ABSTRACT

CEA (French Alternative Energies and Atomic Energy Commission) is both the operator of important nuclear facilities all over the nuclear cycle, in charge of major new built or Decommissioning and Dismantling (D&D) projects and a R&D group with dynamic policy of technology transfer.

The position of CEA in D&D is unique because of the number and the wide diversity of facilities under decommissioning, with some high level of contamination.

Innovative solutions are being developed in 6 main axes to protect the operators, to minimize the overall costs and the volumes of waste, especially used when preparing D&D operations: Investigations in the facilities, Radiological measurement of waste, Technologies for hostile environment, Decontamination of soils and structures, Waste treatment and conditioning and Methods and Information Technology (IT) Tools for project and waste management.

The last developments are shown and examples of industrial applications given. CEA is willing to share actions in partnership with other operators or with industrials dealing with the same problems to solve.

INTRODUCTION

The position of CEA in decommissioning and legacy waste management is unique because of the numbers of facilities involved (21 nuclear installations are under decommissioning operations out of 43), with contamination levels sometimes very high, and a wide diversity of facilities from laboratory scale to industrial plants: almost all kind of reactors (pool, fast breeders, gas graphite CO2 cooled, …), accelerators and irradiators, laboratories, fuel cycle processing units, Effluent treatment stations, Waste treatment and storage facilities, etc. Almost 800 CEA employees and between 2000 and 2 500 employees from suppliers companies work for CEA programs.

While conducting these very specific and demanding D&D projects, CEA gained skills and feedback in the various management and technical fields involved: project management (cost control, scheduling, risks and opportunities, reporting, etc.), safety and security, waste management, transportation and specific expertise in
remote control operations, measurement of nuclear wastes, characterizations for investigations, process engineering, 3D Models information systems, Nuclear Ventilation, etc.

When solutions were not available on the shelves in the supply chain, CEA had to develop technologies, processes, methods and software by its own, in support of its programs always with the aim to reduce cost, schedule, doses incurred and amount of waste produced and to improve safety and security. CEA took thus advantage of its very specific position, being both operator and research organization and put in place an organization able to develop expertise in the 6 main axes of R&D and expertise for D&D, as detailed in the next chapters:

- Investigations in the facilities,
- Radiological measurement of waste,
- Technologies for hostile environment,
- Decontamination of soils and structures,
- Waste treatment and conditioning
- Methods and Information Technology (IT) Tools for project and waste management.

**IMPORTANCE OF PREPARATION**

Several issues can affect D&D planning and execution from the lack of initial state knowledge to the evolution of final state definition, including safety exigencies, regulation evolutions, delay in authorization processes, waste management difficulties, upper limit of the financial resources or project management and technical issues.

In order to master these issues, apart from human factor and organization, a pluri-annual strategic vision leading to prioritization of the different tasks is necessary and preparation with the help of R&D and expertise is crucial.

**DEVELOPMENTS FOR INVESTIGATIONS IN THE FACILITIES**

Characterization of the radiological and physical states of the facilities is a key point in D&D, including historical waste management, to provide right data for scenarios, to minimize hazards during workshops and thus save time and money and work safer or to avoid overestimating associated waste facilities. Investigations with sampling operations and in situ characterization are then necessary for assessment of the initial state in order to prepare workshops:

- for comprehensive measurement and mapping of the residual radioactivity, with level of radioactivity and type of emission.
- to quantify residues / deposits / sludges located in the components, to obtain reliable data (activities, dose rate, quantities) for waste management studies
- to launch soon enough inventories, feasibility studies and waste management report in order to anticipate technical difficulties and waste intermediate storage needs, etc.
- to Anticipate R&D needed to develop conditioning matrices.

Methods and tools have been developed. These tools are necessary from the identification of characterization objectives through to the final physical and radiological inventory.

Coming from complex in situ measurement issues on its own D&D & R workshops, CEA gained experience in analysis of characterization needs, choice of appropriate measurement systems or measurement method in order to validate and optimize a characterization process. A major challenge for developments in this field is to minimize destructive analysis in order to minimize doses integrated by workers and to relieve congested sites laboratories.

**From design to integration and qualification of complex measurement systems**

CEA developed new in situ techniques to map facilities and soil, to localize hot spots, to identify radionuclides, to estimate radioactivity, and to minimize and sometime prevent the number of samplings necessary or to process numerous radiochemical analyses simultaneously. These techniques are already used on CEA D&D workshops, some being already commercialized (Ex: Geostatistics, others being at prototype scale, on the way to industrialization, Ex: Gamma camera (Fig. 1.), Alpha camera (Fig. 2.) or Auto-radiography (Fig. 3.) for Beta emitters, LIBS technology, etc.
CEA also works on the coupling of measurement tools and on the integration
on carriers, ex: Robot RICA (Fig 3) with Gamma Camera.

