ORGANISATION DE COOPÉRATION ET DE DÉVELOPPEMENT ÉCONOMIQUES

OCDE

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

OECD-NEA Workshop on Future Criticality Safety Research Needs

VALDUC Laboratory Criticality Experiment Facilities

Service de Recherche en Neutronique et Criticité

CEA-DAM, Centre de Valduc, F-21120 Is sur Tille, France

AEN NEA Agence pour l'énergie nucléaire Nuclear Energy Agency

Workshop on Future Criticality Safety Research Needs

Pocatello, Idaho, USA – September 21-22, 2009

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OECD-NEA Workshop on Future Criticality Safety Research Needs

TEST POTENTIAL OF THE CEA VALDUC CRITICALITY LABORATORY

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Session VI
STATUS AND PERSPECTIVES OF CRITICAL EXPERIMENTS

AEN NEA Agence pour l'énergie nucléaire Nuclear Energy Agency

Workshop on Future Criticality Safety Research Needs

OUTLINES OF THE PRESENTATION

- ⇨ The CEA Valduc Criticality Experiment Facilities
  - Locations
  - Missions
  - Experimental Devices and Abilities
- ⇨ Overview of Appareillage B
  - Description and Main Performances
  - Few major contributions (recent main applications)
- ⇨ Overview of SILENE
  - Description and Main Performances
  - Few major contributions (experimental abilities)
- ⇨ Overview of CALIBAN
  - Description and Main Performances
  - Few major contributions (recent main applications)
- ⇨ Conclusions and Perspectives
  - A French – US Common Vision for the Future

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A LITTLE PART OF OUR CRITICALITY HISTORY …

- The CEA Valduc Criticality Experiment Facilities (located in near Dijon, France) are known all over the world for nearly 45 years of experiences in the field of criticality

- It is today an unique set of human capabilities and experimental facilities and devices located and operated in the same place especially concerning critical solutions assemblies

- The CEA Valduc Criticality Laboratory operates different facilities designed in the 1960-1970's to meet specific objectives. These facilities are still in operation but we have to look toward Future …

OUR MISSIONS

- Operating experimental devices in the field of nuclear criticality safety and neutron science experiments for:
  - Nuclear Criticality Safety Program needs
  - Nuclear Data and Codes Qualification Program needs

- Supplying with reactors and accelerators a wide range of radiation (neutron and photon) to meet any requirements, from very low to very high doses to the benefit of different internal (CEA) or external (Industrials) customers

- Holding the “Center of Excellence” in charge of Criticality Accidents Studies for CEA witch was established to support its needs in the field of Criticality Accidents Expertise based on:
  - Preservation and dissemination of the CEA background
  - Experiments on SILENE for solutions accidents studies
  - Experiments on CALIBAN for metallic accidents studies

EXPERIMENTAL DEVICES LOCATED IN THE BUILDING 010

- ⇨ **An Experimental Reactor with solution core:**

  SILENE (1974)

- ⇨ **A bench devoted to Airborne Release Fraction studies:**

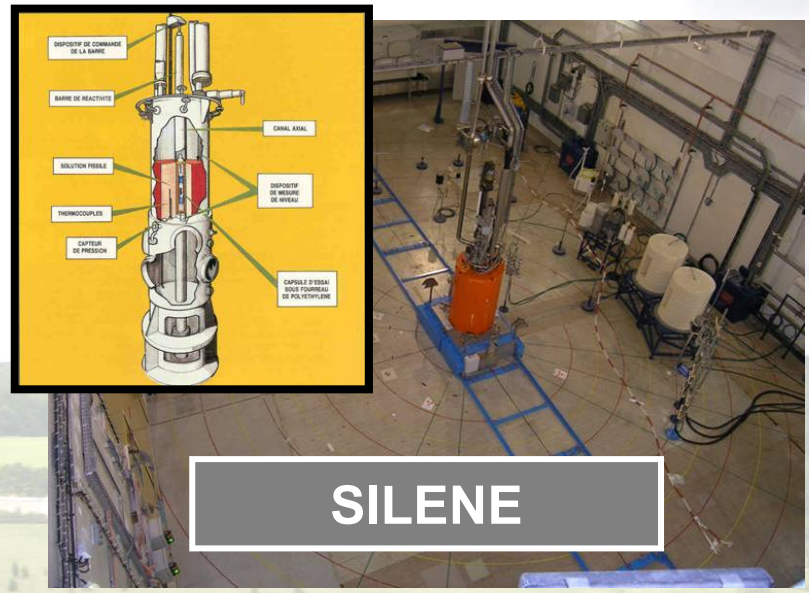
  BISE (2002)

- ⇨ **A sub-critical facility:**

  Appareillage B (1963)

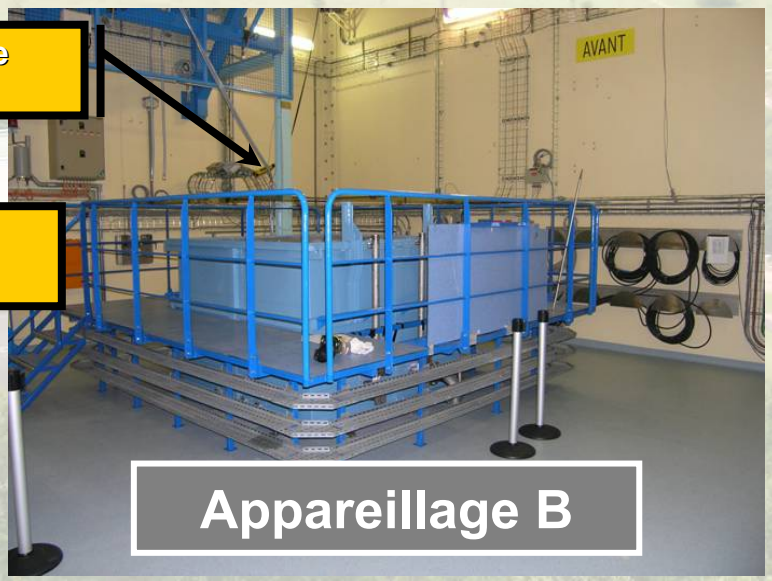
- ⇨ **A large Special Nuclear Materials inventory:**
  - Solutions (Highly Enriched Uranium and Reactor-Grade Plutonium)
  - PWR type rods (uranium oxides rods called REP)
  - PWR High BurnUp type rods (mixed uranium and plutonium rods called HTC)
- ⇨ **Related equipment:**
  - Physico-chemical analysis en fuel recycling laboratories for uranium and plutonium
  - Counting laboratory (Dosimetry and α, β, γ radiations measurement)

EXPERIMENTAL DEVICES' MAP – Building 010



Pool Core Design

MIRTE Program



Cylindrical Core Design

Pu Temperature Program

EXPERIMENTAL DEVICES LOCATED IN OTHER BUILDINGS

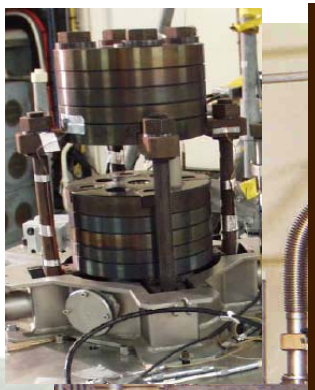
⇨ **Two Experimental Reactors with metallic cores:**

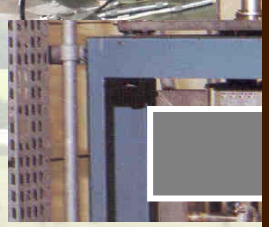
CALIBAN (1971)
PROSPERO

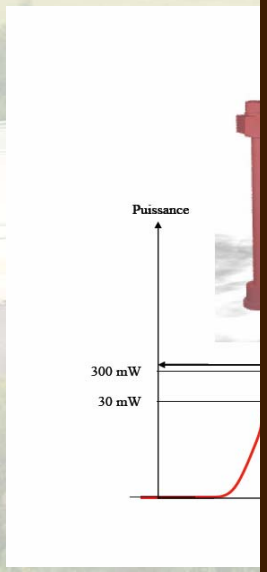
⇨ **Two Electrostatic Accelerators:**

SAMES
ALVAREZ

EXPERIMENTAL DEVICES' MAP – Other Buildings



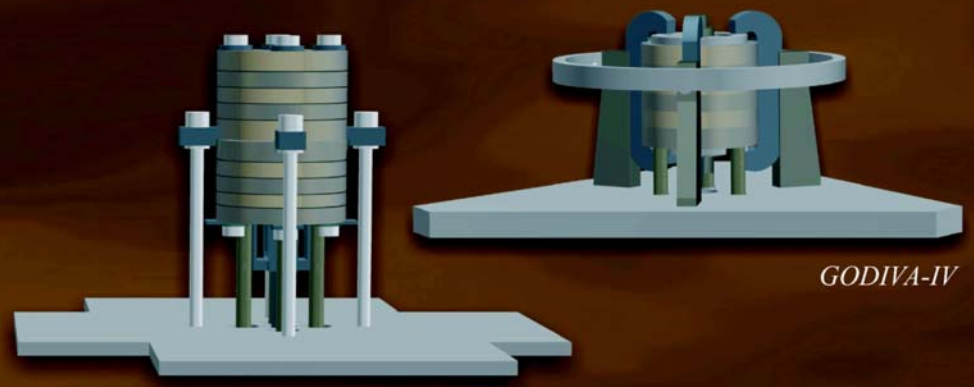




NEA/NSC/DOC(95)03 September 2008 Edition

NEA Nuclear Science Committee

INTERNATIONAL HANDBOOK OF EVALUATED CRITICALITY SAFETY BENCHMARK EXPERIMENTS



NUCLEAR ENERGY AGENCY
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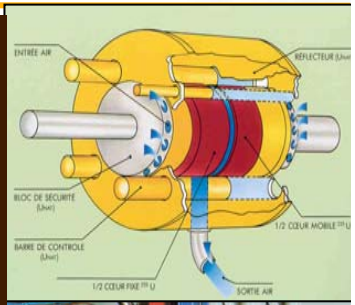

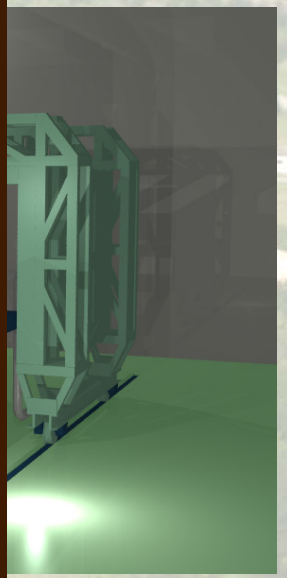

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VALDUC Laboratory Criticality Experiment Facilities

OVERVIEW OF Appareillage B

A Sub-Critical (*) Facility able to reproduce and study a wide range of criticality configurations

