this collective dose and the possibility of modifying those operations. Considering the facilities, the feasible contaminant and type of equipment that can be sent to RDL to be decontaminated, the options will consider the costs of the equipment and objects subdivided in several levels as to facilitate the study of the options and the dose involved due to the amount of the contaminant possible to be on the surface.
  - 5) Estimate performance of the options:  
With the data assembled as a starting point, the costs and performance of each option identified will be assessed. Changes in the organizational structure or internal working procedures, are difficult to quantify in either aspect but may have a greater long-term impact.
  - 6) Estimate the options that can not be ALARA:  
Using the cost-effectiveness analysis the option that can never become the optimum solution will be eliminated.
  - 7) Use of quantitative decision-aiding techniques and qualitative assessments:  
In order to compare the performance and costs of the options, different quantitative techniques are available.
  - 8) Result of the optimization study:  
The result of these quantitative and qualitative analyses will generally lead to identification of an option indicating where changes could beneficially be applied, together with an indication of the likely result of such changes. There also likely to be recommendations as to gaps or omissions in the data that were available for carrying out the study, together with suggestions as to the levels of performance that should be achieved and the need and frequency for further reviews.
  - 9) Reaching a decision:  
If the study is fairly simple and unlikely to be affected by factors outside the scope of radiological protection, these results and recommendations will generally be accepted as decisions and translated directly to actions. Is it worth to decontaminate, or consider as radioactive waste and buy a new one, considering the waste management and disposal costs.
  - 10) General working rules:

It is expected that experience with a number of operational optimization studies in similar situations should enable general guidance to be established on standard operational procedures, target doses or dose distributions [2].

#### **4.1. *Quantitative Decision-Aiding Techniques***

ALARA is a procedure aimed at achieving a satisfactory compromise between generally conflicting aims, for example reducing the number of health effects and saving money. Stated in rather broad terms, the assumption is that in making resource allocation decisions for protection, it is proper to carry out some kind of balancing of the resources put into protection and the level of protection obtained against a background of other factors and constraints [7].

The options that will be considered are aimed at reducing the exposure to ionizing radiation, although it is important to remember that these options may have consequences for other types of risk, such as radiation risks to groups other than the one for which the options were originally considered, chemical risks or engineering risks. The assessment of individual options should reflect not only the reduction in radiological risk, but also the favourable or unfavourable consequences with respect to the other kinds of risk. The correct knowledge of the performance and the cost associated with each of the alternative options enables them to be compared, through the appropriate quantitative technique, in order to select the solution which offers the best balance between protection costs and risk reduction.

Different quantitative techniques are available for comparing the various available options as they are characterized by their cost, detriment and other factors. The choice will depend on the decision level involved. When these options may affect many factors such as productivity of the plant or the level of safety, rather more complex methods such as multi-attribute utility analysis or multi-criteria outranking analysis may be envisaged.

The availability, quality of the data and the number of attributes required to carry out the quantitative analysis, may influence the choice of the technique. When there is a large radiation protection disparity, multi-criteria outranking analysis is preferable. If the attributes present large uncertainties, no technique can compensate for very large ones.

Decision-aiding techniques can be divided into two broad categories: multi-criteria outranking analysis and aggregative methods.

Multi-criteria outranking analysis compares options by pairs in order to assess if one outranks the other, and to determine whether one option is preferable to another. Strength of the technique is that it can be used to compare options that have little difference in a number of criteria but substantial difference in others. Sometimes for a pair of options there is no preference, the options are either too close to be distinguished or they are too heterogeneous to be compared.

In the aggregative methods, the performance of each option for the various criteria is combined to yield a single value that is used to rank the different options. It is essential to quantify the performance of each option adequately for each criterion and to bring them into a form in which they can be combined. The most widely used aggregative methods are based on utility functions related to the different criteria. Utility functions are not in general linear, and the foundation for obtaining them is preference, usually that of the "decision maker". Account is taken of the relative importance assigned to the various criteria by giving a relative weight to each. The best option is then the one that maximizes the total utility.

Taking into account the uncertainties through a sensitivity analysis provides important insights into the stability of the results under variation of the assumptions and judgments introduced in the analytical procedure. It indicates the items that are the most crucial in terms of radiological protection management, and where allocation of resources to research may most usefully contribute to filling the gaps in knowledge.

Being considered an integral part of the analytical procedure, it may also provide an opportunity to assess the solution emerging from the optimization procedure against the remaining factors that were not integrated in the analytical procedure.

The optimization procedure will have fulfilled a valuable role, clarifying for the decision maker the main relevant factors and the implications of the value judgments that lie behind the ultimate choice [7].

#### **4.2. Sensibility analysis**

One of the factors that affect the analytical solution is the reference value of unit collective dose, alpha. The alpha value can range from US\$ 3000 Sv.p<sup>-1</sup> to US\$ 40000 Sv.p<sup>-1</sup>. In Brazil the official value is US\$ 10000 Sv.p<sup>-1</sup>, although some studies demonstrated that this value does not reflect the country reality. The calculated value [8] is around US\$ 3300 Sv.p<sup>-1</sup>.

All the attributes, criteria and utility function can change their value in a presumable range and then it can be performed a sensibility analysis in their own range.

### **5. Conclusion**

Due to the diversity of prices among the countries and the different economies that allow laboratories to be well or poor furnished, the suggested analysis in this paper is not able to give a general result applied to all countries, but only one result that is specific to the original country or at most a regional one, if the countries constituting the region are economically and industrially alike.

A Cost-effectiveness analysis would not allow to consider all the factors necessary for a complete solution for the RDL study case. It will be important to evaluate as much as possible the factors mentioned before. For so it will be necessary to estimate all the costs involved in each decontamination procedure. Maybe it would be less difficult to group the equipments and objects in some levels of prices, lifetime, frequency of decontamination. Therefore for quantifying all the factors it is necessary to some effort. Some factors are not so important, but affects the cost in a way that has to be considered, can be estimated as other costs (normally 20%).

The most appropriate aiding-technique for achieving the analytical result for the base case proposed here seems to be the multi-attribute utility analysis and it would extend to the multi-criteria outranking analysis for the options that do not have behaviour homogeneous for the most important factors.

In order to achieve reliable analytical solutions among the options of decontamination or not, it must be done in advance an account of the costs, decontamination frequency, residual contamination after decontamination, quantity of objects of the same kind, considering all of the factors presented in this paper prior to elaborate the viable options for the analysis using the decision aiding techniques.

The sensibility analysis will permit to know the real influence and the levels in which the most important factors considered for the decontamination procedure change the optimal option. It will be valuable to do a sensibility analysis considering the alpha values ranging from the minimal permitted up to the maximum and, also the comparison between the official and the calculated one for Brazil; the attributes; the criteria; or utility function.

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