

RADIOLOGICAL IMPACT ASSESMENT OF A URANIUM MILL TAILINGS REPOSITORY.

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1. INTRODUCTION

The quantity of uranium mill tailings currently stored in France is about 50 million tonnes distributed on 20 sites (Figure 1-1), five of which hold more than 5 million tonnes (Table 1-1). The half-life of some radionuclides (^{230}Th is 75,000 years, ^{226}Ra 1,600 years) present on repositories means that the period during which nuisances will be present will be practically infinite when considering a human life span.

The radiological impact of repositories for these tailings currently takes account of :

- the external exposure ;
- internal exposures due to incorporation by inhalation of uranium dust, ^{220}Rn and ^{222}Rn , and ingestion of soluble ^{226}Ra and uranium,

induced by living close to the site, without considering the time factor.

Remediations currently being made to these sites limit the radiological impact.

Region	District	Sites	Mill Tailing Quantity (kt)	Radionuclides ^{226}Ra	
				(TBq)	(Bq/g)
POITOU CHARENTE	Vendée	La Commanderie	250	1	4,0
PAYS DE LA LOIRE	Loire Atlantique	L'Ecarpière	11 350	182,1	16,0
LIMOUSIN	Haute Vienne	Bellezane	1 556	49,1	31,5
		Brugeaud	5 782	131,2	22,7
		Croix du Breuil	554	3	5,4
		Lavaugrassse	5 681	142,5	25,1
		Montmassacrot	737	19	25,8
	Jouac (en activité)	1 347	79	58,6	
	Creuse	La Ribière	196	0,85	4,3
AUVERGNE	Puy de Dôme	Rophin	30	0,31	10,3
	Cantal	Saint Pierre du Cantal	605	7,9	13,0
BOURGOGNE	Saône et Loire	Bauzot	16	2,9	181,2
	Saône et Loire	Gueugnon	185	10,4	56,2
LANGUEDOC ROUSSILLON	Lozère	Le Cellier	5 947	43,1	7,2
	Hérault	Lodève (en activité)	5 223	175,4	33,5
		Le Bosc	2 970	118,1	39,7
MIDI-PYRENEES	Aveyron	Bertholène	476	7,6	16
RHONE ALPES	Loire	Bois noirs - Limouzat	1 300	74,6	57,4
ALSACE	Haut Rhin	Teufelsloch et Shaentzel	4	0,025	18,5

However, the potential risk of these repositories will vary as a function of their "natural" dynamics, namely modification to barriers consisting of solid or liquid coverage and dikes when there are any, and changes to their environment. Since they are surface

repositories, the evaluation of the risk involves the definition and analysis of different scenarios, based on consequences of climatic and geodynamic events and events caused by human intrusion.



Figure 1-1 : Localisation géographique des principaux sites géographiques de stockage de résidus de traitement de minerai d'uranium

The following sections describe the current radiological impact assessment methodology of uranium mill tailings repositories as it was practiced since 1990 (section 2) and some of its results (section 3). The restriction of the impact assessment to the short term, the lack of realism of the present critical group and the lowering of the dose limit to 1 mSv/y led to review these methodology (section 4). Its application to Lodeve repository (remediation in progress) and to Jouac site (still in activity), at least, will be the opportunity to appreciate, on real cases, the expected consequences of reducing the effective dose limit (section 5).

2. CURRENT FRENCH PRACTICE

Regulatory Framework

Authorization to close a mining site ⁽¹⁾ and management of uranium mill tailings repositories are governed particularly by decree n° 90-222 . This decree introduces the principle of added exposure, or the Annual Added Exposure Rate (TAETA) that corresponds to the difference between exposure due to repository after remediation and the natural exposure of the site before it was exploited. This natural exposure is due in particular to the presence of natural radioactive substances on the site and in its

¹ A "mining site" is any installation that includes one or several of the following components: mining site, quarry, tailings repository, effluent treatment station.

immediate vicinity.

