Science Centre
North Rhine-Westphalia
Institute of Work
and Technology

Institute for
Culture Studies
Wuppertal Institute for
Climate, Environment and
Energy

Comparison among different decommissioning funds methodologies for nuclear installations

Final Report

Technical Overview on Decommissioning of Nuclear Facilities in Europe

on behalf of the European Commission
Directorate-General Energy and Transport, H2

Service Contract TREN/05/NUCL/S07.55436

Wuppertal, 2007

Editor:

Wuppertal Institut für Klima, Umwelt, Energie GmbH
im Wissenschaftszentrum Nordrhein-Westfalen

NRW.

Hôtel d'entreprises 14 rue de la Hacquinière 91440 Bures sur Yvette (France) Tél : 00 33 1 60 19 54 86 Email : ben.ameur@neuf.fr	**REPORT TITLE** **Technical overview: Dismantling of nuclear facilities in the European Community**

REFERENCES CLIENT :

Customer: Wuppertal Institute for Climate, Environment, Energy
Contract number: TREN/05/NUCL/S07.55436

REFERENCES DOCUMENT	SUPPORT INFORMATIQUE
Doc: 05_10_CEE_Démantèlement_02	Système : Windows 2000 Logiciel : Word 2000

AUTHOR	VERIFICATION	APPROBATION
A. AMEUR		

EDITION	MODIFICATION	DATE
2	**FINAL REPORT**	31 October 2006

SUMMARY:

This report is centered on the technical aspects related to decommissioning - dismantling. It is part of the European Commission study "**Comparison among different decommissioning funds methodologies for nuclear facilities**" (Reference: Official Journal of the European Union No. S140 of 22/07/2005), co-ordinated by the Wuppertal Institute for Climate, Environment, Energy.

CIRCULATION:

SOCIETY OR ORGANISM	RECIPIENT
Wuppertal Institute for Climate, Environment, Energy	Irrek Wolfgang

CONTENTS

TABLES

1 CONTEXT

This report is part of the European Commission study "**Comparison among different decommissioning funds methodologies for nuclear facilities**" (Reference: Official Journal of the European Union No. S140 of 22/07/2005).
The **European Commission** (DG TREN, Unit H2, Nuclear Energy and Waste Management) has recently initiated this study to compare different decommissioning funds methodologies for nuclear facilities within the Member States of the European Union as well as in Bulgaria and Romania.
.
The main aims of this project are

- to take stock of the various current approaches followed in the EU Member States and accession countries to quantify the decommissioning costs;
- as a key point of the study, to analyse the risks relating to the various methods to set aside financial resources for decommissioning purposes, in particular from the financial point of view;
- to identify the stakeholders, their role and their motivations with regards the existing methodologies on quantifying decommissioning costs as well as constituting and managing decommissioning funds.

The Contractor for this study is a **consortium** lead by the Wuppertal Institut für Umwelt, Klima, Energie GmbH (D), and consists as partners Ellipson AG (CH), Antony Patrick Froggatt (UK), Kuhbier Law Firm (BE), PSIRU Public Services International Research Unit at the University of Greenwich (UK), VTT Technical Research Centre (FI), Ameur Sciences et Techniques (FR) and Mycle Schneider Consulting (FR). In addition, the consortium will take benefit from the services of the following subcontractors: AAPC (LT), AEKI (HU), Ian Smith (UK/RO), Öko-Institut eV (DE), and Energia2000 and its partner organisations Energia tretieho tisicrocia Kosice and Za Matku Zem (SK) (the last two organizations being sub-contractors of Energia2000).

Decommissioning is defined by the International Atomic Energy Agency [21] as the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility.
The use of the term 'decommissioning' implies that no further use of the facility for its existing purpose is foreseen. The actions taken in decommissioning need to be such as to ensure the protection of the work force and continuous protection of the public and the environment. This typically includes reducing levels of residual radionuclides so that material and buildings can be safely released and reused.

According to the document titled "TemplateDecommFundsCountry060313_Final" written by Wolfgang Irrek : "for the purpose of this study, decommissioning comprises all activities covering the technical decommissioning of the nuclear facilities (decontamination, dismantling and demolition) and waste management (management and disposal of radioactive waste and spent fuel) leading to the release of the nuclear facilities from radiological restrictions".

Then, one has to understand "dismantling" as related to equipment disassembly, and "demolition" as concerning buildings. In both cases, radioactive wastes induced are removed to storage or disposal facilities.

This report is centered on the technical aspects related to decommissioning – dismantling - demolition. As a matter of fact, the European Commission concentrates on facilities coming into the process of decommissioning and of dismantling, in particular from the point of view of the financial contribution to these operations needed for a safe decommissioning, considering the increasing number of facilities to be reformed.

More than 500 nuclear facilities were already built and operated worldwide and most of them are located in the Member States of the OECD-NEA.
Types of these facilities are :

- Gas-cooled reactor (GCR)
- Boiling water reactor (BWR)
- Pressurised water reactor (PWR)
- Pressurised heavy water reactor (PHWR)
- various types of demonstration facilities
    - High temperature reactor (HTR)
    - Fast breeder with fast neutrons cooled by a liquid metal (FBR)
- Conversion facilities,
- Enrichment plants,
- Fuel fabrication plants,
- Reprocessing plants,
- Waste management plants,
- Stores.

These facilities are designed to operate for a period of time. At the end of this period, what next ?
This question is the more crucial as, until 2002, only 80 of these facilities were put out of service, including the first demonstration facilities. Others among these will arrive to the time of their decommissioning and their dismantling. The European Commission estimates that 50 to 60 of the 155 reactors currently operating in the enlarged European Union will need to be decommissioned by 2025.

In appendix 1 are listed decommissioned facilities, or facilities being dismantled or facilities already dismantled for every relevant country of the European Community.

In this report, we aim:

- to describe the various strategies of dismantling which can be implemented by the Community, the States and the utilities; and what they imply from the technical point of view,
- to introduce various operations related to dismantling and the specific regulation associated to them.

2 ORIGIN AND NATURE OF CONTAMINATION

Nuclear industry consists of the following operations:

- Nuclear reactors,
- Nuclear fuel production facilities
    - Conversion facilities,
    - Enrichment plants,
- Nuclear reprocessing facilities (used fuel),
- Waste management plants,
    - Interim storage,
    - Final disposal facilities.