(*) *Criticality is approached up to a value around* $k_{eff} = 1-\beta/10$

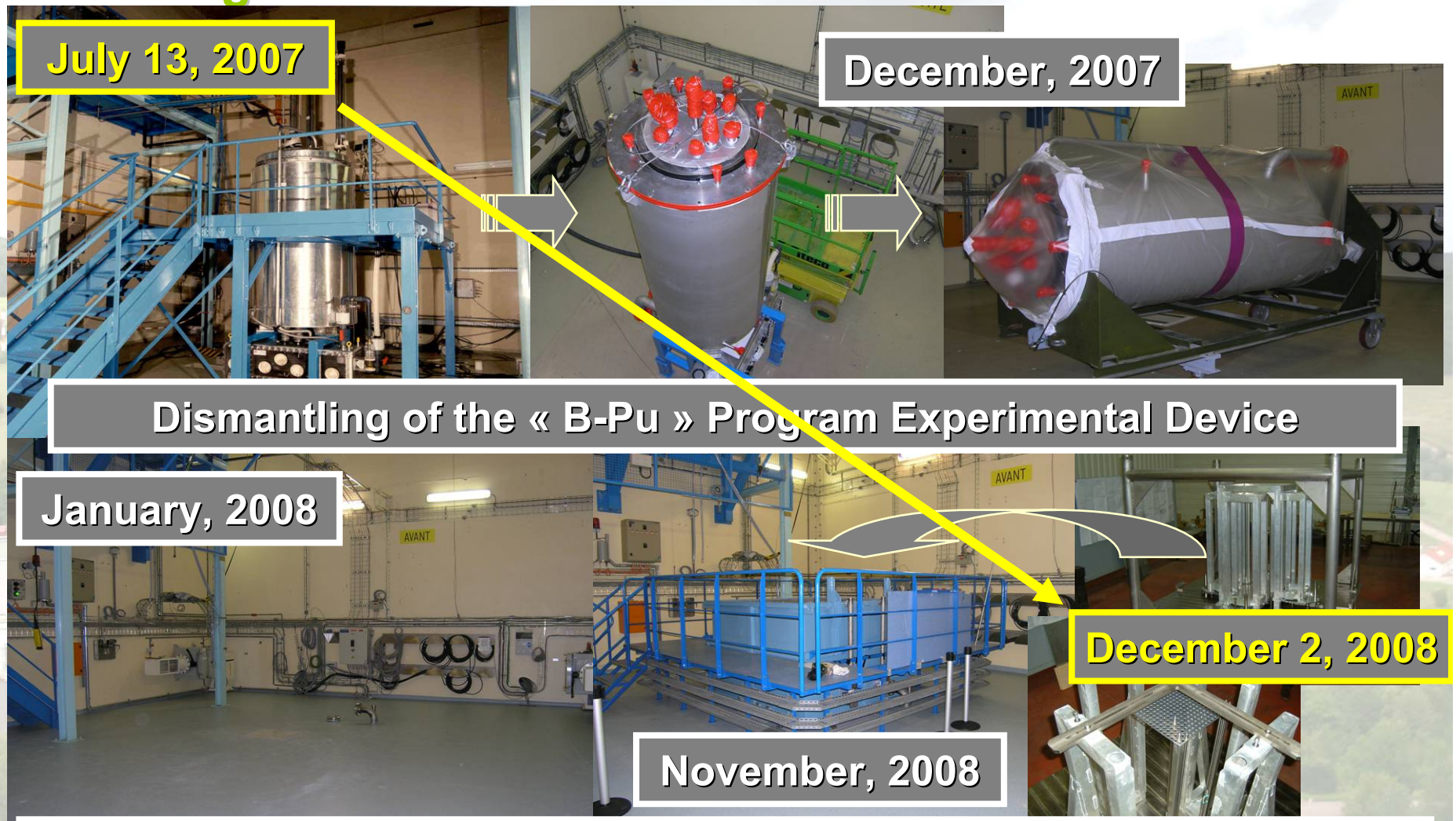
Appareillage B
Key Dates and Experimental Abilities

- ⇨ 1963:
  - First Critical Experiment conducted at Valduc
- ⇨ 1963-1995:
  - CEA Programs supporting the French nuclear fuel cycle plants and associated R&D facilities
- ⇨ 1995-1997:
  - Full renovation of Appareillage B in compliance with the new safety and security requirements of French nuclear facilities
- ⇨ 1998-2004:
  - Joint CEA/IPSN (IRSN) – COGEMA (AREVA) programs
- ⇨ 2004-2011:
  - IRSN programs (Pu Temperatures / MIRTE)
- ⇨ More than **3000 sub-critical experiments** were performed with Appareillage B since 1963

Appareillage B
Assets

- Experimental Platform using:
  - Large Special Nuclear Materials inventory
  - Related equipment
- Adaptable to different experimental needs:
  - Modular design and versatility (experimental core, storages, etc.)
  - Multipurpose control system (programmable controllers, etc.)
- Flexible and easy to operate:
  - Quick modification of test configurations (rod array setups, solution concentration and acidity adjustments, etc.)
  - Immediate access to experimental cell following use of sub-critical approach
- Attractive features:
  - Representative configurations of fissile media and geometries encountered in laboratories, plants and transportations
  - Reduced and well known experimental uncertainties in the order of 100 pcm (2σ) magnitude
  - Allows reactivity worth measurement due to its high sensivity to perturbations (moderation, concentration, acidity, poisoning, temperature, etc.)
  - Accommodates to implement sub-critical measurement technique
- Major assets of interest:
  - Suitable for Criticality Safety Package Qualification
  - Preserves and disseminates selected information that enables to sustain Nuclear Criticality Safety expertise capability

Appareillage B
One Program toward an Other One …



Appareillage B

A Large Contribution to Code Validation

⇨ Highly accurate integral experiments conducted by teams from Valduc Criticality Experiment Facilities contribute to:

- the qualification of the CRISTAL (*) Criticality Safety Package

  → **517 Benchmarks**

  (*) CRISTAL is a French system of well-established codes and data for performing nuclear criticality safety analyses

- provide a wide range of criticality safety-related experimental benchmark data for the OECD-NEA ICSBEP Handbook

  → **40 Evaluations involving a total of 681 critical configurations**

⇨ The Valduc Criticality Laboratory is involved in:

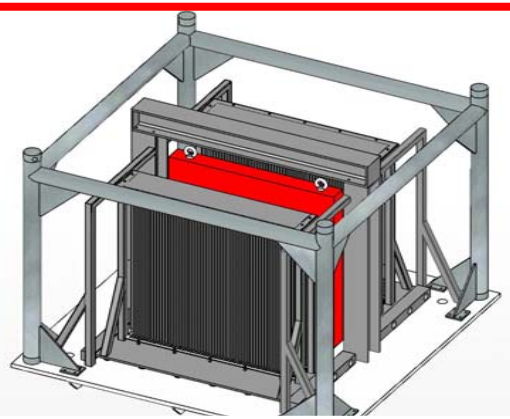
- **OECD-NEA ICSBEP Working Group** as Internal or External Reviewer of Benchmark Description Reports
- **OECD-NEA Working Party on Nuclear Criticality Safety** (WPNCS) as Members of the Expert Group on Criticality Excursion Analysis
- **ISO/TC 85/SC 5 Group** as Project Leader of Nuclear Criticality Safety – Analysis of a postulated Criticality Accident Standard (ISO/DIS 27467)

Appareillage B
Recent main applications

- ⇨ Qualification of the decrease from ^{241}Pu to ^{241}Am
  - "Aging" Effect Program (2004 – 2005)
  - ~ 10 experiments performed
  - Preliminary calculations have shown an effect about 3% on k_{eff}
- ⇨ Measurement of the temperature coefficient of dilute plutonium solutions
  - B-Pu Program (2006 – 2007)
  - 13 experiments performed
  - Some of them had demonstrated a positive temperature effect
- ⇨ Qualification of structural materials cross-sections
  - MIRTE Program (2007 – To be continued)

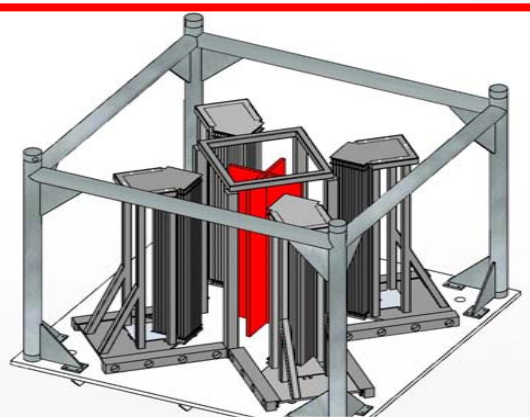
MIRTE PROGRAM

Matériaux en Interaction et en Réflexion Toutes Épaisseurs



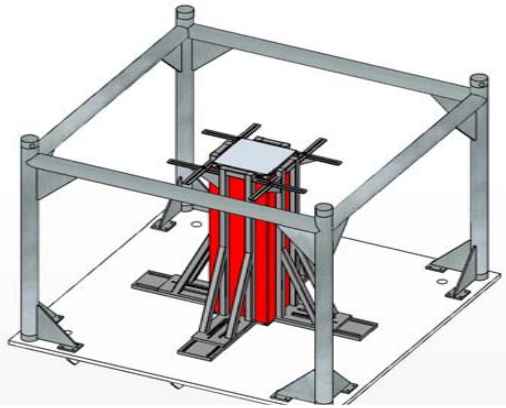
INTERACTION FORTE EPAISSEUR

- ✓ Aluminum
- ✓ Copper
- ✓ Steel
- ✓ Nickel
- ✓ Lead
- ✓ Zircalloy
- ✓ Concrete
- ✓ Glass