CEA owns several laboratories equipped for nuclear instrumentation
(Gamma camera, gamma spectrometry probes, means dedicated to
calculation, LIBS, radioactive sources, calibration setups) and test
platforms to accommodate large systems or to train operators to the
use and interpretation of measurement systems

DEVELOPMENTS FOR WASTE MEASUREMENT

From its management as operator of various nuclear facilities
and from R&D developments, CEA gained experience both in
destructive (Beta long live) and non-destructive analysis (X, γ
and α imaging, γ spectrometry, Neutronic measurement).
This knowledge is very useful for D&D & R projects where
optimization and validation of waste characterization strategy is
needed:
  • drawing up objectives for radiological, physical and
elementary waste characterization.
  • choice of equipment and scenarios to implement
(Ex: Fig. 5.)
  • optimization of characterization procedures
  • high-performance modeling and simulation tools
to enable optimization of measurement equipment
and scenarios (fig. 6.)

Design, qualification and industrialization of complex customized measurement devices
CEA became specialized in the design and qualification of customized characterization devices to avoid destructive analysis, or to meet changes in regulatory requirements and special issues related to D&D and R (Fig.7. and Fig.8.). These systems could also be transposition of prototypes to industrial scale or adaptation of existing system.

**Fig. 7. Passive neutronic measurement of Plutonium**

**Fig. 8. Passive neutronic measurement of Uranium**

CEA owns high performance modeling and simulation tools and ten industrial-type non-destructive characterization platforms, able to handle large-scale objects for calibrations and qualifications of all sorts of waste measurement.

**SPECIFIC DEVICES AND SIMULATION FOR OPERATIONS IN HOSTILE ENVIRONMENT**

CEA needed to develop tools for its own D&D projects when they didn’t exist on the market: robots, tele-operated equipment, cutting process and software for validation and optimization of intervention scenarios. For 20 years, project managers had the dream to get 3D cartographies from in situ investigations and to use them as entrance data to scenarios conception in an immersive room. All the elementary technological bricks are now available ready to be linked from collection to conception up to training of operators.

**Fig. 9. A complete model: characterization, tele-operation, simulation and costing**
Design and nuclearization of remotely-handled equipment

CEA learnt how to choose devices suitable for workshops with specific physico-chemical and radiological conditions by nuclearization of off-the-shelf systems or complete design of fine-tuning innovative systems for computer-assisted tele-operation actions, as well as carriers. MAESTRO (Fig. 10.) is an example of remote handling designed arm for high resistance radiations and for adaptation to all kind of carrier: on a crane, on a telescopic mast, on a remote controlled machine, etc.

In order to improve cutting yields while limiting aerosols and waste generated, CEA had to develop powered Laser processes with safety demonstrations regarding dust treatment or risks of inappropriate cuttings. Specific laser heads had to be conceived: heads for cutting in air with air-cooling to prevent water leaking and heads for cutting under water (Fig. 11.).

CEA also developed Control devices and devices to guarantee dynamic containment in case of fire.

Simulation for scenarios optimization and equipment qualification

CEA developed various platforms and tools for scenarios optimization and equipment qualification from feasibility studies to tests, demonstration and training:
- Test and demonstration platforms for cold qualification,
- 3D simulation software and virtual reality in Immersive room to compare alternative scenarios, qualify remotely-controlled equipment, or ensure that an equipment will be accepted by Safety Authorities,
- 3D simulation and doses calculation software, in immersive situation to choose the best way to operate with minimum dose integration,
- Pilot job sites for qualification under real conditions

DECONTAMINATION OF SOLIDS, SOILS AND STRUCTURES
CEA developed technologies for decontamination of solids adaptable to many geometrical configurations, and to a wide range of materials and natures of contamination: self-drying coating gels, laser ablation, viscous foams or active solutions, float foams or supercritical fluid

Several chemical medium formulations were studied with associated physic-chemical characterizations and suitable techniques, to help for implementation on pilot or industrial site in order to decrease radiological and chemical releases.

Other processes were also developed for decontamination of facilities by various rinsing reagents:

Ex: Before dismantling, all the process units of APM were cleaned up by a 4-step process: intensive rinsing (nitric acid) to remove the maximum of uranium and plutonium, degreasing (sodium hydroxide + surfactants) to eliminate organic matter, alkaline oxidation (sodium hydroxide + ozone) to eliminate hot spots, pickling (nitric acid + cerium + ozone) to eliminate encrusted contamination to a depth of 2–10 μm. This process limited the long-lived intermediate-level waste to only 11 metric tons instead of an initially estimated 200 tons, significantly diminishing the residual radioactivity for dismantling.