In a nuclear reactor, the only material transformed is the fuel. In other facilities, several other chemical reactions are involved, which makes the dismantling problem more complex.

2.1. CONTAMINATION FROM REACTOR OPERATION

In a nuclear reactor, the bulk contamination comes from the primary cooling system during normal operation or during unplanned events.
Several factors lead to contamination:

- fission products released by fuel cladding defects,
- corrosion and erosion products activation in coolant,
- primary cooling system leakage,
- outage and repair activities,
- fuel unloading operations,
- operation unplanned events,
- effluents and radioactive waste treatment and storage,

With regard to the radioactive inventories, great differences exist depending on the type of reactor [1]:

- for similar facilities, the greater the power, the greater is the neutron flux, and the greater are the quantities of activation products,
- the greater the burn-up rate and the operation periods, the greater is the probability of fission products escape, implying surfaces contamination.

We have to note that gas cooled reactors, because of their physical bulk, produce a large amount of waste compared to pressurized water reactors or boiled water reactors, which are more compact. The cost of waste disposal in facilities is not well established, especially for intermediate level waste and long-lived low-level waste because of the lack of experience in building facilities to take this waste.

Contamination usually accumulates on facility and systems surfaces. Contamination penetration is not deep except for concrete. Two occurrences are possible [1]:

- it is possible to get rid of contamination by simple mechanical means,
- fixed contamination needs more aggressive means.

Material activation produces radionuclides inside the matter, so that the heart of the matter is contaminated. Getting rid of this type of contamination means getting rid of this material. Surface cleaning is not enough.

Activated elements could be contaminated by other radionuclides. On the other hand, contaminated surfaces cannot be activated if far from neutron flux.

Fission products and actinides concentration in residual contamination vary from one facility to another.

2.1.1 Internal circuits contamination

Radioactive matter able to be released and dispersed from any source inside primary cooling system or any other system is internal circuits contamination [3].
For example, fission products released from fuel rods can be transported by coolant along the primary cooling system.
These products get along internal circuit surfaces and stay there until the end of the facility life.
Fuel defects can occur during operation cycles, due to any cause from manufacture defects to mechanical or abrasion damage.

2.1.2 External circuits contamination

External contamination is generated by primary cooling system vapor leakage. This can occur as aerosol dispersion [3]. It can be either fixed or not, once incorporated in materials through their surfaces.
Suspended contamination can lead to wall, ceiling and ventilation system deposit.

2.1.3 Concrete contamination

Reactor building is usually contaminated by primary cooling system vapor in operation.
Activation can occur from surface to important depths. For example, in belgian BR-3 reactor, concrete has been activated until 60 cm deep, mainly Co-60 [1].

2.2. CONTAMINATION FROM OTHER NUCLEAR FACILITIES THAN REACTORS

Contamination is a generic problem: the physical processes involved are the same. But in the other facilities:

- chemical reactions and nuclear reactions might interact,
- the facility design looks more like a laboratory design, leading to unrecorded building and operation modifications,
- unplanned events (incidents, accidents) are not recorded,
- wastes are of several different types and less manageable.

In reprocessing, enrichment and conversion plants, the greater contamination is due to alpha radiation because the only matters handled are alpha emitters.
Criticity events excepted, safety problems are not the same in reactors and in fuel cycle facilities because in the lattest the three barriers are lacking.
As a consequence, dismantling operations are harder and more complicated in these facilities.
In storage facilities, only leakage may lead to contamination risks.

3 NUCLEAR WASTE

Nuclear wastes can be listed like:

- process waste, related to processing, used reagent and processed material
- technological waste, all the tools and equipments used in nuclear facilities for intervention and maintenance
- particular waste like graphite sleeve, reprocessing waste, cladding waste
- decommissioning waste

A widely used qualitative classification system separates radioactive waste into three classes: low level waste (LLW), intermediate level waste (ILW) and high level waste (HLW). A further distinction is made between short lived and long lived waste. These classes address activity content, radiotoxicity and thermal power. The differentiation between the long and short-lived radionuclide content is made to assist in the choice of the appropriate type of repository. This system mainly serves the purpose of facilitating international communication.

3.1. LOW LEVEL WASTES (LLW)

Waste that, because of its low radionuclide content, does not require shielding during normal handling and transportation. In other terms, wastes other than those suitable for disposal with ordinary refuse but not exceeding specified levels of radioactivity**.**
Most LLW can be sent for disposal at a near surface disposal facility. LLW unsuitable for disposal is mostly reflector and shield graphite from reactor cores, which contains concentrations of carbon-14 radioactivity above those acceptable at a near surface disposal facility.

3.2. INTERMEDIATE LEVEL WASTES (ILW)

Wastes exceeding the upper boundaries for LLW, but which do not need heat to be taken into account in the design of storage or disposal facilities. Waste which, because of its radionuclide content requires shielding but needs little or no provision for heat dissipation during its handling and transportation
The major components of ILW are metal items such as nuclear fuel casing and nuclear reactor components, moderator graphite from reactor cores, and sludges from the treatment of radioactive effluents.
Non-heat generating waste is stored in tanks, vaults and drums. In time it will be retrieved, and packaged as ILW by immobilizing the wastes in cement-based materials within stainless steel drums, or for large items in higher capacity steel or concrete boxes.

3.3. HIGH LEVEL WASTES (HLW)

Wastes in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities.
HLW comprises :

- the highly radioactive liquid, containing mainly fission products, as well as some actinides, which is separated during chemical reprocessing of irradiated fuel (aqueous waste from the first solvent extraction cycle and those waste streams combined with it. These waste products arise in the form of highly radioactive nitric acid solutions which are being converted into borosilicate glass within stainless steel canisters)
- any other waste with radioactivity levels intense enough to generate significant quantities of heat by the radioactive decay process,
- spent reactor fuel, if it is declared a waste

4 DISMANTLING STRATEGY AND ORGANISATION

4.1. DISMANTLING STRATEGIES

There is not only one way to decommission or dismantle nuclear facilities. It depends on several parameters and framework conditions, decommissioning stage aimed and of future use of the site. Operators of nuclear facilities usually take radiation protection, employment and financial aspects into account when deciding on a decommissioning strategy.
From the perspective of radiation protection, there is one major argument for deferred decommissioning, which is radioactivity decay thus dose rate reduction for workers.