INTERACTION FAIBLE EPAISSEUR

- ✓ Copper
- ✓ Steel
- ✓ Nickel
- ✓ Titanium



REFLEXION

- ✓ Aluminum
- ✓ Glass

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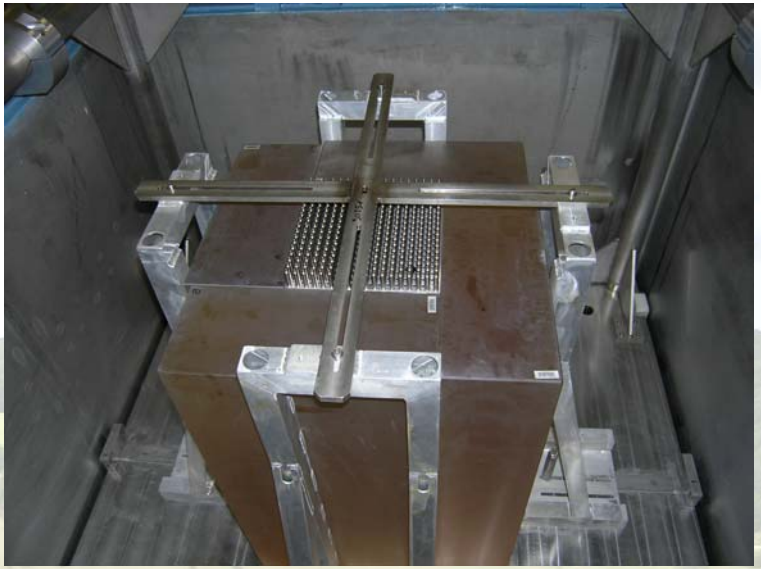
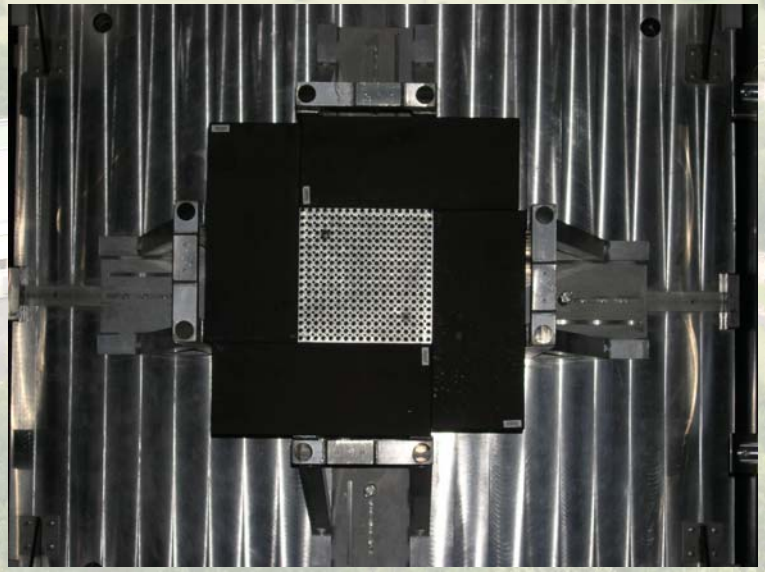
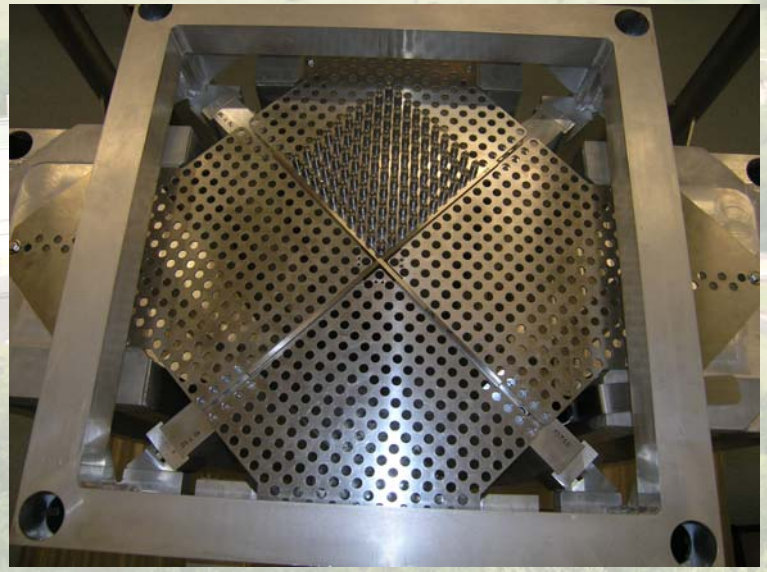
AREVA ANDRA NNSA National Nuclear Security Administration

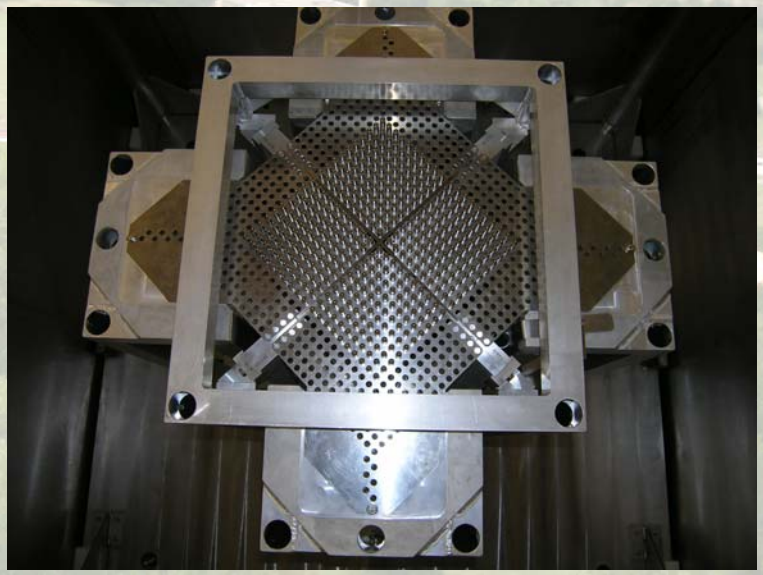
MIRTE PROGRAM – Glass (March 25 – April 1, 2009)





MIRTE PROGRAM – Titanium (September 09-18, 2009)





Appareillage B
Perspectives

- ⇨ Appareillage B programs are currently “planned” until 2012
- ⇨ Appareillage B uses are currently “available” until 2014
- ⇨ IRSN strongly supports Appareillage B as the major response to Criticality Safety Package Qualification needs
- ⇨ Appareillage B Licensing, in compliance with the new safety and security requirements of French nuclear facilities, will have to be done after 2015

VALDUC Laboratory
Criticality Experiment Facilities

OVERVIEW OF SILENE

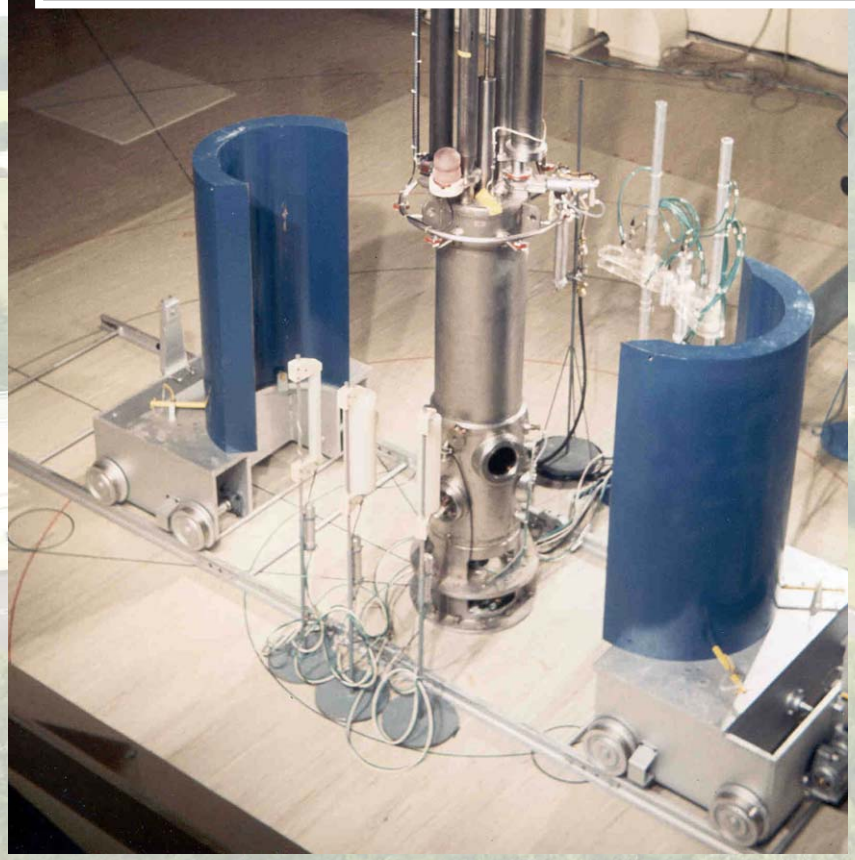
A Super-Critical (*) Reactor able to reproduce and study a wide range of criticality accidents kinetics in fissile solution

(*) *For a Super Prompt Critical Pulse a 3β reactivity step can be inserted*

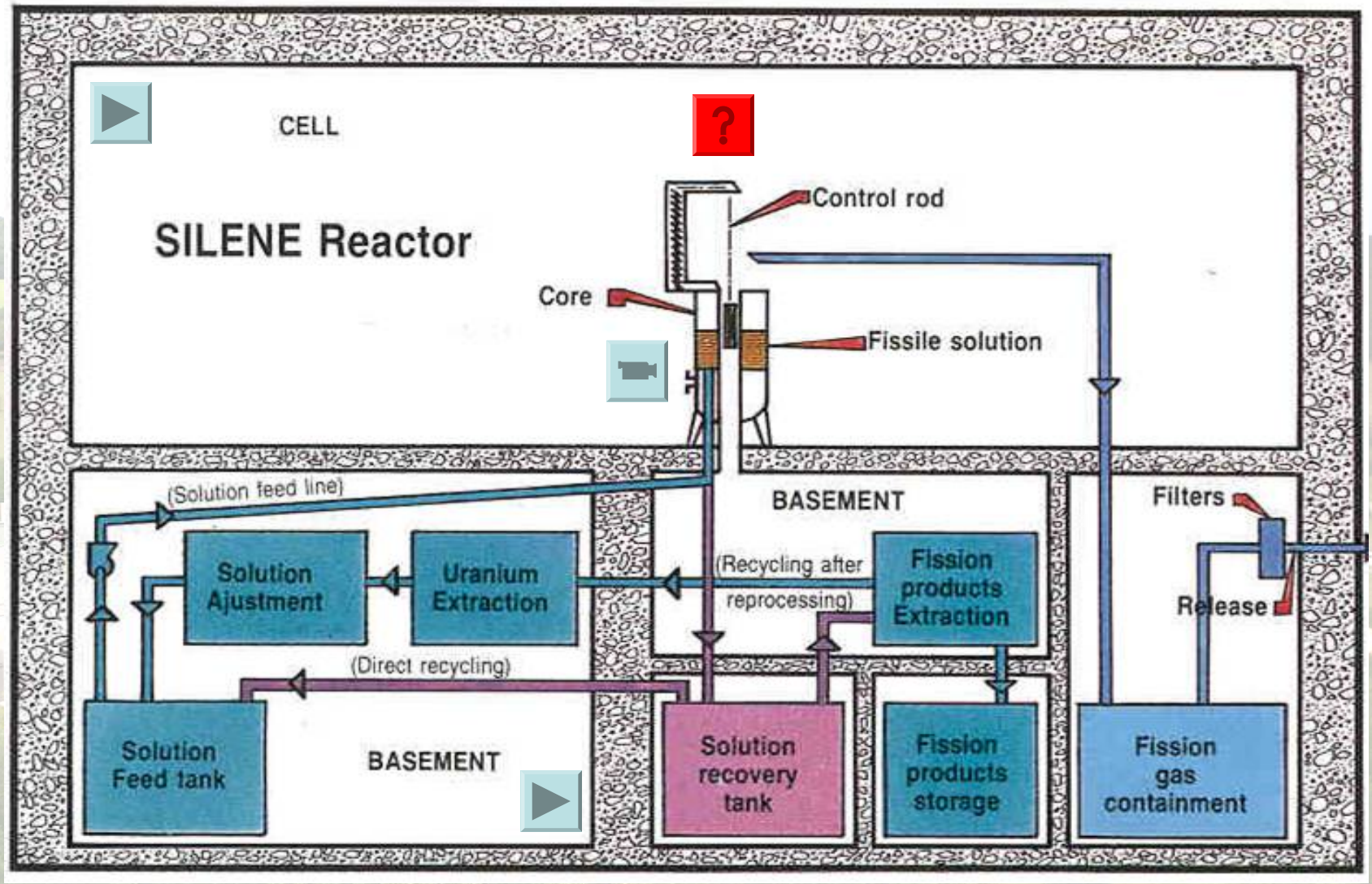
SILENE
Solution Reactor and Chemical Process Facility