Ex: For Concentrated fission product storage tanks D&D, the decision was also taken in 2005 to rinse the tanks of AVM with “specific” reagents. The objective was to decontaminate them while minimizing the effluent volume generated, and to ensure that during the dismantling phase a maximum of intermediate-level long-lived waste could be reclassified as low- and intermediate-level long-lived waste. These operations required the construction of a new evaporator. Rinsing operations allowed decategorization of 5% of ILW LL waste in LILW LL.

WASTE TREATMENT AND CONDITIONING

For its own facilities and D&D workshops, CEA had to develop efficient treatments for complex radioactive waste to enhance the efficiency of decontamination, to minimize the volumes of secondary waste, to protect the operators and to minimize the overall costs.

Now, CEA possesses a longstanding experience in both solid and liquid waste treatment, from the initial waste to the final disposal form. Innovative solutions have being and continue to be developed with processes involving chemical, electrochemical, hydrometallurgical, pyro chemical as well as thermal techniques.

Decontamination of effluents
CEA developed and implemented decontamination processes for radioactive radioactive effluents through physico-chemical techniques to reduce downtime and improve effluent treatment facilities, e.g. decrease radiological and chemical releases.

CEA specialized in design and development of optimized equipment and customized synthesis of reagents (Fig. 15.). It owns cutting-edge experimental means enabling inactive and active investigations and testing at laboratory and pilot scales, as well as experimental studies and modeling for extrapolation and associated technological development.

**Treatment of Sodium Waste**

An example of CEA R&D application to D&D workshops is the treatment by carbonatation of the sodium removed from Phenix and Rapsodie fast breeders, one of the major tasks prior to the dismantling of these reactors. The process designed in CEA Cadarache laboratories will be implemented in a facility under construction in Marcoule, close to Phenix reactor (Fig. 13.). It has already been implemented by EDF for SuperPhenix D&D.

**Treatment of organic liquids**

CEA developed several processes for the treatment of solid or liquid organic radioactive waste: incineration, mineralization of organic liquids by hydrothermal oxidation or by plasma incineration.

A new process for incineration of radioactive solvents containing chlorine or Fluor by plasma under water is under way of industrialization (Fig. 14.). The use of plasma under water should simplify dust treatment and prevent corrosion of the facilities.

**Waste conditioning**

CEA R&D capabilities and skills cover all fields related to waste conditioning:

• Formulation and qualification of conditioning matrices,

• Conditioning process development

• Validation for all steps through to industrial scale and qualification information for waste packages during their storage and disposal
Historically, two major fields of development are cementation and vitrification, finding applications in D&D &R: cementation with mineral geopolymers for encapsulation of Magnesium (Fig. 15.), and vitrification “in can melting” for high level waste, for example for UP1 reprocessing plant powdered waste (Fig. 16.).

**METHODS AND INFORMATION TECHNOLOGY (IT) TOOLS FOR PROJECT AND WASTE MANAGEMENT**

This field has to deal with our expertise as operator of big D&D &R projects on several sites CEA has set up a network of interconnected operational IT tools for all the steps involved in nuclear facility decommissioning and dismantling procedures, from cost estimation to waste and transportation management so that we can ensure traceability and harmonize the data provided.

**Estimation, methods and tools**

CEA developed certified tools and methods to evaluate dismantling forecasts. These tools are also available to know the probable future dismantling costs for a facility before its construction or to compare dismantling scenarios in order to optimize factors such as costs, scheduling, integrated doses, and amounts of waste generated.

**Inventories, transportation and waste management**

Even more than during operation information systems and data management are key to ensure the quality of adequate radiological and physico-chemical data concerning the facility and its equipment and of information collected during operating and dismantling phases is a key strategic element for well-run operations, efficiently-oriented scenarios and improved procedures.

CEA developed a network of interconnected operational IT tool (Fig. 17.) to ensure traceability and harmonization of the data provided by decommissioning and dismantling job sites in a centralized record base and be able to optimize waste management scenarios (storage, shipment, waste packages route, etc.).

**Key figures:**
- 3000 technico-economic costing ratios,
- +50 product headings,
- 225,000 packages
- +300 users.
CONCLUSIONS

The position of CEA is quite unique:
- on one side the operator of a great number of facilities under decommissioning, with and a wide diversity from laboratory scale to industrial plants and contamination levels sometimes very high,
- on the other side a research organization with a nice range of experimental setups: integrated test benches for work with real wastes, means to analyze and characterize in inactive and active conditions, calculation and modeling tools, methodological tools, technological platforms, irradiators, etc.