There are 3 dismantling strategies [1, 16]:

- Decontamination and dismantling immediately after operation period. Every material contaminated is cleaned until no more regulatory control is required. It is then dismantled as soon as the end of operation period.
- Safe storage (deferred dismantling). The nuclear plant is kept intact and placed in protective storage for long enough so that radionuclides activity decays and reaches satisfactory level. First of all, spent fuel is removed from the facility. Plant is then put and kept in a safe and stable state, until actual decontamination and dismantling. During this period, All remaining fluids are drained from the systems and adequately treated. Radionuclide activity decaying keeps going in order to minimize radioactive and contaminated materials to be evacuated.
- Entombment. This option involves encasing radioactive structures, systems and components in a long-lived substance, such as concrete. The encased plant would be appropriately maintained, and surveillance would continue until the radioactivity decays to a level that permits termination of the plant's license and end any regulatory control. Most nuclear plants will have radionuclide concentrations exceeding the limits for unrestricted use even after 100 years. Therefore, special provisions will be needed for the extended monitoring period this option requires. To date, no facility owners have proposed the entombment option for any nuclear power plants undergoing decommissioning. This option is, in fact, similar to declaring the site as a shallow land burial site. In fact, this is not a strategy it is an emergency option used only in the case of Chernobyl accident.

A mix of parts of these strategies is, however, possible.

The first two strategies rely on:

- removing :
    - all fuels (spent or fresh) in the case of nuclear plants,
    - all radioactive material stored for any use.
- decontaminating buildings surfaces, tools and equipment.

These two tasks achieved, the following important accident risks can be considered reduced:

- workers radiation exposures,
- or environment unplanned radioactive releases during demolition and disassembly tasks.

Nevertheless, removing and decontaminating can lead to:

- higher exposures than those occurring during normal operation,
- increase minor accident risks and unexpected situation probability.

Disassembly and demolition unfortunately lead to radioactive release. Exposure rates might then be higher than those expected during usual operation. Accidental release of toxic or dangerous substances probability is higher as well.
All this shows how dismantling work should be realized cautiously and only after thorough and planned preparation with detailed procedures. Nothing should rely on random.

4.2. ORGANIZING DISMANTLING

Once a strategy chosen and adopted, dismantling tasks have to be organized.
Experience shows that those tasks requirements and waste management should be:

- Taken into account as soon as nuclear plant conception begins,
- Monitored and put up to date at any change either in operation management or facility modification.

IAEA underlines that:

- dismantling requirements should be considered as soon as conception stage for new nuclear power plant and as soon as possible for plants in operation [18].
- And requires as well that dismantling detailed planning should begin 5 years before strategy choice and its realization [17].

Following IAEA position, OECD-NEA [16] states that decommissioning projects and procedures are key elements for nuclear plant conception, authorization and operation.
Dismantling experience feedback should be taken into account for next dismantling and new nuclear plant conception.
For example, although reactors are in operation, Finland required at the beginning of the 80's that dismantling programs be reviewed and updated every 5 years [1] in order to keep facility technical memory.

OECD/NEA current orientations are such that in most of member countries, decommissioning projects should be [16]:

- established before operation authorization is granted
- and controlled in the inspection framework operation life along.

As a consequence, utility should not be in such a position as to improvise during dismantling stage. Dismantling plans should be established during operation, long before the dismantling stage itself. Nevertheless, after the shut down of a facility, these plans have to be reconsidered and more detailed plans have to be developed.

2 surveys are in progress [16]:

- one about actual regulations in state members,
- another about new international regulation criteria and regulatory supervision .

At worldwide scale, question is about current rules adequacy with effective facility safety during the time between end of operation and closing, even if delays occur [16].

4.3. EXAMPLE OF DISMANTLING PHASES REACTOR

The different phases in an usual dismantling process are presented below (German example from a [22]):

1. Operational phase of the plant
2. Final shutdown
3. Intermediate phase between operation and decommissioning: Fuel elements and operational waste are removed from the plant
4. Start of dismantling with decontamination of the primary system (optional) and dismantling of inactive parts
5. Dismantling of contaminated parts
6. Remote-controlled dismantling of activated parts, reactor pressure vessel, biological shield, activated building structures
7. Decontamination of the buildings
8. Measurements for the release of the total plant from nuclear regulatory control

9. Release of the facility from the scope of the national nuclear energy law (clearance)
10. Conventional demolition of the buildings

4.4. RADIATION KNOWLEDGE MANAGEMENT BEFORE DISMANTLING

Since no facility is leak proof, contamination is dispersed inside and outside.

Concerning dismantling organization, IAEA [1] insists on:

- getting a knowledge as complete as possible on neutron activation facility history and contamination levels linked to operation states and transients,
- and activity assessment at the end of operation.

To get knowledge, one has to establish [1]:

- knowledge on how the reactor was operated, knowing :
  - Effluents detection and unplanned contaminant dispersions,
  - Analysis of exposure rates measured during regulatory controls, outage, repair period…
  - Analysis of exposure rates when handling heavily contaminated parts,
  - Fuel damage rate inside primary cooling system,
  - zones where radionuclides dispersed,
  - ion exchange resin contamination,
- computer code assessment of reactor activity and of its close vicinity,
- sampling in every room near the reactor and measure of activity and concentration of radionuclides.