SILENE is not only a reactor but also a chemical process facility supporting:

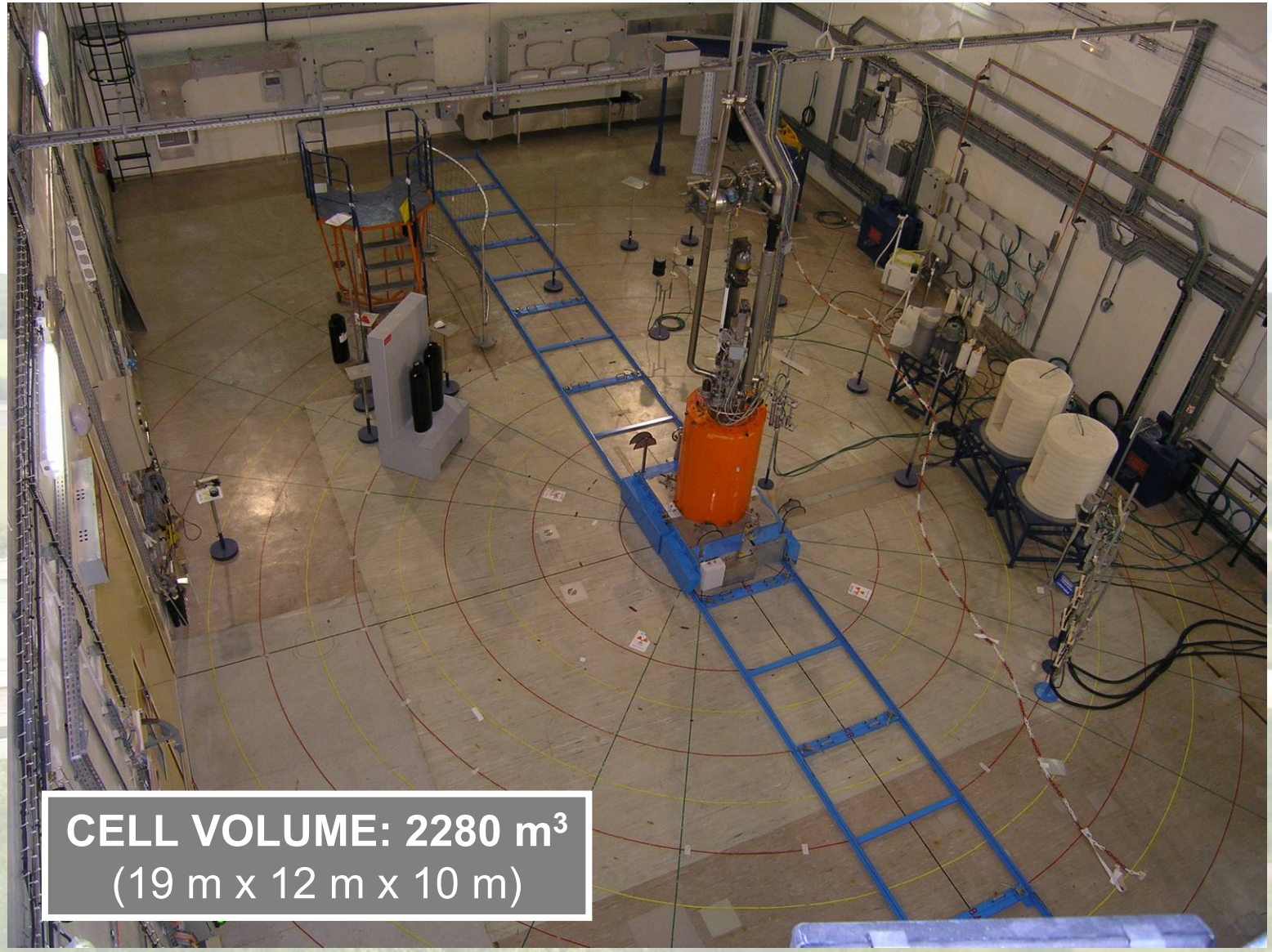
- Critical or sub-critical experiments
- Fissile solutions storage for the fuel before and after experiments
- Fuel adjustment and purification according to a PUREX Process



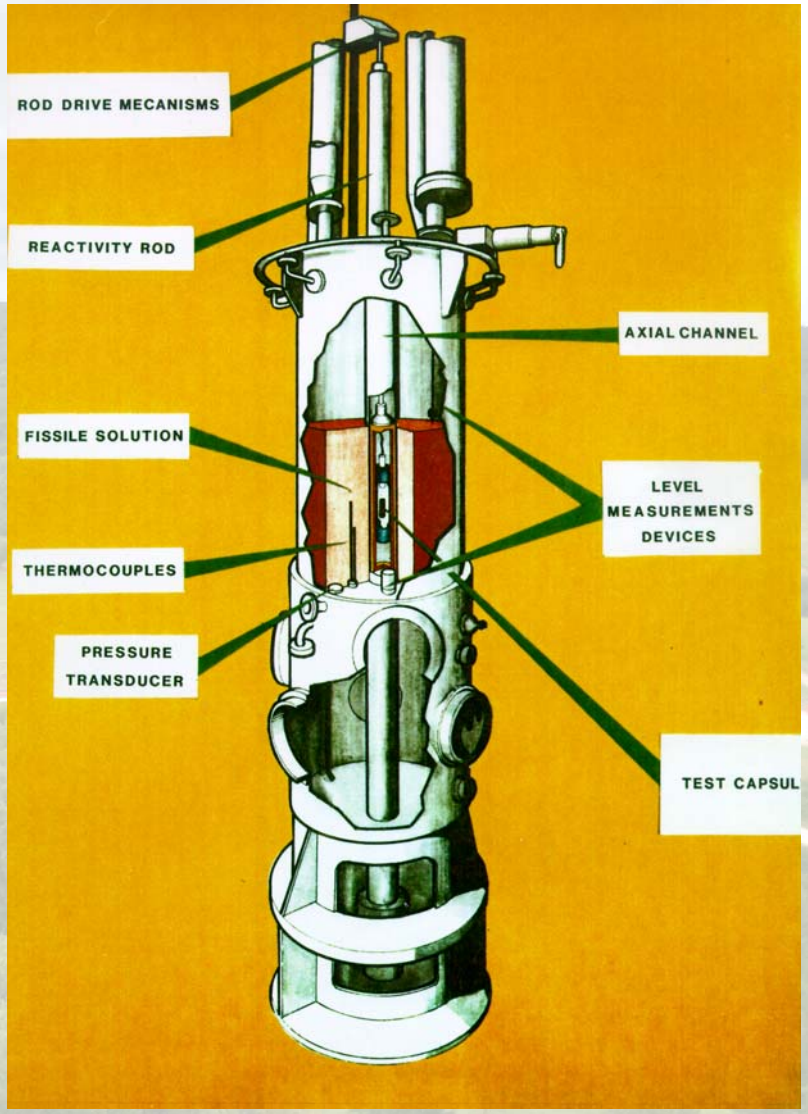
SILENE
Reactor Core, Tanks and Chemical Glove Boxes



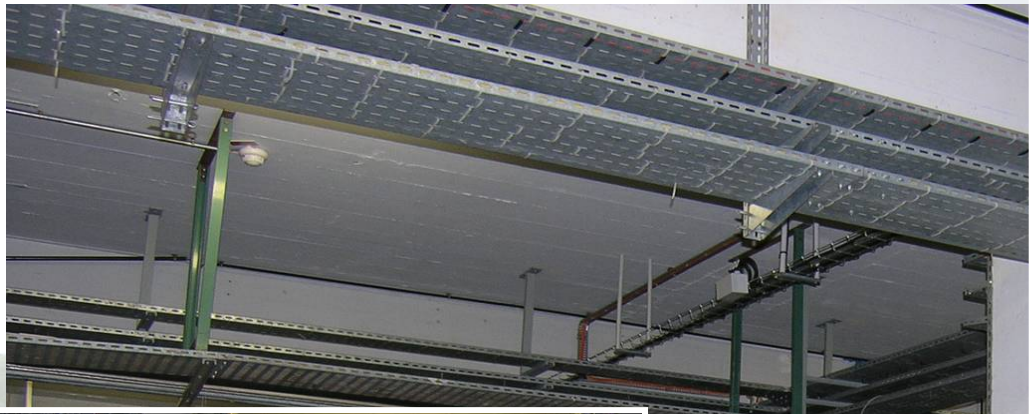
A LARGE CONCRETE IRRADIATION ROOM

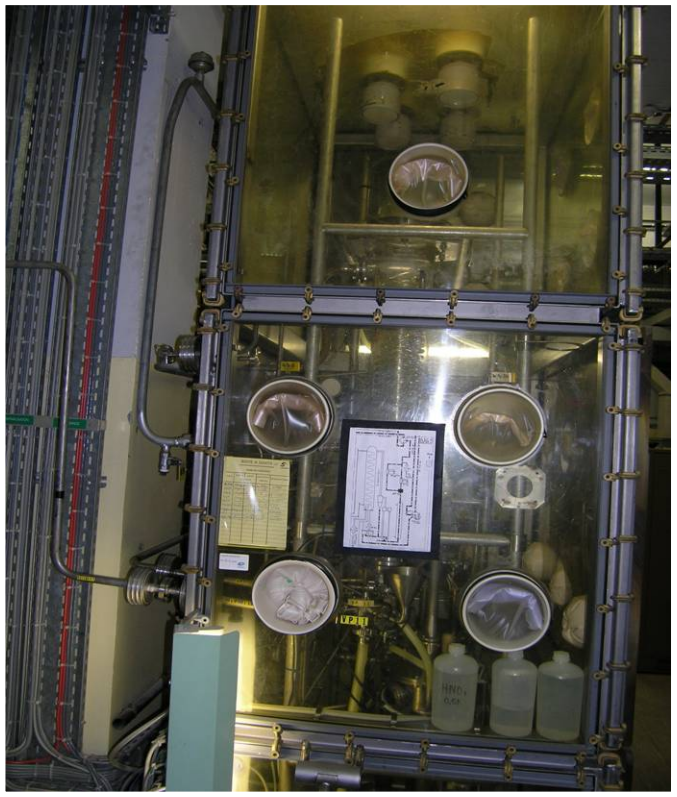


TURN AROUND THE SILENE CORE

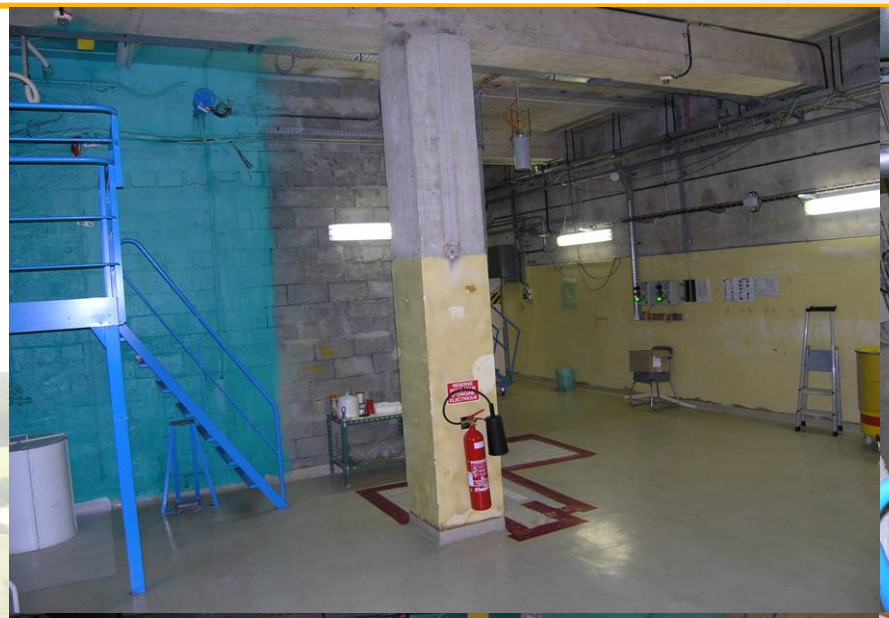


OVERVIEW OF THE BASEMENT (1)