The remediation must be done such that the repository radiological impact on the environment is as low as reasonably achievable using the techniques available at acceptable cost, both during the exploitation period and after final shutdown.

TAETA
calculation

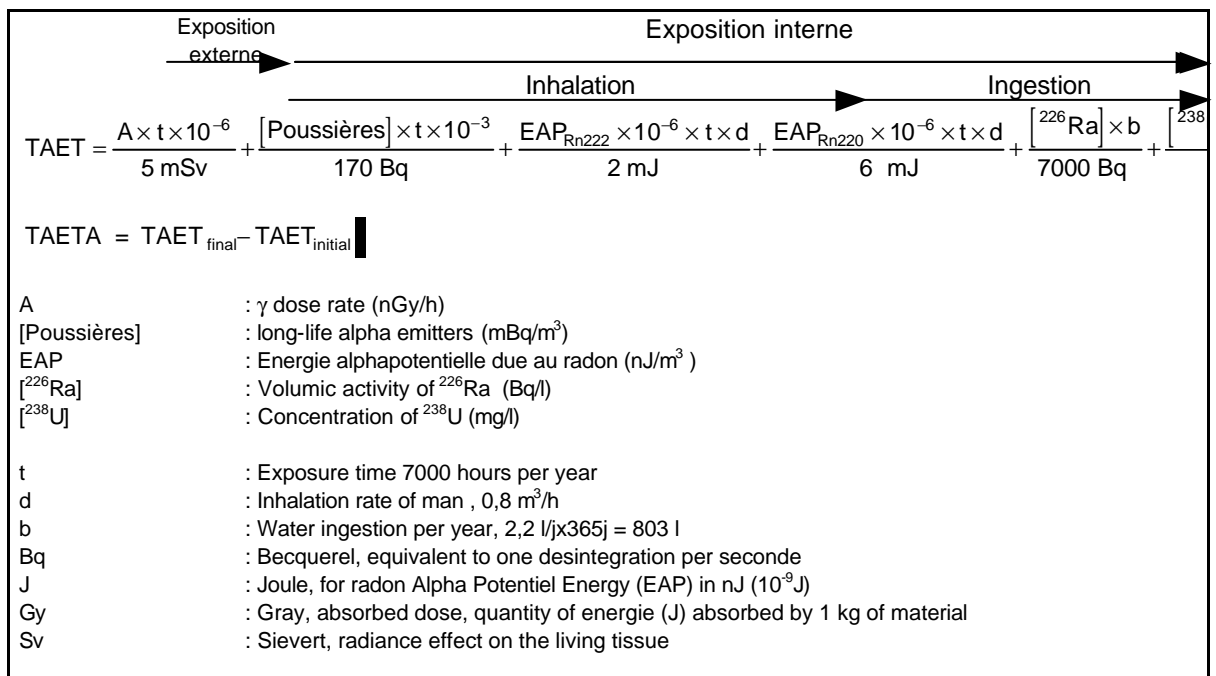
The calculation of TAETA is applicable to the most highly exposed persons, by fixing exposure parameters (quantity of ingested water, inhaled air, time present on the site).

The radiological impact on the environment is considered to be acceptable when the TAETA for member of the public is less than 1, which currently corresponds to an effective added dose of 5 mSv.

The TAETA is obtained by summing the values of the components of added exposure over a year, compared with the annual incorporation limits defined as follows (Figure 2-1) :

- 5 mSv for external exposure ;
- 170 Bq for long-life alpha emitters in the uranium 238 chain present in inhaled dust in suspension in air, 2 mJ of potential alpha energy for short-life descendants of inhaled radon 222 ;
- 7 kBq for ingested ²²⁶Ra ;
- 2 g for ingested uranium, the daily quantity of hexavalent compounds that can be ingested not exceeding 150 mg.

Figure 2-1 : Calcul du Taux Annuel d'Exposition Totale Ajoutée (décret n°90-222 du 10 mars 1990).