The table below summarizes the needs and methods for contamination knowledge [3]:

Contamination knowledge needs	collection methods
1 Radiation dose (α, β, γ) or exposure rate	Direct radiation measurement, precision level, air monitoring
2. Contamination fixed or not on surfaces	Samples and smear analysis correlated with radiation measurements
3. Radiation sources scanning, hot contamination spots	Direct radiations scanning, time evolution description
4. Contamination penetration in walls and floor volume	Scanning and sampling analysis
5. Ground contamination level under facility and around	Ground samples analysis, time evolution description

Table 1: radiation knowledge management before dismantling

5 DECONTAMINATION AND DISMANTLING TECHNIQUES

5.1. OVERVIEW

Decontamination is defined as the removal of contamination from surfaces of facilities or equipment by washing, heating, chemical or electrochemical action, mechanical cleaning, or other techniques. An extensive decontamination program may often require a facility capable of treating secondary waste from decontamination (processing chemical solutions, aerosol, debris,…)

The following scheme gives an overview of when, where in the facility and how decontamination techniques are used in dismantling [19]

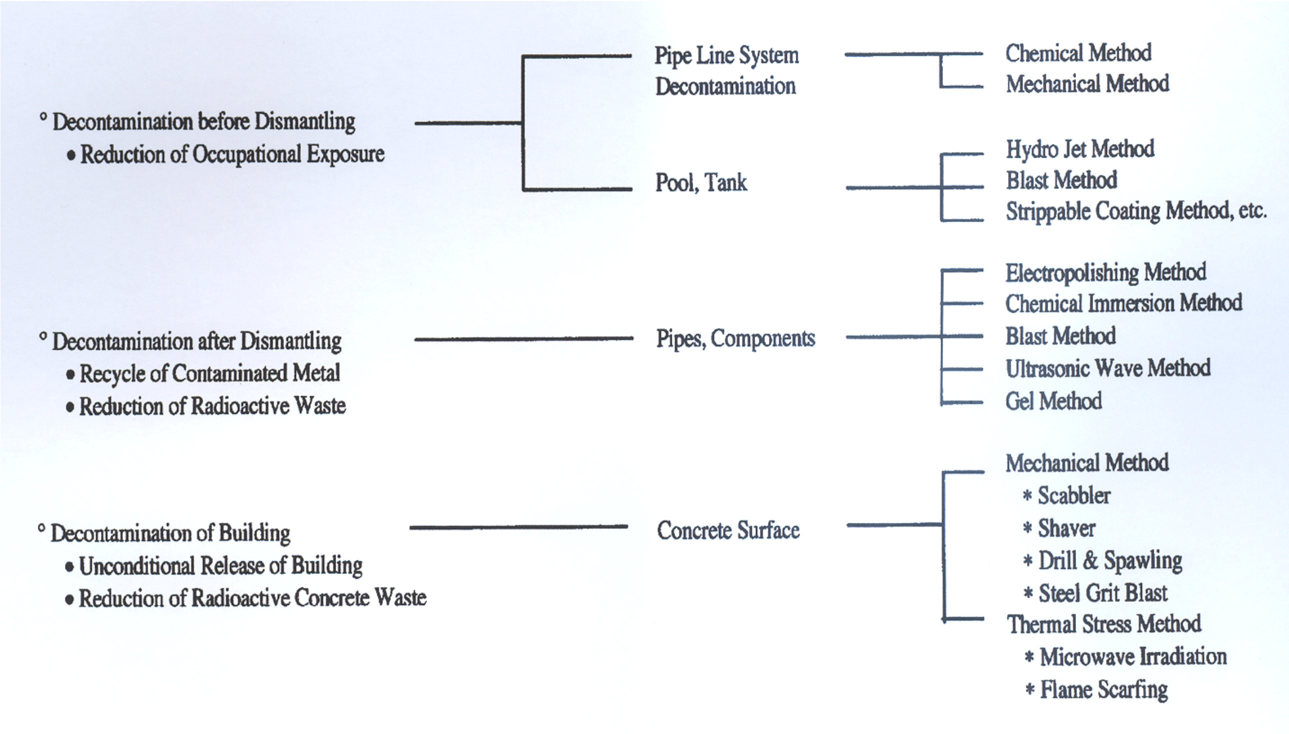

Table 2 : Situation of decontamination techniques in dismantling stages

In the following, the report deals with risk assessment, detailing different ways of exposure for workers. Then, we insist on weakness of scale factors to determine α risk, because nowadays it is considered as the major one on dismantling field. Finally, we end with a presentation of decontamination and dismantling techniques.

5.2. RISKS ASSESSMENT

Risks to which workers are exposed during dismantling fall into 2 categories:

- irradiation risk because of ionizing radiations exposure,
- contamination risk because of incorporation (inhalation and ingestion).

Incorporation may occur through [1]:

- aerosols inhalation of radioactive particles due to activated circuits leakage, outage,
- wounded skin transfer,
- mouth ingestion in an α emitters contaminated zone.

As a matter of fact, contrary to β and γ rays, α rays exposure is not external. The only risk is due to internal exposure following ingestion of particles containing α radionuclide emitters.
On dismantling sites, one looks for α ray sources because of internal contamination risk, through respiratory way.
Irradiation protection is better managed, since it relies on shielding, minimizing exposure time, or getting away from sources.
But inhalable dusts or aerosols could convey β and γ rays, the risk being thus comparable to α risk.

For instance, if a nuclear power plant unit had strong fuel matter dissemination during one operation cycle, then dry air measurement analysis results would be :

- for collected aerosols:

- Mainly particles of diameter < 1 µm (inhalable particles),
- Otherwise, particles of diameter > 10 µm.
- particle size analysis shows that α emitters and γ emitters have almost the same distribution.

On a dismantling site, α emitters radiotoxicity is 1 000 to 5 000 more important than β emitters' one [1].
The main current problem for α contamination is to assess suspension factor, relying on surface contamination to determine volume contamination inhalable or ingestible. Suspension factor describes contaminants transfer from surface to volume. It is defined as[1]: $K\ (m^{-1}) = \frac{\text{volume activity or concentration}}{\text{surface activity or concentration}}$

5.3. α ASSESSMENT METHOD

α emitters determination can be achieved through β emitters or γ emitters. Determination is based on ratio between β or γ activity and α, usually called scaling factor. Measured β or γ emitters must be fission products with [6]:

- a half life, long enough,
- similar chemical properties (solubility, mobility,…)
- easy detection and quantification through γ spectrometry,
- constant ratio with α emitters, not time-dependant, representative of the place, the system or the element in the facility.

Cs-137 and Co-60 emitters are often taken as referent radionuclides to assess α emitters. Scaling factors are based on them. However, according to EPRI, Cs-137 is not a good choice due to high mobility and solubility [5]. Nevertheless, in France, EDF still uses it as an α indicator.