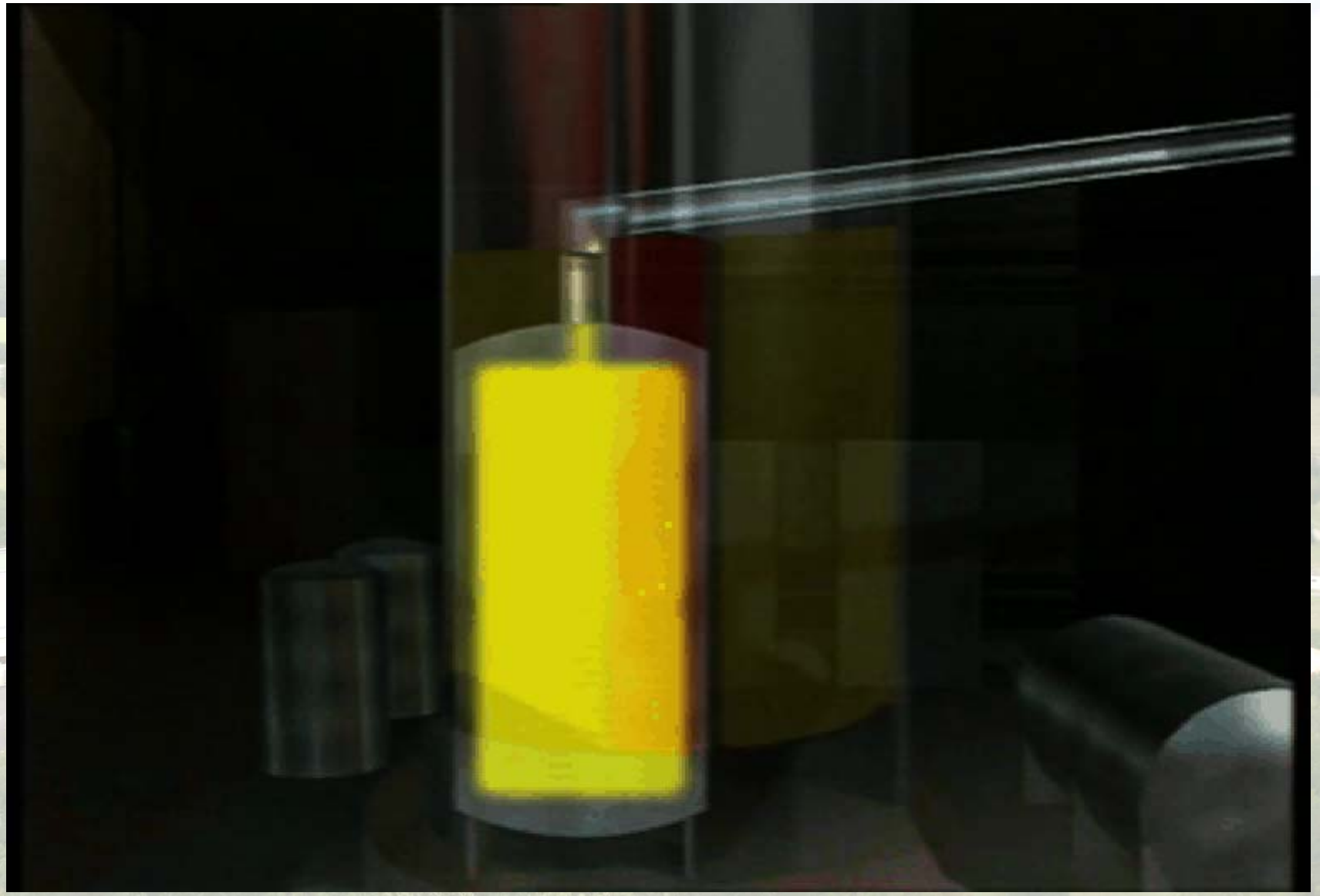




OVERVIEW OF THE BASEMENT (2)



HOW DOES IT WORK ?



SILENE
Key Dates and Experimental Abilities

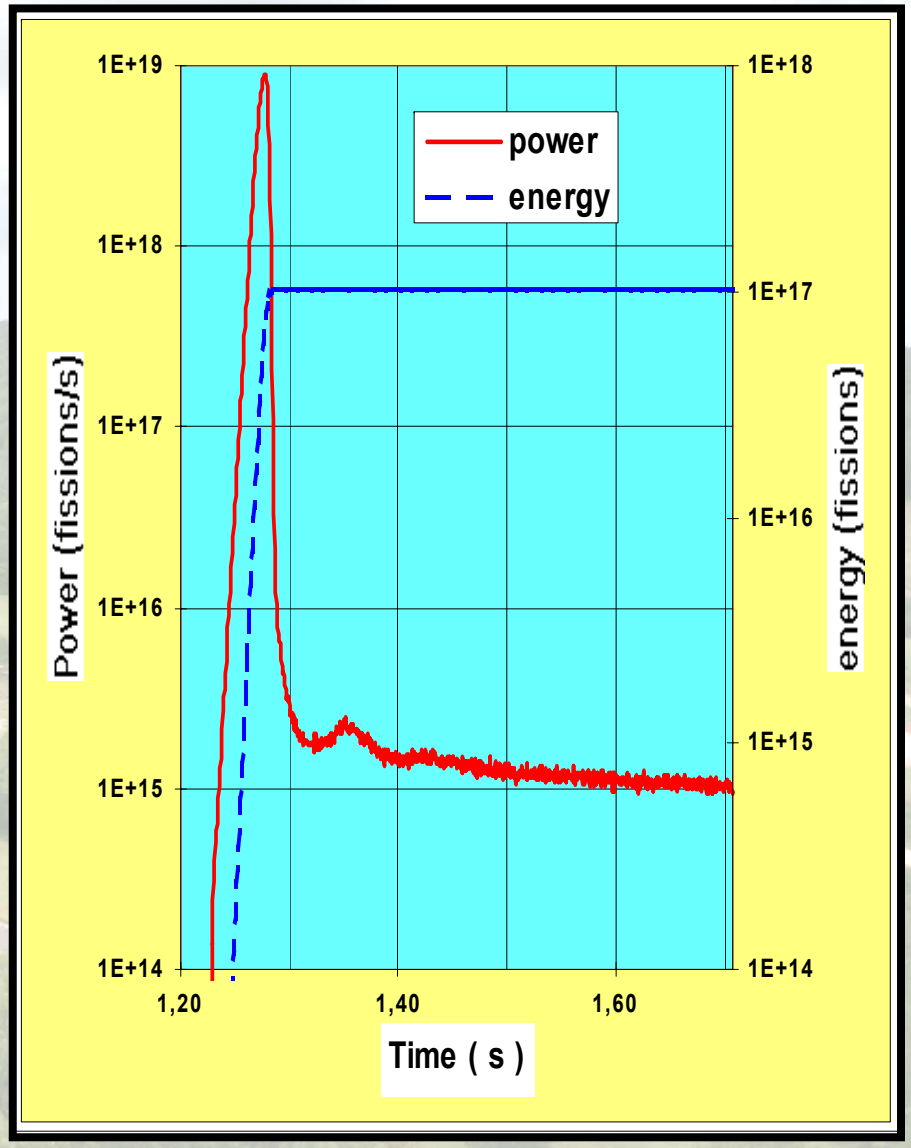
- ⇨ December 14, 1964:
  - 107 Kg HEU (UF6) coming from Oak Ridge (Union Carbide Gazeous Diffusion Plant)
- ⇨ 1967-1972:
  - Criticality Accident Study Program using CRAC Facility
- ⇨ 1974:
  - First Super-Critical Experiment conducted at Valduc with SILENE
- ⇨ More than **2000 divergences and 1000 sub-critical experiments** were performed on the SILENE reactor for criticality accidents and radioprotection studies, and for industrials uses (materials and components irradiation) since 1974

SILENE
Assets

- SILENE is operating following 3 kinetics modes according to rod ejection rate:
  - Pulse mode
  - Free Evolution mode
  - Steady State mode
- SILENE is operating following 4 shielding configurations to obtain mixed leak radiation with a wide range of γ / n ratios:
  - Without — mixed n and γ radiation (1.3)
  - Lead — preponderance of n component (0.2)
  - Polyethylene — preponderance of γ component (11)
  - Steel — degraded energy n spectrum (0.4)

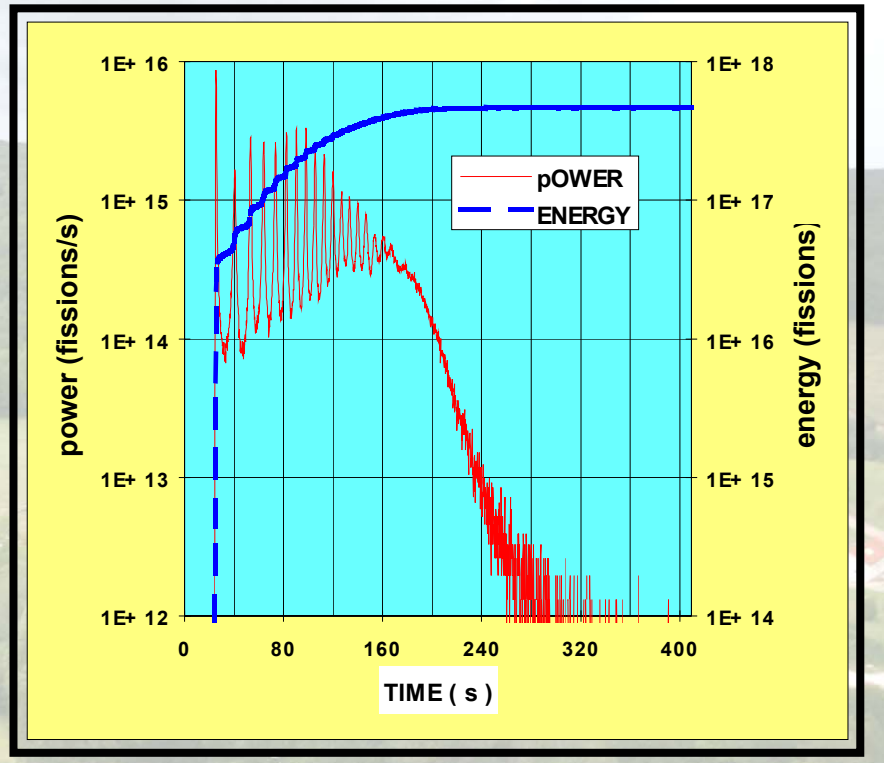
SILENE – PULSE MODE

- Rapid removal of the control rod (2m/s)
- Brief high power excursion
- Power peak up to 1000MW
- Total energy up to 2×10^{17} fissions
- Doubling time down to 1.5ms
- Peak width down to 6ms