Liquid effluents (pumped water from mining sites, water drained from tailings, etc.) are now systematically treated to respect disposal authorizations defined by prefectural orders (Table 2-1).

The evaluation of the current or short-term radiological impact of a tailings repository

Table 2-1 : Concentration limits on uranium and radium fixed for liquid effluents. Instruction letter for decree n°90-222.

		(annual average)	
²²⁶ Ra	soluble	370 mBq/l	
²²⁶ Ra	insoluble	3,7	Bq/l
²³⁸ U	soluble	1,8	mg/l

Inspection
means

depends on a monitoring network that is mostly installed during the mining site exploitation phase. This network considers the main transfer pathways (water and air) and consists of :

- fixed stations for the atmospheric pathway, equipped with means of measuring
 - . the gamma dose rate, by thermoluminescent dose meters ;
 - . concentrations of potential alpha energy due to short-life descendants of ²²²Rn and ²²⁰Rn, by site alpha dose meters ;
 - . the volumetric activity of long-life alpha emitters, by site alpha dose meters or by atmospheric sampling on filters.
- permanent checks of water courses for the water pathway :
 - . by continuous or occasional sampling of different half lives ;
 - . by a monthly analysis of soluble and insoluble ²²⁶Ra and ²³⁸U ;
 - . by checks on the food chain (aquatic fauna in water courses on the downstream side of repositories, fruit and vegetables, eggs ...).

Critical Group

The current regulations define a critical group with the following characteristics:

- exposure times : 7,000 h/year ;
- inhalation rate : 0.8 m³/h ;
- ingestion during 365 days, of 2.2 l/d of water sampled in the receiving water course immediately below disposal points.

Some consider that this scenario (which is already severe) is still not sufficiently conservative, and recommend :

- the installation of inspection stations at the boundary of the repository, at the point at which exposure factors are highest (even if its improbable or even impossible for a person to stay at this point) ;

- the exposure time over 100 % of the year (namely 8760 hours instead of 7000 h) ;
- consideration of water ingestion at the disposal point, without dilution in the natural environment ;
- direct consideration of the main links in the food chain, in addition to water, as suggested in the circular for application of decree 90-222.

3. AVAILABLE EVALUATIONS

The order of magnitude of the effective added doses for the main French repositories evaluated based on this scenario is summarized in Table 3-1. All these evaluations remain less than 5 mSv/year and satisfy the requirements of decree 90-222.

The relative uncertainty about these results is generally about 30% due to the large variability of the results of measurements of the radon activity per unit volume and the external exposure.

Note firstly that the only site that exceeds the limit defined by the 1 mSv/year criterion specified in Euratom directive 96/29 is the Lodeve site, and work is currently being carried out to improve this repository. The limit of 1 mSv appears to be respected on other sites, however it should be noted that these calculations ignore the uncertainties mentioned above.

Table 3-1 : Order of magnitude of effective added doses corresponding to a scenario of the type defined in decree 90-222, for a critical group under the close influence of the main uranium mill tailings repositories

Site	External exposure mSv/year	Exposure by inhalation mSv/year	Exposure by ingestion mSv/year	Effective dose from the natural environment mSv/year	Effective added dose mSv/year	Ref.
Jouac *	1.7	1.1	0.2	2.2	0.8	2
Bertholène	0.9	0.8	0.9	1.6	1.0	3
Bessines	1.7	1.6	0.2	2.7	0.8	4
L'Ecarpière	1	0.7	0.2	1.5	0.4	5
Lodève **	1.6	0.9	1.3	2.1	1.7	2
La Commanderie	1.6	1.0	0.4	2.6	0.4	2
Forez	1.4	1.3	0.2	1.9	1.0	6
Le Celler	1.5	0.6	0.3	1.8	0.6	7

Site in activity ** Site currently in remediation

Natural variability
and uncertainties

In order to discriminate the dose added by the storage, the radiological impact assessment have to take the local natural background into account, generally elevated