Most used scaling factors are: Ni-63/Co-60, Mo-93/Co-60, Tc-99/Co-60, Sr-90/Cs-137, I-129/Cs-137

Once the conditions described are granted, scaling factors determination are made by point samplings where possible. Samples are analyzed at different periods in order to ensure their representativeness.
α evaluation relies on this scaling factor.
According to EPRI[2] [6],

- if scaling factor > 50, then β or γ ray activities may be used to assess α activity,
- if scaling factor < 50, then α activity is searched radionuclide by radionuclide. This way is tiresome, dangerous and costly.

Minimum α activity to be detected needs a β or γ activity as strong as 833 Bq, which implies a dangerous exposure for the worker making measurements.

α assessment must be made before following listed operations given as example :

- work on external active parts of the primary cooling system,
- work on apparatus directly in contact with spent fuel,
- spent fuel repair,
- work in spent fuel pool,
- removed materials from spent fuel pool,
- leakage on any component of the primary cooling system or linked systems,
- work on effluent systems,
- work on apparatus directly in contact with cooling fluid ,
- work on decontamination and analysis cells,

[1] "Particle resuspension : a review", par George A. Sehmel , Environmental International, 1980, volume 4 pp 107-127
[2] EPRI : Electric Power Research Institute

- cleaning work (tanks, concrete…)
- wherever there is a doubt about "α presence"

When measurements assess α emitters' presence (> to detection threshold), works are labeled "α presence" whatever the detected surface α contamination is.

5.4. EMPLOYED TECHNIQUES

Decontamination and dismantling techniques already exist. Nevertheless, it is often necessary to mix and adapt several techniques according to the specificity of the facility to dismantle.
On conception stage, one tries to select materials easing the use of these techniques. For example, nowadays, one insists on diminishing or even eliminating grit likely to be activated, like cobalt inside concrete or steel.
Techniques employed in the dismantling field are the same as in the conventional industry except that in the nuclear field one has to cope with an exceptional toxic and radioactive environment. Those techniques have been demonstrated successfully on a small scale but until they are applied to a large scale plant, the process can not be seen as proven.
From now on, it is very important to share feedback experience about these techniques applied to bigger facilities throughout the decommissioning-dismantling industrial sector. This knowledge should be integrated to new conception or decommissioning-dismantling projects [16].

The following table concerning decontamination is excerpted from [19].

METAL DECONTAMINATION	Closed systems	Open systems
Chemical processes		
• Oxidation processes		
– ODP/SODP	×	
– Cerium/Sulphuric acid		×
– Cerium/Nitric acid		×
• Oxidation-reduction processes		
– APCE/NPOX	×	×
– TURCO	×	×
– CORD	×	×
– CANDEREM, CANDECON		×
– CONAP		×
– AP/NP + LOMI for PWR	×	
– EMMA	×	
• LOMI for BWR	×	
• Phosphoric-acid-based processes		×
• Foams	×	
• Various reagents		
– HNO_3		×
– HNO_3 + HF	×	×
– HNO_3/NaF	×	×
– HCl	×	×
– DECOHA		×
Electrochemical processes		
• Phosphoric acid		×
• Nitric acid		×
• Nitric acid - Electrodeplating		×
• Sodium sulphate - ELDECON Proc.		×
• Oxalic acid		×
• Citric acid		×
• Sulphuric acid		×
• Other electrolytes		×

METAL DECONTAMINATION	Closed systems	Open systems
Physical processes		
• Ultrasonic cleaning		×
• High pressure water		×
• CO_2 ice blasting		×
• Ice water		×
• Freon substitutes		×
• Abrasives wet	×	×
• Abrasives dry		×
• Grinding/Planing		×
Combined mechanical/Chemical processes		
• Pastes + HP cleaning		×
• Foams/Gels/HP cleaning		×
• Vacuum cleaning (Dry/Wet)		×

CONCRETE DECONTAMINATION	Surface decont.	Concr. demol.
• Kelly process	×	
• Scabbling	×	
• Sand blasting	×	
• Wet abrasives	×	
• Milling	×	
• Explosives		×
• Microwaves	×	
• Drill/Spalling		×
• Drill/Lime expansion		×
• Jackhammer		×

× : decontamination technique applied for open or closed systems.

Table 3 : Decontamination processes

Most important techniques necessary to achieve a wide range of dismantling operations are listed below [1, 2, 17] :

- **decontamination techniques** are used to clean metals, concrete and other surfaces. Usually, surfaces are decontaminated by smear, wash, sprinkle or bath, thanks to chemical, mechanical or thermal processes or a combination. To get rid of upper surface layers of oxide and residues deposited while reactor was in operation, these techniques are mostly employed. For instance, to get rid of upper layers on internal primary cooling system surfaces, was used a two steps chemical process :
    - $KMnO_4$ oxidation with nitric acid,
    - oxalic acid reduction

For belgian BR-3 reactor, having employed these techniques, decontamination effects are summarized in the table below [1]:

Bq/cm^2 Co-60	Before decontamination	After decontamination
Surfaces of contaminated parts	10 000 to 20 000	400 to 1 000

Table 4: Decontamination effects

Let us note that decontamination should take place right after end of operation to benefit the best dose optimization [8].

- **Cutting techniques** rely on classical principles, mechanical (sewage…), thermal (blowtorch, TIG, plasma…), explosives...
  For the same belgian BR-3 reactor, Once the primary cooling system decontaminated, thermal protection was cut, thanks to the following 3 techniques [1]:
    - mechanical cut, (milling)
    - electrical discharge machining
    - plasma cut.

  For example,
    - "Vulcain" internal components were cut with mechanical techniques, milling and sewage [1].
    - The nuclear vessel was cut under water in the fuel loading pool. 2 problems were posed [8] :
        - Concerning pool tightness, it was impossible to position the sealing devices due to some discrepancies between the as built drawing and the field reality,
        - Components corrosion was such, that it was impossible to find screwheads

  Additional filtration and purification facilities were installed to solve turbidity problem (due to thermal insulation corrosion around nuclear vessel) of the pool and allow work resuming.