This position allows CEA to implement technologies and processes from laboratory scale through to industrial application, with very concrete objectives coming from projects. CEA leads R&D actions and develops expertise in the 6 main axes of D&D to afford adequate technologies and processes to solve remaining technical problems and to help decrease costs, schedules and amounts of waste or improve the safety of D&D &R workshops.

CEA is willing to work in partnership with other international contracting authorities and industrialists sharing the same challenges in order to share costs of R&D developments and best practices and to implement the results of this R&D on CEA D&D workshops and on the French and international market.

Fig. 17. Network of interconnected operational IT tools
Benefits from R&D for D&D Projects Preparation

Christine GEORGES
17th February 2016
Wide variety of facilities with no series effect
- Reactors: pool-type, fast breeder, gas graphite…
- Accelerators and irradiators,
- Fuel cycle laboratories, workshops and plants
- Waste treatment and storage facilities

Different facility sizes
- Reactors: Ulysse (piloting training) -> Phénix (Industrial)
- Facilities : FAR or LAMA -> UP1

High contaminated areas
Waste diversity
History and traceability of Old nuclear facilities
WIDE RANGE AND LARGE AMOUNT OF HLW WASTE

Ex UP1: 75 types of legacy wastes, located in 18 different locations:
- ~3150 glass canisters
- ~1630 t of HLW Mg clads
- ~1300 t of powdery waste
- ~1300 drums of alpha-waste
- 60,000 drums of bituminized waste
- Active areas = 140,000 m³
- 26,000 t of waste from active areas

- Very different in their chemical and radionuclide composition
- Long-lived radionuclides
- Re-disposal required
R&D Program has two main purposes:

- **Optimizing R&D activities in support of clean-up and dismantling programs**
  - to reduce the cost, the duration of the work, the doses incurred, the amount of waste produced
  - to improve the safety and security of dismantling worksites

- **Developing and promoting R&D and expertise**
  - to share R&D developments
  - to provide expertise
  - to develop industrial partnerships

CEA leads R&D actions and develops expertise in 6 main axis:

- Overall facility characterization
- Waste characterization
- Work in hostile environment
- Methods and IT tools
- Liquid and solid waste Treatment
- Structure and soil decontamination
Synergy between R&D, expertise and experience from D&D workshops

• Orientation of R&D towards industrial needs
• Easy access to pilot workshops in order to give confidence to other users
• Opportunity for sharing with other contracting authorities the development of solutions on same challenges
EXPERTISE AND R&D FOR D&D

- Development of R&D programs,
- Research partnerships,
- Access to pilot job sites,
- Access to laboratories / technological platforms,
- Consulting,
- Technology transfer

- Geostatistics
- Soil remediation

- Waste characterization
- Nuclear measurement
- Fuel conditioning
- Corium behavior
- Tritium waste
- Sodium waste
- Impact studies

- Structure and soil characterization
- Remote control,
- Simulation
- Cementation
- Vitrification
- Decontamination

- Waste behavior
- Characterization / Physical and Chemical analysis
- Laser cutting, Robotics
- Simulation
- Materials
IN SITU CHARACTERIZATION

NEEDS for:
• Better knowledge of radiological and physical states to control hazards management, cost and delay
• Reduction of doses integrated by operators
• Optimization of samplings

EARNINGS
Optimization of D&D scenarios, from the identification of characterization objectives through to the final physical and radiological inventory

IMPROVEMENTS
• to map facilities and soil,
• to localize hot spots,
• to identify radionuclides,
• to estimate radioactivity,

Geostatistics
Gamma spectrometry for concrete contamination
Gamma camera
LIBS technology
Autoradiography
Alpha camera
WASTE CHARACTERISATION

NEEDS for:
- Better knowledge of radiological and physical states with less uncertainties in the measurements
- Transportable and multipurpose systems for different kind of waste

EARNINGS
- Waste minimization
- Good predictive data for storage facilities
- Optimization of characterization processes

IMPROVEMENTS
- Non-destructive analysis:
  - \(\gamma\) et \(\alpha\) imaging
  - \(\gamma\) spectrometry
  - Neutronic measurement
- Destructive analysis:
  - Beta long live analysis

Modeling with pre- and post-measurement
Waste characterization in glove boxes
Active neutronic measurement of U and Pu
Passive neutronic measurement of Uranium
STRUCTURE AND SOIL DECONTAMINATION

**EARNINGS**

- Identify and implement decontamination techniques for radioactive solids, structures and soils
- Waste optimisation

**IMPROVEMENTS**

- Technologies adaptable to many geometrical configurations, and to a wide range of materials and natures of contamination:
  - aspirable self-drying gels,
  - laser ablation,
  - viscous foams or active solutions,
  - float foams or supercritical fluid,
  - coating gels, ...