- 2 Commision for scientific and technical questions related to the management of radioactive waste, working with the C.E.A. (French Atomic Energy Commission) Scientific Council, Tailings, 1993
- 3 IPSN/DPRE report No. 96/12, *Expertise du dossier de réaménagement du site de Bertholène – Expert appraisal of the Bertholène site remediation file*
- 4 IPSN/DPRE report No. 95/19, *Expertise du dossier de réaménagement du site de industriel de Bessines - Expert appraisal of the Bessines industrial site remediation file*
- 5 L'Ecarpière, Monitoring of the environment - COGEMA Management of mining sites, 1996/1997
- 6 Forez, Monitoring of the environment - COGEMA Management of mining sites, 1997
- 7 Le Celler, Monitoring of the environment - COGEMA Management of mining sites, 1997

and fluctuating closeness to the site. This discrimination is not easy because the uranium mill tailings contains only natural radionuclides and no specific markers.

The summary study carried out by IPSN ⁽²⁾ in cooperation with COGEMA illustrates the strong dispersion of effective doses in the natural environment. Table 3-2 summarizes the order of magnitude of these doses, specifying the contribution of each of the exposure pathways. The natural effective dose may occasionally exceed 5 mSv (particularly close to mining sites) due to the high content of uranium in rocks forming the geological environment around sites.

Table 3-2: Order of magnitude of the natural variability of the various exposure factors considered in the evaluation of the radiological impact of a uranium mill tailings repository ⁽²⁾

	Natural environment in France		
	% average	Minimum mSv/year	Maximum mSv/year
External exposure	57%	0.75	1.96
Internal exposure			
· by inhalation	34%	0.35	2.08
· by ingestion	9%	0.01	0.27
Total	100%	1.11	4.31

The relative uncertainty of measurements of the external exposure, activity per unit volume of soluble radon, radium and uranium for a given measurement point alone is about 30% (**Table 3-3**).

Uncertainties associated with the natural effective doses applied to the data in **Table 3-2** vary from 0.3 mSv to 2 mSv. Therefore, they are of the same order of magnitude as the European regulatory limit of 1 mSv, or the fraction of this value recommended by CIPR 77 equal to 0.3 mSv.

Table 3-3: Example of relative error associated with the measurements results of the main parameters for evaluation of the radiological impact of a uranium mill tailings repository

Site	External exposure	Exposure by inhalation	Exposure by ingestion	Ref.
Bertholène	14%	35%	60%	8
Bessines	18%	25%	-	9
Lodève *	17%	30%	54%	10

*Site currently being improved

⁸ SMJ remediation file, 1995, part 6, Appendix

⁹ IPSN/DPRE report No. 95/19, ditto ⁽⁴⁾ p. 2

¹⁰ IPSN/DPRE report No. 98/10, *Expertise du dossier de réaménagement du site de Bertholène, Expert appraisal of the Bertholène industrial site remediation file*, 1996, 34 p.

Encountered
difficulties

The appreciation of the present radiological impact of repositories leans, according to the actual regulation, on a logical and coherent methodology. But, this radiological assessment remains sensitive, complex and therefore subject to objectives critiques.

The main critical points are :

- the lack of measurement on old sites, in order to determine the initial level of natural radioactivity before all industrial operation. The evaluation of this initial state is particularly sensitive for the EAP of ^{222}Rn which may account for more than one third of the exposure due to the repository, and to a lesser extent for the water pathway ;
- the representativeness of the number and location of measurement points, in order to determine the initial radioactivity and the natural regional radioactivity excluding the influence of the mining site when the initial measurements do not exist ;
- the uncertainty associated to measurements that results of spatial variations of the natural background. These uncertainty could be in the same order of the signal research ;
- the use of a «all purpose » scenario defining the group of population that would be the more exposed whatever the repository doesn't take into account the real living conditions of populations. These kind of scenario could be penalizing by certain aspects (ingestion during 365 days of 2.2 l of water coming downstream from the site) and doesn't consider the different links of the food chain ;
- the assessment of the radiological impact limited to the very short term relatively to the half-life of radionuclides stored.