- **Remote controlled techniques** are employed to work at distance from sources or behind a protection screen:
    - remote handling machines
    - semi-automatic tools allowing people to work at distance from radioactive sources
    - lifting and handling apparatus to take remote controlled system on working radioactive zones, while keeping them tight.

- **Protection techniques for workers and environment** :
    - removable temporary shields ;
    - temporary lock chambers and cells ;
    - mobile ventilation and filtration systems ;
    - special gears (ventilated suits, masks, etc.).

- **Waste treatment and transformation techniques** in accordance with rules and transportation standards. These techniques take into account procedures of gas effluent filtration and liquid effluent treatment.

6 RISKS PREVENTION

Prevention basic principles are [1]:

- keep contamination tight in the source vicinity,
- permanent containment,
- protect workers with adapted suits, dressing with care, undressing with care while in the lock chambers,
- global radioactivity monitoring of the facility, particularly air contamination monnitoring and control in buildings and periodical surface contamination control of access and inside roads,
- individual medical monitoring and medical file update by physicians,
- effluents and waste from radioactive zones sorting out and management,
- tools and apparatus used where α emitters were present are to be checked-up and separated from others and decontaminated.

6.1. INDIVIDUAL AND COLLECTIVE PROTECTIONS

During dismantling, one can not rely on existing purifying and ventilation systems put out of order. But, taking into account the existing system status, one designs a stationary or mobile device to purify or ventilate. These devices combine collective and individual protections.

6.1.1 Collective protection

6.1.1.1 Dynamic containment

Dynamic containment catches contamination at its emission source. The device is made :

- either with a false cap,
- or with a specific depresser.

These 2 elements have to be equipped with VHE (very high efficiency) filter, and when iodine is present on site, active charcoal filter must be added [1]. Let us note that active charcoal filter effective only in dry conditions, being very susceptible to humidity.

Concerning the specific depresser, catching mouth should be placed as close as possible to emission source. As a matter of fact, the efficiency of a catching mouth is inversely proportional to the mouth-source distance.
For a distance over several mouth diameters, efficiency is almost zero.

At the exit of the work site and to control contamination, workers are monitored by a contamination meter [1].
Dynamic containments should be tested before put in service. These tests can be realised with fumes [1].

6.1.1.2 Stato-dynamic containment

Stato-dynamic containment system keeps working zone depressed. Aspiration depresser device is equipped with VHE filter plus active charcoal filter specific to iodine risk. Moreover, if works takes place in no ventilated zone, a second VHE filter is added.

6.1.2 Individual protection

On work sites where "α presence" is confirmed, workers have to put over basic gear, protection suit and respiratory protection (mask, independent ventilated suit) [1].
Protection suit gears are:

- vinyl gloves,
- vinyl over-boots,
- over-suit.

Over a pollution level threshold, workers are to wear a respiratory protection. And over a higher one, independent ventilated suit is required [1].

7 CONCLUSION

This report is an overview about dismantling nuclear facilities; it is related to the following subjects:

- origin and nature of contamination in nuclear facilities,
- scaling factor to quantify α contamination in dismantling work
- the choice among dismantling strategies,
- the work organization during dismantling stages,
- the selection of techniques and tools
- workers health and protection,

The relevant points by subject are underlined below:

- about origin and nature of contamination
    - in nuclear reactors, the three types of contamination exist and we have to take them into account in dismantling. Nowadays, inhalation and ingestion risk is based only on α rays exposure probability. But it is obvious that β or γ particles should be considered as well when they are associated to inhalable dust or aerosols. To take into account β/γ ingestion and inhalation risks, one has to know the dust loading, size and dispersion of aerosols in dismantling work,
    - in reprocessing, enrichment and conversion facilities, manipulated materials are α emitters so, the major contamination expected is due to α particles,
    - in waste storage, contamination comes from leakage. We do not have enough feedback, especially for the two most dangerous categories. And since these categories are not well known, it is very difficult to assess future waste storage facilities' cost. If end-user is compelled to pay for waste treatment, since one has already paid waste provision on electricity bill (French case), at least one will ask for detailed information and for safety guarantee on waste treatment facility operation,
    - most scientific publications concerning dismantling deal with reactors. Only few of them deal with other facilities,

- about scaling factor,
    - α determination for dismantling work is based on scaling factors relied on Co-60 or Cs-137 evaluation. These radionuclides, especially Cs-137, have mobility and solubility which do not allow assessment reproducibility.

- about dismantling strategy,
    - it is described like a general outline to be done. No further detail for field intervention is given. Among the 3 possible major decommissioning strategies, only dismantling as soon as facility closes, remains credible with regard to information needs in order to dismantle. To choose dismantling strategy, one makes assumption that a perfect knowledge of facility operation history is available. This is a major difficulty for old facilities as well as younger with regard to required detail to choose and to plan dismantling. This is practically impossible for reprocessing facilities and nuclear laboratories. It would be better to assume that additional knowledge has to be gained and secured based on qualified workers interviews and, as far as possible, by having experienced workers taking part in the decommissioning activities. This only first option seems credible because civil society is more vigilant about its future and next generations' one to let facilities in expectative. In all cases, it is important, as soon as nuclear facility closes,
        - to remove fuel and decontaminate cooling system in the case of the reactor ,
        - and to remove radioactive materials and decontaminate process systems in the other cases,

- about dismantling organization
    - before choosing organization, one has to update building "as-built" maps considering what has actually be done and taking into account what was modified along any facility's life,
    - bibliography shows lack of standards and procedures like those existing for construction (RCC in France, ASME in USA…)
    - the dismantling method choice is free and relies on the utility know-how. This underlines discrepancies between nuclear facility construction stage and dismantling stage, where there are no written procedures. The only applied procedure is dosimetry optimization (dose management and ALARA principle)
    - dismantling, being a recent activity in nuclear field, shows a lack of written procedures. One assumption to explain lack of information published on the subject is that most dismantling works were realized by sub-contractors who do not publish their know-how. These rules have to be actually written,
    - Although plans exist, experience shows that they are rarely thoroughly followed. EC position could then consist in : standardizing strategies and procedures, ensuring strict application of planned and written rules and procedures.
    - when planning dismantling, the European Community could be useful in organizing information and feedback sharing between member states. Let us note that all these countries are already linked by Euratom treaty. The latest states that the European Community is responsible for enacting public health rules against ionizing radiations as uniformly as possible [16]

- about techniques and tools used in dismantling,
    - techniques used in dismantling only consists in adaptation and mix of existing techniques. As an example, improvement may be realized through remote control or systematic trials with proven techniques. There is no research about dismantling techniques, but getting from small scale to large scale. Dismantling techniques are still not proven for a large-scale plant,
    - no complete reactor dismantling experience has been published in detail yet,

- about protection
    - concerning individual protection, we have to note that paper or ventilated clothes reduce worker comfort. For example, working 45 minutes with paper clothes generate anoxia. Then, if worker continue his job after this period, he has to corrupt his protection.