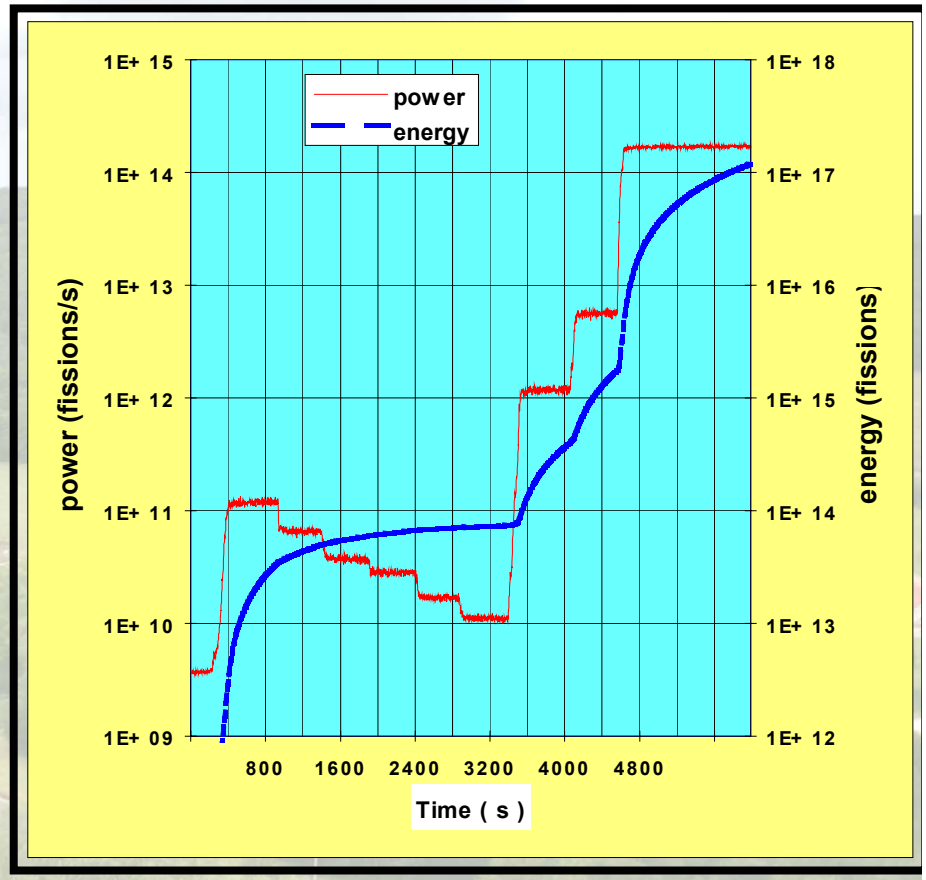
SILENE – FREE EVOLUTION MODE

- Slowly removal of the control rod (1cm/s)
- Representative of a criticality accident
- 1st peak:
  - power : 2×10^{17} fissions
  - energy : 5×10^{16} fissions
- Total energy: 5×10^{17} fissions
- Duration: few minutes



SILENE – STEADY STATE MODE

- ⇨ Stable power level
- ⇨ Slow displacement of the control rod (1mm/s)
- ⇨ Power from 0.01W to 10kW
- ⇨ Total energy up to $5x10^{17}$ fissions
- ⇨ Allows to perform complex kinetics
- ⇨ Suitable for long irradiations (several hours)



EXPERIMENTAL ABILITIES (1)

- Studies of criticality accident phenomena, intended to better define and model accident mechanisms and phenomenology and provide data for safety assesments, relevant to surveillance and prevention policies
- Enhancing detection instruments and qualifying them in various criticality accidents scenarios (Criticality Accident Alarm System qualification and testing)
- Research and development of dose measurement methods
- Radiation Protection studies
- Biological dosimetry and studies on physiopathology of complex irradiations
- Experimental validation of calculations codes in the fields of Criticality Accidents or Health Physic Protection

EXPERIMENTAL ABILITIES (2)

- Training of teams for emergency preparedness (organizing actions such as personnel evacuation, rapid medical screening, training of teams to deal with criticality emergency situations) as mentioned in ANSI/ANS 8.23-1997
  - *Emergency response personnel training*
  - *Re-entry team personnel training*
  - *Technical staff training*

- Development of the hands-on training and training for operators proficiency
- Information Preservation and Dissemination to sustain knowledge in criticality safety

- Reactivity worth measurements
- Sub-critical measurements

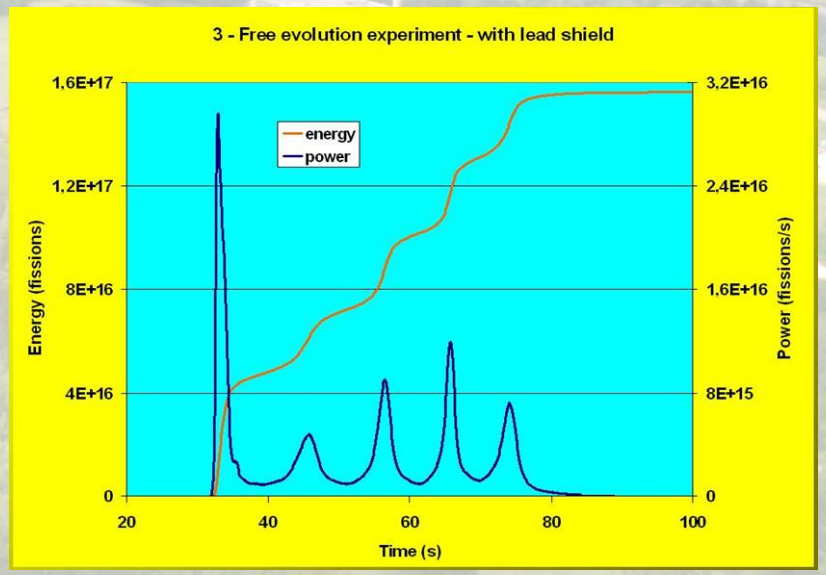
SILENE
Radiobiology studies

- ⇨ Study the effects of intense mixed radiation fields
- ⇨ Improve biological dosimetry
  - Relationships between chromosome failures and doses using irradiated blood samples
- ⇨ Therapeutic strategy for criticality accidents victims
  - Better knowledge of letal doses
  - Dosimetric management for the triage of victims
- ⇨ International exercices for clinical biochemistry laboratories

Phantom prepared for irradiation with blood samples and hair

LAST INTERNATIONAL INTERCOMPARAISON DOSIMETRY EXERCICE – Valduc, 2002

- 6th International Exercise of Criticality dosimetry
  - 1970CRAC, 1993SILENE
  - 1971, 1973, 1975
- 60 laboratories participating, 20 in Valduc (during 2 weeks)
- First comparaison between biological and physical dosimetries
- 3 simuled criticality accidents with SILENE:
  - Integrated Doses (n-γ) en Gy: (1,9-2,3), (0,9-0,2), (1,9-0,3)
  - One steady state and two free evolution kinetics
  - More than 200 dosimeters used per run
- NEUDOS'9 specific session
- OECD – CEE – IRSN – CEA



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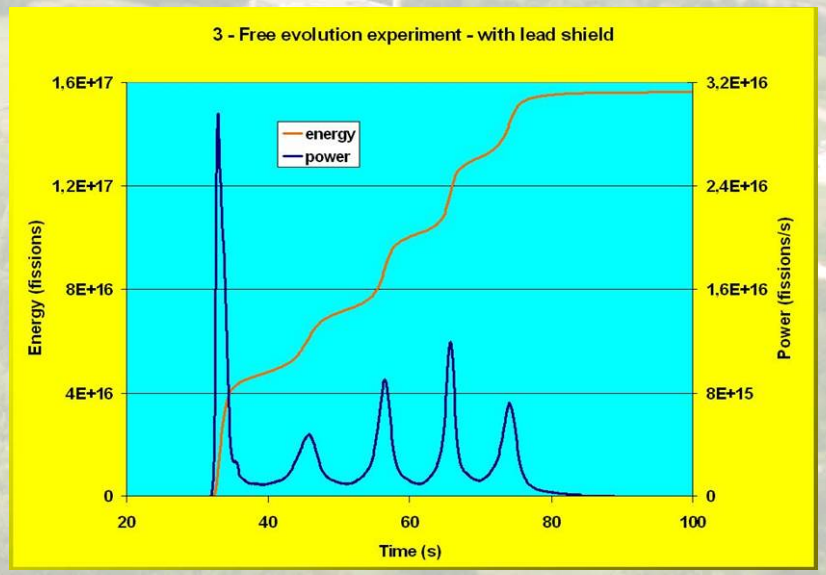
NEXT PLANNED INTERNATIONAL INTERCOMPARAISON DOSIMETRY EXERCICE – Valduc, 2010

- Invitation to participate for US Laboratories to the next National Exercise of Criticality dosimetry
- Schedule on SILENE in week 2009/42

- 7th International Exercise of Criticality dosimetry
  - 1970CRAC, 1993SILENE
  - 1971, 1973, 1975
  - 2002SILENE
  - 2010SILENE (?)