The respect of the limit of 1 mSv/an effective dose (or less if one considers the limit of 0,3 mSvs recommended by the ICRP) and needs of assessment for long term of the radiological impact of uranium mill tailings repositories drove to review conditions of these assessments and to propose a more compliant methodology to the present recommendations of radioprotection.

4. CHANGES NOW BEING MADE AND PLANNED CHANGES

European directive Euratom 96/29, May 13, 1996 fixes the public dose limit at 1 mSv per year, or an annual average of 1 mSv/year over five years. Since uranium mill tailings repositories are within the scope of this directive, its transcription into French law will in particular require a revision to decree 90/222.

Revision to the
"regulatory scenario"

Respecting the fraction of 1 mSv recommended by the CIPR applied to uranium mill tailings repository would aggravate the consequences of the deliberately pessimistic assumptions currently made in decree 90/222. A simple calculation shows that authorized disposal threshold values would have to be divided by a factor of 15, which would have direct consequences on effluent treatment processes used at the present time.

In any case, transcription of Euratom directive 96/29 into French law would make it necessary to revise the definition of the "critical group" and the associated regulatory scenario. The approach adopted by the Ministry of the Environment ⁽¹¹⁾ emphasizes the necessity to select realistic assumptions for the behavior of individuals in the short and medium term, for example based on consumption habits observed in the repository region. Consequently, this involves a change from the critical group concept to the reference group concept recommended by directive 96/29. Internal exposure by ingestion should be most sensitive to this configuration since it currently contributes 10% to 30% of the effective added dose of a critical group living close to the repository (Table 3-1).

The half life of the radionuclides present in uranium mill tailings introduces a special problem with these surface repositories. There is no way of guaranteeing monitoring and maintenance in the medium and long term, in other words over several hundreds or several thousands of years.

The accepted doctrine concerning the methodology of evaluating the radiological impact of tailings repositories prepared by the Ministry of the Environment ⁽¹¹⁾, recommends that a distinction should be made :

- in the short term, a phase known as «active surveillance» is characterised by regular servicing of the repository, maintenance of the engineered structures and treatment facilities, and by checking that the restriction of use are respected (administrative decision) ;
- in the medium term, a «passive surveillance» phase during which the restrictions of use are always known but servicing and maintenance operations of the means of monitoring and processing are halted when they prove to be no longer necessary ;
- a period in which the surveillance of the repository can not be guaranteed. During this period, the consequences for the integrity of the repository as a result of possible human activity are maximised.

For the long term, it is necessary to consider changes to the characteristics of the repository due to natural phenomena (seismicity, climatic events), or possible human intrusions (residence, construction site on the repository area). Therefore, the procedure for evaluating a repository will include an analysis of :

- a normal situation, in which the integrity of the naturally evolving repository is maintained (coverage, dike when there is one) with reference groups living outside the repository with the possibility of walking and playing on the repository ;
- altered situations involving the loss of integrity of repository systems and human intrusions such as residence on the repository and construction work involving earthworks or excavation.

¹¹ *Doctrine regarding the remediation of repositories for uranium mill tailings*, Ministry of the Environment, letter to prefect, 7 mai 1999

To date, a certain number of conventional scenarios have been studied. They are chosen on the grounds of a consensus of expert opinion. However, the reasoning behind the choice made is somewhat vague or not formally stated and does not always make them as «all embracing» as they should be.

The diversity of events, and their sequences or consequences which could diminish the long-term containment capacity of the repository, leads to a complex system to be analysed.