8 ANNEX : MAJOR EUROPEAN REACTORS IN COURSE OF DISMANTLING

Country	Name	Type	Operation	Stage	Comments
Belgium	BR3 Mol	REP	1962-87	-3	Small power reactor
Denmark	DR-2	DR	1959-1975	2	Building re-used
France	G1 Marcoule	GCR	1956-68	3*	Small power reactor
	G2 Marcoule	GCR	1959-80	-2	Small power reactor
	G3 Marcoule	GCR	1960-84	-2	Small power reactor
	Bugey	GCR	1972-94	-2	Large power reactor
	Chinon-A1	GCR	1963-73	1,a	Small power reactor
	Chinon-A2	GCR	1965-85	-2	Large power reactor
	Chinon-A3	GCR	1966-90	-2	Large power reactor
	Chooz A	PWR	1967-91	-2	Large power reactor
	St Laurent A1	GCR	1969-90	-2	Large power reactor
	St Laurent A2	GCR	1971-92	-2	Large power reactor
	EL 4 Monts d'Arrée	HWR	1969-90	-3*	Small power reactor
	EL 2 Saclay	HWR	1952-65	3*	Small power reactor
	EL 3 Saclay	HWR	1957-79	3*	Small power reactor
	PEGASE Cadarache	PWR	1963-74	3,b	Small power reactor
	RAPSODIE Cadarache	FBR	1967-83	-2	Small power reactor
	TRITON Fontenay	PR	1959-82	3	Small power reactor
	MELUSINE Grenoble	PR	1958-88	-2	Small power reactor
	MINERVE Saclay	LW-PR	1954-76	3*	Small power reactor
	ZOE Fontenay	HW	1948-75	3,a	Small power reactor
	NEREIDE Fontenay	LW-PR	1959-82	3	Small power reactor
	PEGGY Cadarache	GCR	1961-75	3	Small power reactor
	CESAR Cadarache	-	1964-74	3	Critical Assembly

Country	Name	Type	Operation	Stage	Comments
	MARIUS Cadarache	-	1960-83	3	Critical Assembly
	ELAN II B La Hague	-	1970-73	-2	Source fabrication plant
	ELAN II A La Hague	-	1968-70	3*	Pilot plant for Elan II B
	SUPERPHENIX	FBR	1986-98	-1	Large power reactor
Germany	HDR Grosswelzheim	BWR	1970-71	-3	Large power reactor
	KKN Niederaichbach	HWR	1973-74	-3	Large power reactor
	KRB A Gundremmingen	BWR	1967-77	-3	Large power reactor
	KWL Lingen	BWR	1968-77	2	Large power reactor
	MZFR Karlsruhe	HWR	1966-84	-3	Large power reactor
	VAK Kahl	BWR	1962-85	-3	Large power reactor
	AVR Jülich	HTR	1969-88	-1	Large power reactor
	THTR 300 Hamm-Uentrop	HTR	1987-88	-1	Large power reactor
	KKR Rheinsberg	PWR	1966-90	-3	Large power reactor
	KGR 1 Greifswald	PWR	1974-90	-3	Large power reactor
	KGR 2 Greifswald	PWR	1975-90	-3	Large power reactor
	KGR 3 Greifswald	PWR	1978-90	-3	Large power reactor
	KGR 4 Greifswald	PWR	1979-90	-3	Large power reactor
	KGR 5 Greifswald	PWR	1989-90	-3	Large power reactor
	KNK-II Karslruhe	FBR	1979-91	-2	Large power reactor
	KWW Wurgassen	PWR	1975-94	0	Large power reactor
	Otto-Hahn ship reactor	PWR	1968-79	3	Small power reactor
	FR-2 Karlsruhe	HWR	1961-86	2	Small power reactor
	FRJ-1 Merlin Jülich	PR	1962-85	-2	Small power reactor
	RFR Rossendorf	PR	1957-91	-3	Small power reactor
	FRN TRIGA III Neuherberg	TRIGA	1972-82	2	Small power reactor
	FRF-2 Frankfurt	TRIGA	1977-83	2	Small power reactor

Country	Name	Type	Operation	Stage	Comments
	FRG-2 Geesthacht	PR	1963-95	-3	Small power reactor
	SNEAK	-	-	-	Fast critical assembly
	SNR	FBR	-	-	Small power reactor
Italy	Garigliano	BWR	1964-78	-2	Large power reactor
	Latina	GCR	1963-86	-2	Large power reactor
	Caorso	BWR	1978-86	-1	Large power reactor
	Trino	PWR	1964-87	-1	Large power reactor
	Avogadro Compes	PR	1959-71	2,b	Small reactor plant
	ISPRA-1 (EU)	HWR	1958-74	-2	Small reactor plant
	Galileo Galilei,Cisam,Pisa	PR	1963-80	2	Small reactor plant
	ESSOR Ispra (EU)	HWR	1967-83	-2	Small reactor plant
Netherlands	Dodewaard	BWR	1968-1997	0	Small power reactor
Spain	Vandellos 1	GCR	1972-89	-2	Large power reactor
	JEN-1 Madrid	PR	1958-87	1	Small reactor plant
	ARBI Bilbao	Arg	1962-74	1	Small reactor plant
	ARGOS Barcelona	Arg	1963-77	-3	Small reactor plant
	CORAL Madrid	FBR	1968-88	3	Small reactor plant
Sweden	Barsebäck 1	BWR	1975-99	0	Large power reactor
	Agesta	HWR	1964-74	1	Small power reactor
	R1 Stockholm	GR	1954-70	3	Zero power research reactor
	KRITZ Studsvik	PWR	1959-75	3	Zero power research reactor
United Kingdom	DFR Dounreay	FBR	1963-77	-1	Large power reactor
	PFR Dounreay	FBR	1975-94	-1	Large power reactor
	WAGR Windscale	AGR	1962-81	-3	Large power reactor
	SGHWR Winfrith	HWR	1968-90	-1	Large power reactor
	Berkeley 1	GCR	1961-89	-2	Large power reactor