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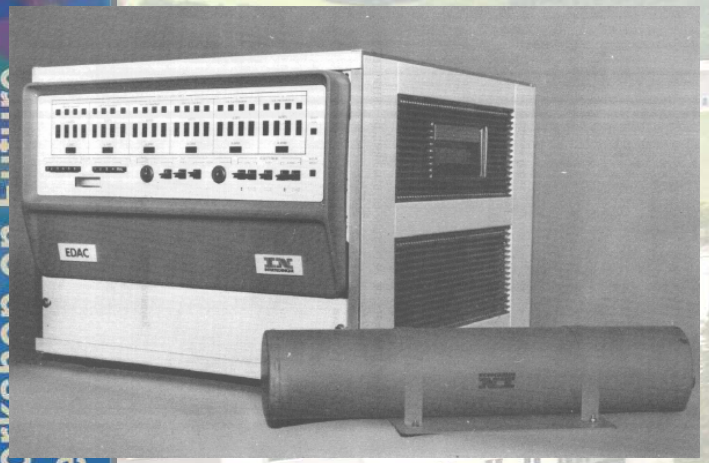
SILENE
A tool to design and support 3 generations of French CAAS (EDAC)

1970 1990 2003

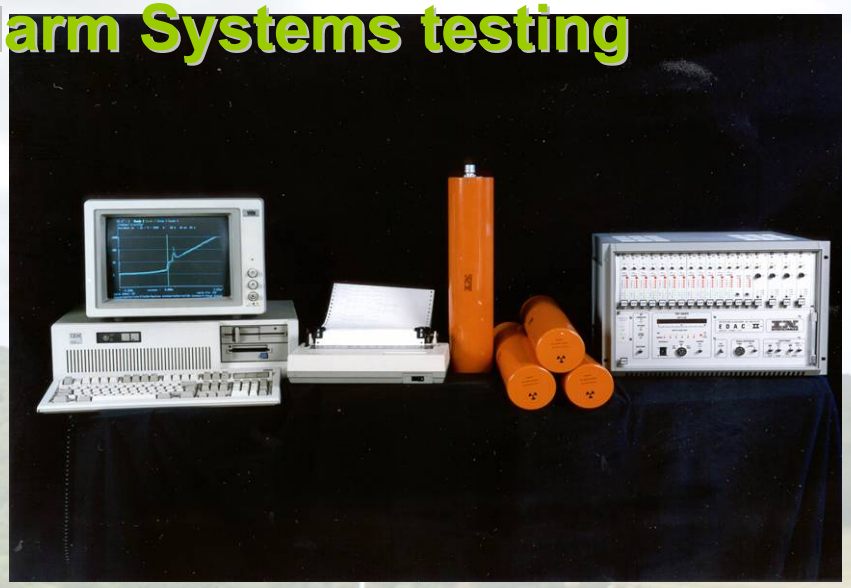


EDAC I **EDAC II** **EDAC 21**

SILENE

Used for Criticality Accident Alarm Systems testing

- CAAS are systems used to detect criticality accidents in nuclear plants or facilities and to initiate workers immediat evacuation to limit exposure risks
- SILENE was used to develop and qualify the French EDAC system (based upon a combination of n and γ measurements)
- SILENE permit EDAC system testing in true conditions



TRAINING FOR OPERATORS PROFECIENCY

- International Agreement between LANL and CEA for development of the hands-on training and training for operators proficiency for the US-DOE / NCSP
- US Operators are training in Valduc (between 2008 and 2010)
- Theorical and Practical training on SILENE, CALIBAN and PROSPERO
- Training Attestation delivered by CEA after knowledge verification

SILENE
Perspectives

⇨ SILENE uses are currently “available” until fall 2010

⇨ SILENE Licensing, in compliance with the new safety and security requirements of French nuclear facilities, is probably impossible without a complete refurbishment:

- SILENE Chemical process facilities are difficult to maintain in safe and efficient conditions due to their old design dating from CRAC facility for part of them (glove boxes for example)
- SILENE command control is outdated (1974) and also very difficult to maintain

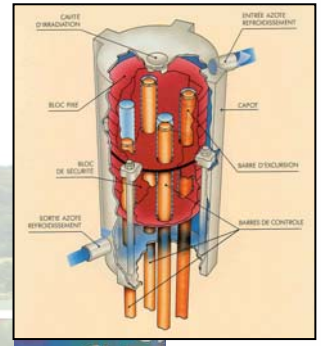
VALDUC Laboratory Criticality Experiment Facilities

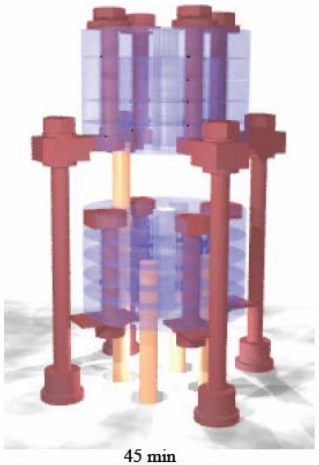
OVERVIEW OF CALIBAN

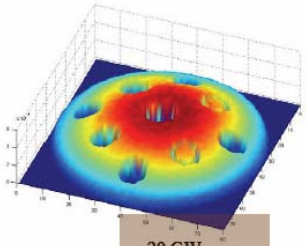
A Super Prompt-Critical (*) Reactor able to study criticality accidents kinetics in metallic systems

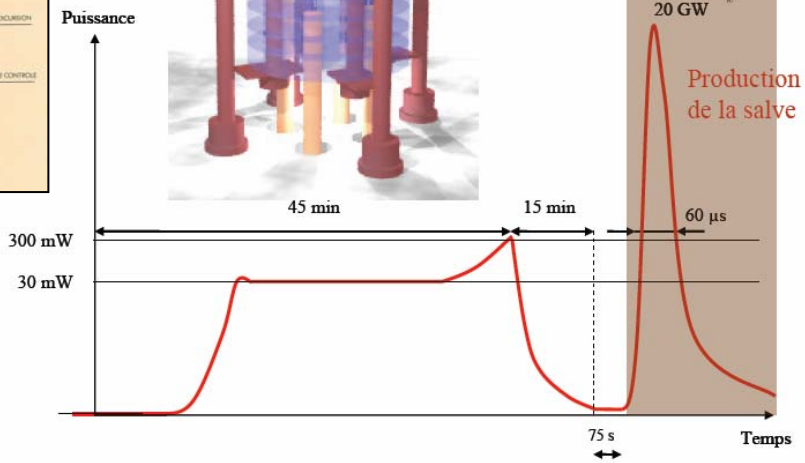
(*) *For a Super Prompt-Critical Pulse a maximum 0.9$ reactivity step can be inserted over prompt critical state*

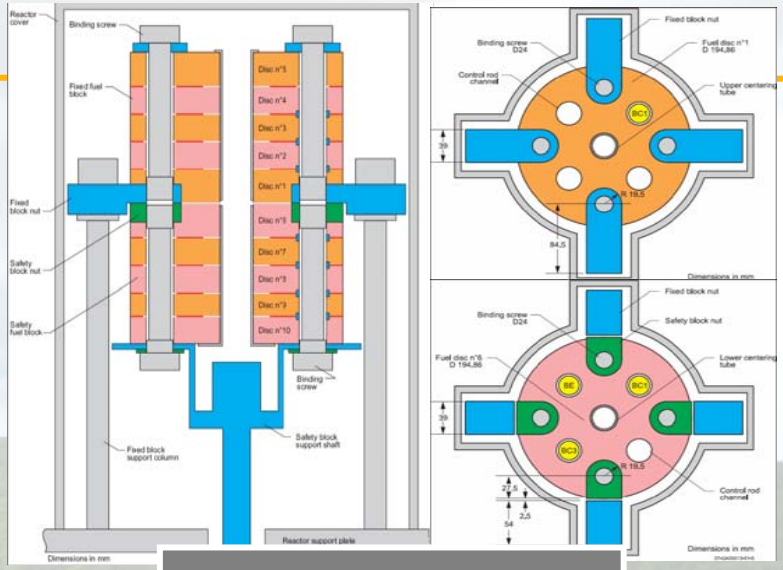
CALIBAN
Super Prompt-Critical Reactor



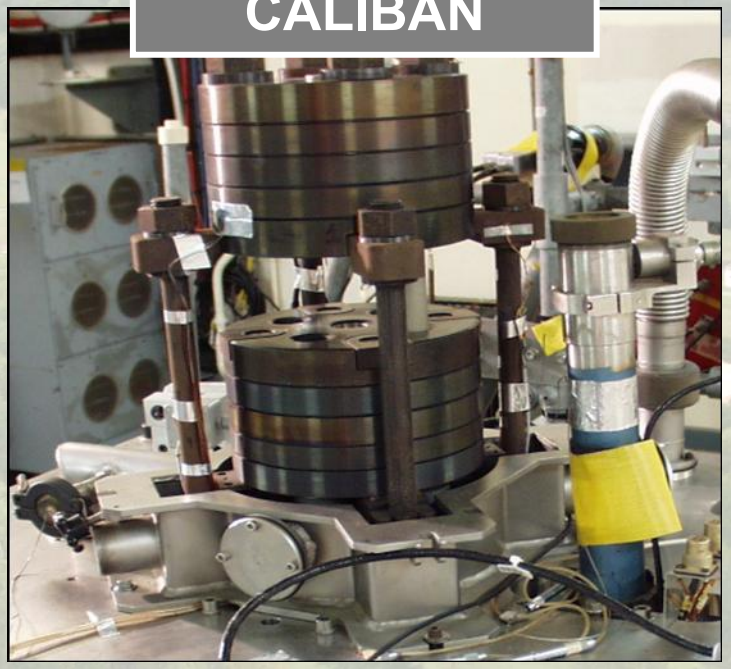


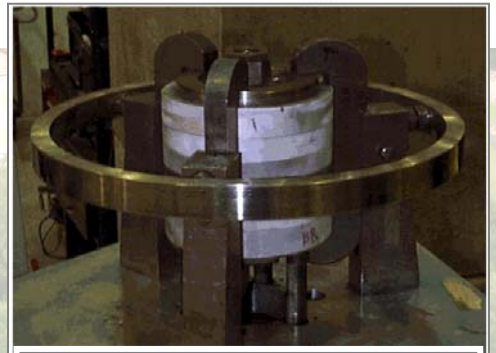






CALIBAN





GODIVA-IV

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
OECD-NEA Workshop on Future Criticality Safety Research Need