In order to facilitate making the choices, as well as formally stating the reasoning, and to avoid any suspicion of «arbitrary selection» of scenarios, a systematic approach to generating scenarios can be adopted. Five stages can be discerned :

- identifying and establishing an inventory of the processes and the events to be used from all the possible ones, in relation to their origin (natural or linked to human activity), the probability of them occurring and the effects which they have in the integrity of the repository ;
- establishing the different possible states and their combinations in order to tend towards an analysis of possible changes in the repository which is as exhaustive as possible ;
- the elimination of certain combinations of states due to their incompatibility or their lack of relevance as regards the events or processes which could produce them ;
- categorising combinations of states, in relation to the type of exposure, the location of the critical group in question of the difficulty in specifically modelling certain configurations ;
- generating and determining stylised exposure scenarios which cover all the categories of combinations of states describing the repository and human activities.

This approach is used to deduce a limited number of stylised exposure scenarios representative of different categories of events or sequences of events whose associated radiological consequences are estimated to be greater amongst those of situations in the same category. Applied to uranium mill tailings repository it permitted to select six scenarios for evaluating the radiological impact of repositories (Table 4-1).

These scenarios are divided into two categories according to the nature of the events and the processes considered :

- **a reference scenario** which corresponds to a normal situation of changes in the repository and must take into account :
 - . normal changes in the natural environment around the repository ;
 - . all the natural factors which can lead, for various reasons, to the gradual modification over time of the performance level and the stability of the repository structures and the stored products.
- **five altered scenarios** : These five scenarios aim to take into account the deterioration of the elements which constitute the repository and its environment due to the following factors:
 - . a natural phenomenon, but of exceptional magnitude ;

. a human action, which could constitute a source of danger for the workers or source of deterioration for the repository structures.

Obviously, the radiological consequences of "altered scenarios" need to be evaluated considering their probability of occurrence.

reference biosphere
and associated
critical group

The radiological impact assessed by the critical groups implicitly suggests that the existence of extreme individual behaviour patterns, which could lead to non-representative radiological exposure, is eliminated.

The assessment of the current radiological impact will be based on a realistic critical group, representative of individuals likely to receive the highest doses in the immediate environment of the repository. The degree of self-sufficiency adopted will be determined with regard to current local lifestyles and, in particular, the origin of water supply and the way in which it is used.

The assessment of the future radiological impact caused by potential releases of radioactivity into the environment will be based on a technological level and current lifestyles in temperate European climatic conditions. Indeed, any extrapolations of living conditions in a distant future would be largely speculative. Two hypothetical critical groups, representative of two types of biosphere will be considered in relation to the variations in water supply :

- sufficient water supply, for a group of individuals living with a high degree of self-sufficiency with their own water supply (daily usage and for drinking purposes), making possible mixed farming (crop irrigation and livestock) ;
- limited water supply (little water from streams etc. and little potential of extraction by means of wells), indicates limited self-sufficiency allowing an irrigated vegetable garden type biosphere, farmed by one or several families.

5. EXPECTED CONSEQUENCES OF REDUCING THE EFFECTIVE DOSE LIMIT

The results of Table 3-1 correspond to the calculated radiological impact of a repository after remediation estimated based on the "regulatory scenario", for a critical group located close to and influenced by the repository. It is usually a critical group located in the village nearest to the installation, the typical behavior of which is described in section 2. The results of this scenario show that the effective added doses obtained for an installation exceed the limit of 0.3 mSv due to the natural variability and measurement uncertainties.

The rational approach used by the operator will consist of attempting to demonstrate that he respects the regulations by carrying out a new evaluation of the repository isolation capacity based on assumptions about the behavior of critical groups that are more realistic than the assumptions currently used (for example water consumption adapted to the water resource).

If the result still remains outside regulatory requirements after this re-evaluation, then improvement works to the repository systems (coverage, dike) and the effluent treatment should be considered.

Altered scenarios considering human intrusion lead to very high effective added doses. For example:

- **Walking on the site regularly** considered in a normal evolution scenario, would lead to an increase in the effective dose due to external exposure and inhalation of radon of about 0.5 mSv ⁽¹²⁾. The increase in the effective dose would exceed 3 mSv if there were no coverage on the repository, either due to a random event due to natural causes or due to human activity.
- The **residence on the repository scenario**, considering inhalation of ²²²Rn alone, would lead to an increase in the effective dose from 6 to 10 mSv for a repository with coverage ⁽¹³⁾⁽¹⁴⁾, or about 75 mSv for a repository without coverage.