Country	Name	Type	Operation	Stage	Comments
	Berkeley 2	GCR	1961-88	-2	Large power reactor
	Hinkley Point A	GCR	1965-2000	-1	Large power reactor
	Hunterston A1	GCR	1964-90	-2	Large power reactor
	Hunterston A2	GCR	1964-89	-2	Large power reactor
	Trawsfynydd 1	GCR	1965-93	-2	Large power reactor
	Trawsfynydd 2	GCR	1965-93	-2	Large power reactor
	Windscale Pile 1	GR	1950-57	-2d,e	Small power reactor
	Windscale Pile 2	GR	1951-58	-2e	Small power reactor
	Merlin Aldermaston	PR	1959-62	1	Small power reactor
	BEPO Harwell	GR	1948-68	2	Small power reactor
	DMTR Dounreay	HWR	1958-69	1	Small power reactor
	DRAGON Winfrith	HTR	1965-76	1	Small power reactor
	ZEBRA	-	1967-82	2	Fast critical assembly
	DIDO Harwell	HWR	1956-90	-1	Small power reactor
	PLUTO Harwell	HWR	1956-90	-1	Small power reactor
	GLEEP	GR	1947-90	2	Small power reactor
	NESTOR	Arg	1961-95	1	Small power reactor

Table 5: Dismantling reactors in the European Community

GCR	Gas-cooled reactor
HWR	Heavy Water moderated reactor
PWR	Pressurised water reactor
PR	Pool type reactor
FBR	Fast-breeder reactor
BWR	Boiling water reactor
HTR	High temperature reactor
Arg	Argonaut type reactor
AGR	Advance gas-cooled reactor
GR	Air-cooled graphite reactor

0	Decommissioning announced
1	Decommissioned to stage 1
2	Decommissioned to stage 2
3	Decommissioned to stage 3
3*	Decommissioned to stage 3 without civil engineering

-x	Decommissioning in progress towards stage x

According to AIEA "Organization and management for decommissioning of large nuclear facilities" Technical reports series n°399, AIEA December 2000 (p75, Annex A –3, table 1), stages are defined such as follows :

Stage	Definition	Reactor phase	Typical research activities
Stage 1	Storage with surveillance, removal of fuel, fluids and other mobile radioactive sources.	Phase 1	Remove fuel and heavy water from the facility. Shut down facilities/systems to provide a safe, secure monitoring/surveillance state. Decontaminate the fuel bays complex
Stage 2	Restricted site release. Dismantling of service systems and securing isolation of reactor and contaminated process systems.	Phase 2	Dismantle and decontaminate in order to remove significant accessible sources, secure reactor and remaining contaminated process systems
		Phase 3	Deferment period
Stage 3	Unrestricted site use. Removal of reactor and remaining contaminated/activated materials.	Phase 4	Removal of reactor and remaining contaminated systems. Decontamination of site to meet use or release requirements.

9 REFERENCE:

N°	Auteurs	Année	Titre et édition
1	AIEA	1998	Radiological characterization of shut down nuclear reactors for decommissioning purposes, technical report series n° 389
2	AIEA	1999	State of the Art Technology for Decontamination and Dismantling of Nuclear Facilities, Technical Reports Series n° 395
3	DOE	1994	Decommissioning handbook, DOE/EM-0142P
4	DOE	1999	A radiological survey approach to use to decommissioning : results from a technology scanning and assessment project focused on the Chernobyl NPP, PNN-13060
5	EPRI	2000	Decommissioning technology experience reports, n°1000884, décembre 2000
6	EPRI	2001	Program considerations for addressing α emitting radionucleides at nuclear power plants, n° 1003126, novembre 2001
7	EPRI	2002	Guide to assessing radiological elements for license termination of nuclear power plants, n° 1003196, juin 2002
8	EPRI	2002	Spent fuel pool cooling and cleanup systems : experience at decommissioning plants, n° 1003424, mai 2002
9	EPRI	2003	Proceedings : EPRI international decommissioning and radioactive waste workshop at Dounreay, n° 1007651, janvier 2003
10	EPRI	1998	Fuel integrity monitoring and failure evaluation handbook, n° 108779, août 1998
11	EPRI	1999	Utility use of scaling factors, n° 109448, avril 1999
12	EPRI	1999	Decontamination handbook, n° 112352, juillet 1999
13	Libmann J	1997	Éléments de sûreté nucléaire, éditions de Physique, 1997
14	AIEA	1997	Normes fondamentales internationales de protection contre les rayonnements ionisants et de sûreté des sources de rayonnement, collection sécurité n° 115
15	ASME	2002	Nuclear Facility Decommissioning Handbook, ASME
16	OCDE	2002	Déclassement et démantèlement des facilities nucléaires : état des lieux, démarches et défis, les éditions de l'OCDE, Paris
17	AIEA	2002	Safe and effective nuclear power plant life cycle management towards decommissioning, AIEA TEC DOC n° 1305, août 2002
18	AIEA	1999	Decommissioning of Nuclear Power Plants and Research Reactors, Safety Guide n° WS-G-2.1
19	OCDE	2003	Decontamination Techniques Used in Decommissioning Activities: A Report by the NEA Task Group on Decontamination
20	CERRIE	2004	Report of the Committee Examining Radiation Risks of Internal Emitters (CERRIE), ISBN 0-85951-545-1, www.cerrie.org
21	AIEA	2005	Selection of decommissioning strategies: issues and factors IAEA-TECDOC-1478, Nov. 2005
22	BMU	2001	Decommissioning of Nuclear Facilities, Brochure of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Berlin