- Studies of chemical medium formulations with associated physico-chemical characterizations,
**DECONTAMINATION OF LIQUID WASTE**

### EARNINGS
- Increase decontamination efficiency
- Minimization of generated waste
- Compatibility with large flowrates
- Compatibility with existing waste treatment (cementation, vitrification)

### IMPROVEMENTS
- Innovative decontamination process design
- Innovative Cs and Sr sorbents design
- Sorbent synthesis from laboratory scale up to industrial scale.

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**SORBMATECH® FOR Cs**

**NEW SORBENTS FOR Sr**

**200µm**

**Reactors design**

**Synthesis reactor**

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**International Symposium on Preparation for Decommissioning**

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**CTI**
**EARNINGS**

- Develop efficient treatments for complex radioactive wastes (mercurials, sodics, tritiated, Mg from decladding, powders, graphite, sludges, other legacy waste, ..)

**IMPROVEMENTS**

- Design and carry out radioactive waste treatment processes from laboratory scale through to industrialization phases.

- Several thermal processes for the treatment of solid or liquid organic radioactive wastes:
  - ✔ incineration, 
  - ✔ mineralization of organic liquids by hydrothermal oxidation or by plasma incineration
  - ✔ Vitrification (in-can melting)
  - ✔ Encapsulation with geopolymers (Mg, oils), 
  - ✔ Mercury, sodium, tritium waste, treatment, etc.
**EDR R FEACH T CINDUS**

**REMOTE TECHNOLOGIES**

- **EARNINGS**
  - Validate intervention scenario feasibility
  - Reduce the doses integrated by operators
  - Minimize cost, delay, waste volume, cuttings
  - Compare alternative scenarios
  - Qualify remotely-controlled

- **IMPROVEMENTS**
  - Design, adaptation of fine-tuning innovative systems for computer-assisted tele-operation actions, as well as carriers: remote handling MAESTRO
  - Development of laser cutting processes in air or under water to improve cutting yields while limiting the aerosols and waste generated.
  - Development of 3D simulation software and virtual reality: Immersive Room for training
REMOTE DISMANTLING OF THE DISSOLVERS
The use of Virtual Reality to secure the project

RESULTS

- Optimization of cutting sequences
- Modification of video cameras positions
- Modification of tool rack design
- Assessment of Maestro arm introduction into dissolver “stack”
- Operators formation
- Simplification of the mock-up testing program
- Optimization of cutting sequences
- Simplification of the mock-up testing program
Several factory tools have been studied, developed, and qualified.

- Alternating saw
- Hydraulic shears
- Disk grinder
- Nibbler
- Gamma camera
- Drill
- Video camera
- Laser torch
- Offset screwdriver
- IF104 radiation probe
MAESTRO PERSPECTIVES

Pétrus – Building 18

Rapsodie

UP1 – Dissolvers MAR 200

APM

Phénix

UP1 - AVM
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Operators formation

Modification of tool rack design

Assessment of Maestro arm introduction into dissolver “stack”
DEFINITION OF SCENARIOS: A COMPLETE MODEL

- Characterization
  - Simulation, virtual reality
  - Remote technologies, robotics
Tools for estimation of overall costs (ETE – EVAL)
Tools for project management (DEM +, Saphir, etc.)
Tools for transportation management (SINTRA)
Tools for waste management (CARAÏB, INFLUVAL)

Key figures:
- 3000 technico-economic costing ratios,
- +50 product headings,
- 225 000 packages recorded
- +300 users.
CONCLUSION: MAIN CHALLENGES of D&D

- Preparation
- Strategic vision / priorization
- Integrated organization and Synergy between technical trades, operators, project management teams and R&D teams
- Need for R&D to afford adequate technologies and processes with need to get involved since engineering studies.
- Need for international sharing of R&D and best practices

- Unique position of CEA both Operator and Research Organization
- Numerous facilities under decommissioning, with contamination levels sometimes very high, and a wide diversity from laboratory scale to industrial plants.
- CEA leads R&D actions and develops expertise in the 6 main axis of D&D
- R&D has a special role to help decrease costs, schedules and amounts of waste and to improve the safety of workshops.
- CEA is willing to work in partnership with other contracting authorities and industrialists in order to share R&D developments and to implement results.
Thank you for your attention