The probability of the latter scenario is based on a number of assumptions

- a constant specific activity of the tailings over a period of 10⁴ years (in other words for a time much longer than the time for which it is possible to guarantee that the coverage and the dikes will remain effective) ;
- disappearance of the coverage in the long term, due to the long time period considered.

Evaluations of the radiological impact resulting from altered scenarios do not necessarily have to be used in the design of improvements to repository. However, it may be thought that a reduction in the dose limit applied to the evaluation of a normal evolution scenario for the repository would have consequences on the acceptability of degraded "human intrusion" type scenarios. The acceptability of an altered scenario

¹² 400 h/year on the repository (external exposure + inhalation of ²²²Rn).

¹³ House with an unventilated cellar. Time in the house = 7,000h/year in a main room and 100 h/year in an unventilated cellar. See ⁽¹⁴⁾ for calculation principles. Thickness of coverage considered 4m and 3m. The average specific activity of the tailings 16 Bq/g.

¹⁴ IPSN/DPRE report No. 98/16, *Simplified model of "radon accumulation in dwellings built on repositories containing ²²⁶Ra - Calculation of the associated radiological impact*

will become more difficult as the difference between the regulatory threshold applicable to the "normal" exposure situation and the effective dose resulting from a degraded scenario increases.

6. CONCLUSION

As all radioactive waste disposal, the basic radiological objective of a uranium mill tailing repository consists in ensuring the immediate and future protection of people and the environment. We have to recall the particular character of these repositories. Considering the importance of volumes stored (about 50 millions tons) and the absence of any solution bringing an appreciable improvement, the present repositories must be considered as being in their definitive configuration.

After completion of improvements already made or being made, and treatment of effluents, all French uranium mill tailings repositories will have to satisfy the 1 mSv regulatory criterion. For the medium and long term, the achieved remediations (covers, reinforcement of repository structures toward risks of erosion, infiltration ..., treatment of liquid effluents ...), and the dispositions taken during the surveillance period should permit :

- to ensure the respect of the dose limit by maintenance of a monitoring network (waters and air). These radiological monitoring network is the one installed at the time of exploitation and maintained during the remediation ;
- to avoid the human intrusions link to the utilization of soil (i.e interdiction of dwelling construction, opening of quarry, water drill on the site ...) ;
- to control and ensure the upkeep and the stability of repository structures and those intended to geotechnical monitoring (drains, basins of water collection...).

The surveillance period is an opportunity to improve the knowledge of the remediation efficiency and to learn more about the evolution of the repository (hydrology, geochemistry, mineralogy ...) in order to demonstrate the acceptable limit of the radiological impact.

The half-life of the radionuclides, 4.5 billion of years for ^{238}U , 75,000 years for the ^{230}Th and 1,600 years for the ^{226}Ra , imply that the assessment of the long term confinement capacity of the repository should be found on a forecast modelling, based on studies of long term evolution (erosion, pedology, geochemistry, mineralogy...) and on the return of experience acquired during the surveillance period.

This progressive process include several interactive steps :

- the description and the understanding of the repository evolution and its different barriers, including the remediation choices according to the radiological criterias previously definite ;
- the inventory and the identification of events or processes wich represent a potential risk of change for the host cavity and other repository structures ;
- the selection of plausible scenarios based on the selection of events and processes an describing the potential transfer pathways to man ;
- the analysis of the induces effects of the repository on the efficiency and the stability of dams and covers as well as on the hydrogeology of the site.

The methodology introduce here, particularly the definition of critical group and

exposure scenarios to be evaluated in the short, medium and long term, would make it possible to assess radiological impacts of uranium mill tailings repositories more objectively with regard to radioprotection objectives.