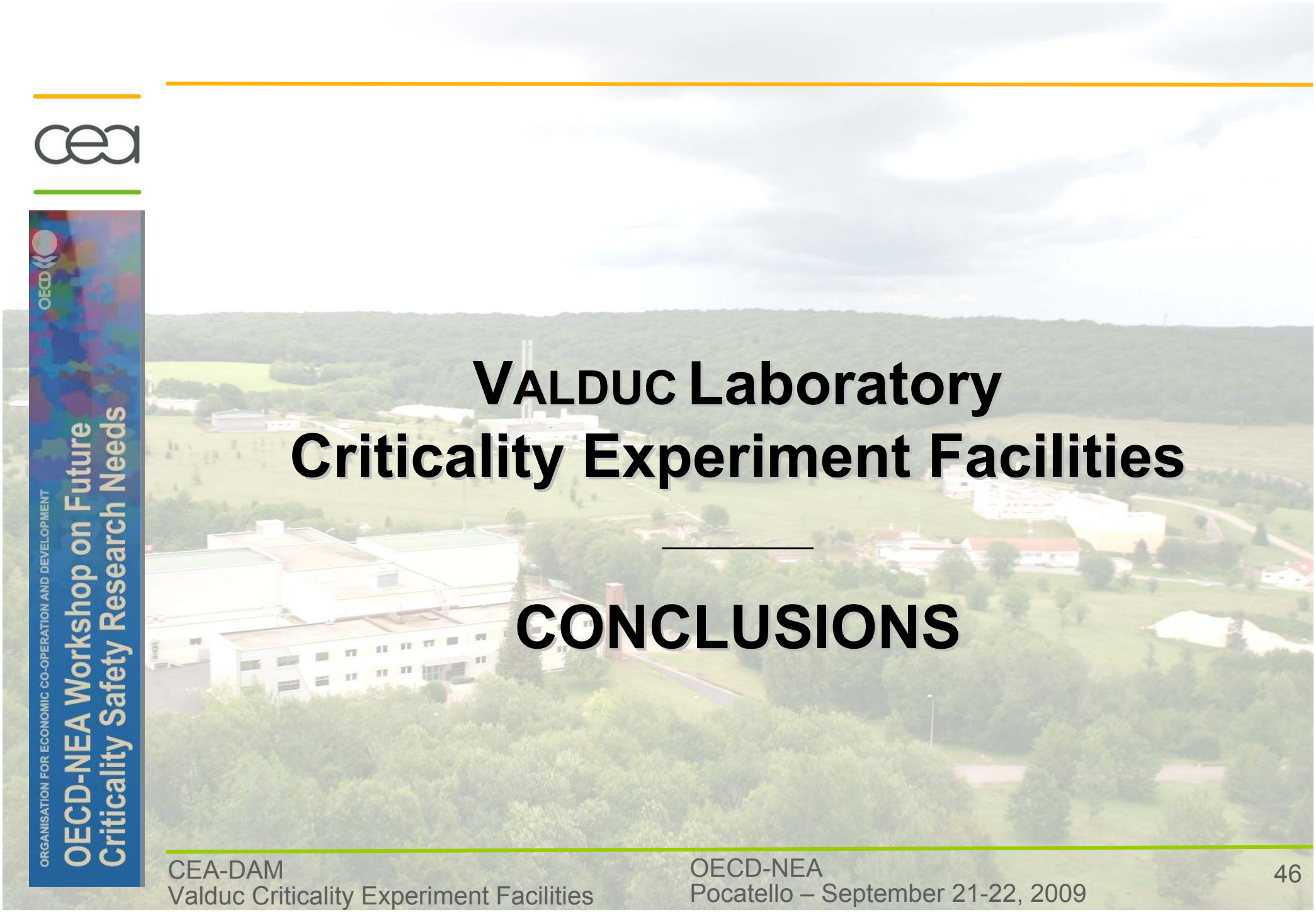
CALIBAN
Key Dates and Experimental Abilities

- ⇨ 1971:
  - First Super Prompt-Critical Experiment conducted at Valduc with CALIBAN
- ⇨ 1971-2009:
  - CEA-DAM Programs supporting the French Nuclear Weapons Stockpiles Stewardship and associated R&D
- ⇨ More than **3000 divergences and sub-critical experiments** were performed on the CALIBAN reactor for criticality studies, and various other applications (neutron science studies, materials and components irradiation for hardness testing)

CALIBAN

Recent main applications

- Integral measurement of ^{235}U isomer with CALIBAN Reactor
  - US-DOE / NNSA – CEA-DAM – ^{235m}U Program (2005 – 2006)
  - ~ 60 experiments were performed
  - The results of this experiment have been compared to the last evaluated cross section and presented in the 5th NEMEA Workshop
- Reactivity worth measurements by perturbation method with CALIBAN and SILENE reactors
  - Experiments have been already performed with CALIBAN since few years (^{239}Pu – ^{237}Np) and some other experiments are planned
  - Calculations have been recently performed to prepare future experiments on new materials, such as light elements, structural materials, fission products and actinides
- Calculation of kinetic parameters of CALIBAN Reactor from stochastic neutron measurements
  - Few experiments have been already performed with CALIBAN using few methods (2007 – To be continued)
  - Sub-critical, critical, and even super-critical experiments were performed. With the Rossi-α method, it was found that the prompt neutron decay constant at criticality was 6.02×10^5 s^{-1} ± 9%



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VALDUC Laboratory Criticality Experiment Facilities

CONCLUSIONS

FUTURE OF THE BUILDING 010 …

- SILENE uses have continiously decrease between 2003 and 2006 with the IRSN progressive withdrawal of radiobiology and radioprotection studies programs
- In January 2005, IRSN decided to stop using SILENE
- SILENE Facility is planed to be dismantled in 2012 after the ultimate Fission Product's PUREX purification campaign and HEU solutions reconditioning for long term storage
- The Plutonium Purification Laboratory was used until fall 2005 and it is planed to be dismantled in 2010 after plutonium solutions reconditioning for long term storage and americium solutions evacuation
- Radiochemistry Analysis Laboratories will be necessary until complete refusbishment or as long as U or Pu solutions will be under process into the Building 010

TO CONCLUDE CONCERNING THE BUILDING 010

- ⇨ It is an unique combination of people and materials located in the same place
- ⇨ It is nearly the last facility of its kind in the world with such fissile material inventory witch is now impossible to reproduce
- ⇨ It is considered as vital by French and US Experts to maintain such abilities to support fissile material operations and to prevent criticality accidents

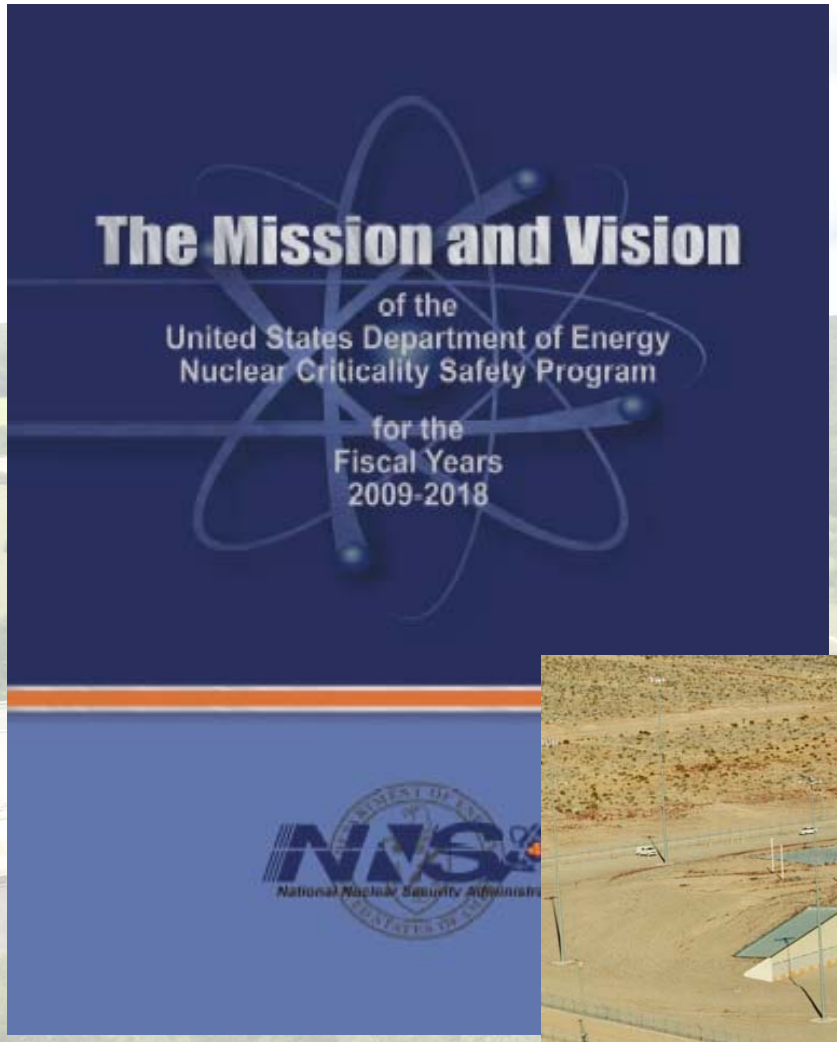
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

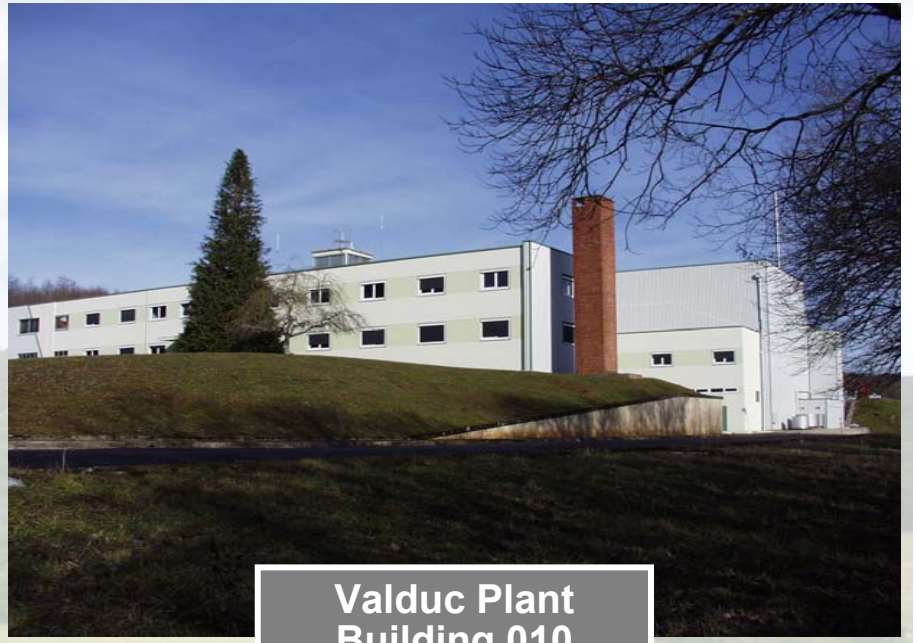
OECD-NEA Workshop on Future Criticality Safety Research Needs

VALDUC Laboratory
Criticality Experiment Facilities

NEEDS FOR FUTUR
FRENCH – US COMMON INTEREST

A COMMON VISION …





Valduc Plant
Building 010

Nevada Test Site
Device Assembly Facility

POSSIBLE FRENCH – US COLLABORATION

- Possible French – US collaboration between CEA, IRSN and US-DOE / NNSA for jointly refurbish Valduc Criticality Experiments Facilities (Building 010) witch need to be up graded to be in compliance with the new safety and security requirements of French nuclear facilities to be able to performed new experiments

- Capability to propose a New and French – US Common Experimental Platform for Neutron Science and Criticality able to be a response for future world needs and to sustain state-of-the-art and up-grade our knowledge in Criticality Safety

TIME SCHEDULE FOR THE NEW PLATFORM PROJECT

- ⇨ **2009-2011**: Dismantling of the Chemical Plutonium Recycling Laboratory
- ⇨ **2011-2014**: Dismantling of existing Experimental Devices and related facilities
- ⇨ **2014-2015**: Dismantling of the Radiochemistry Analysis Laboratories

- ⇨ **2010-2011**: Approval of the **General Specifications**
- ⇨ **2010-2013**: Feasibility Studies, Definition of General Purpose for Safety and Security Objectives ⇨ **Preliminary Design**
- ⇨ **2012-2018**: Final Design, Construction and First Tests