DE LA RECHERCHE À L'INDUSTRIE

POST IRRADIATION TESTING CAPABILITIES OF EXPERIMENTAL REACTOR COMPONENTS AT THE LECI FACILITY FOR SERVICE LIFE ASSESSMENT

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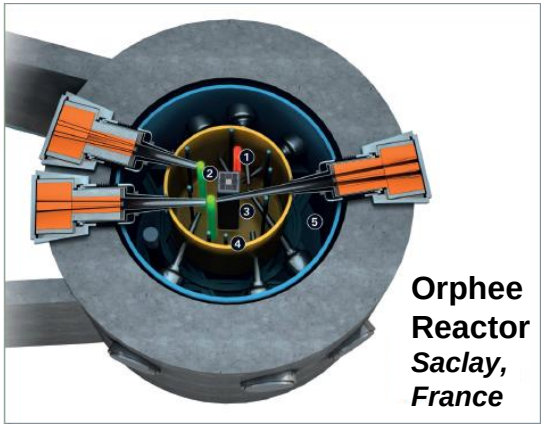
BACKGROUND

Assessment of the environmental degradation of experimental core components is crucial for:

- Safe et efficient operation of experimental reactors
- Determination of achievable service time and replacement schedule

Feedback is needed in particular on:

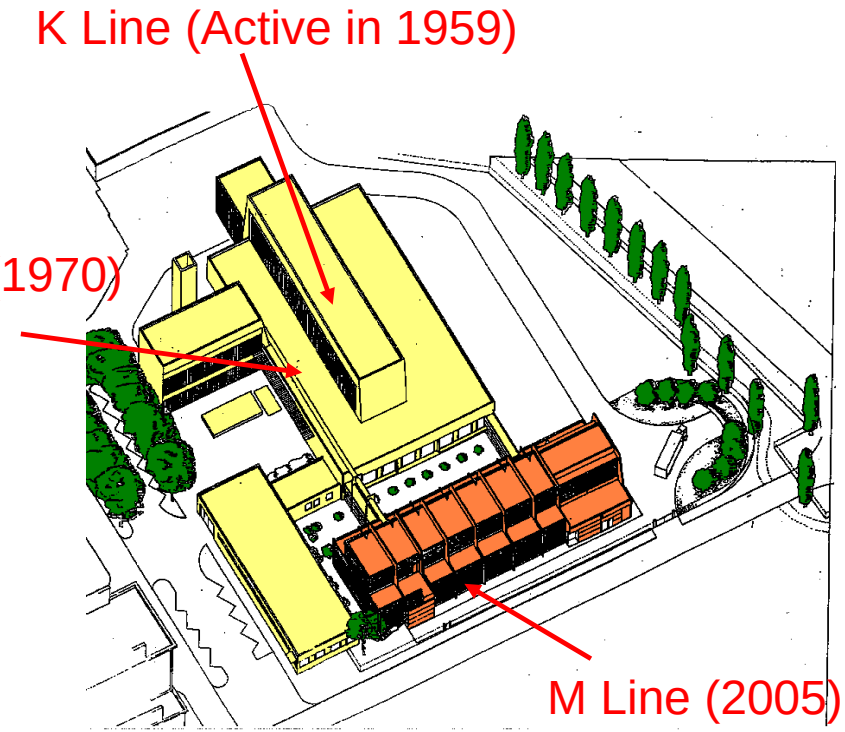
- Mechanical properties evolution under irradiation
- Amount of Al to Si transmuted
- Corrosion behavior
- Swelling



[Monographies DEN, Research Nuclear Reactors, CEA, 2012]

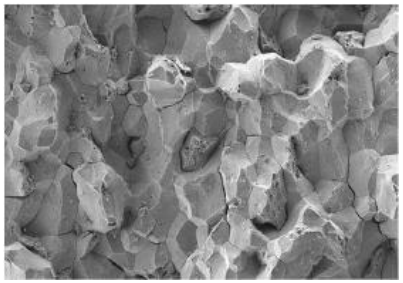
THE LECI FACILITY

- **Hotlab located in Saclay, near Paris, France**
- **Three lines of hotcells**
- **Mission:** characterization of non-fissile irradiated materials
  - Determination of behavior in normal, accidental or storage conditions
  - Prediction of in-service lifetime
- **Materials studied:**
  - Gen 2&3 reactors (RPV Steel, Zr alloys)
  - **MTR (Aluminum alloys)**
  - Gen 4 reactors (sodium or gas cooled FBR)



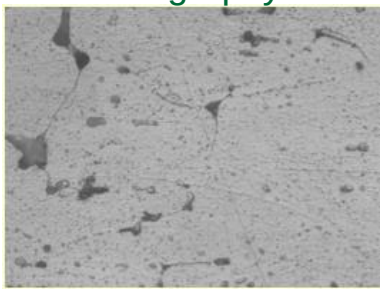
CHARACTERIZATION OF MATERIALS AT THE LECI FACILITY

Fractography

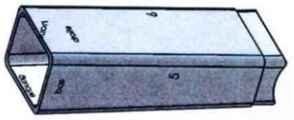


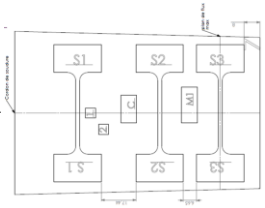
Microstructure

Metallography

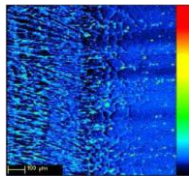


Orphee 4F cold finger

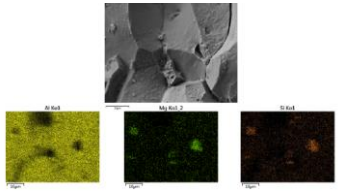




EPMA

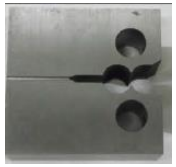


EDS



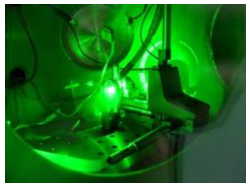
Tensile tests

Fracture Toughness



Impact Testing

LIBS

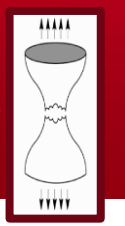


ICP-AES

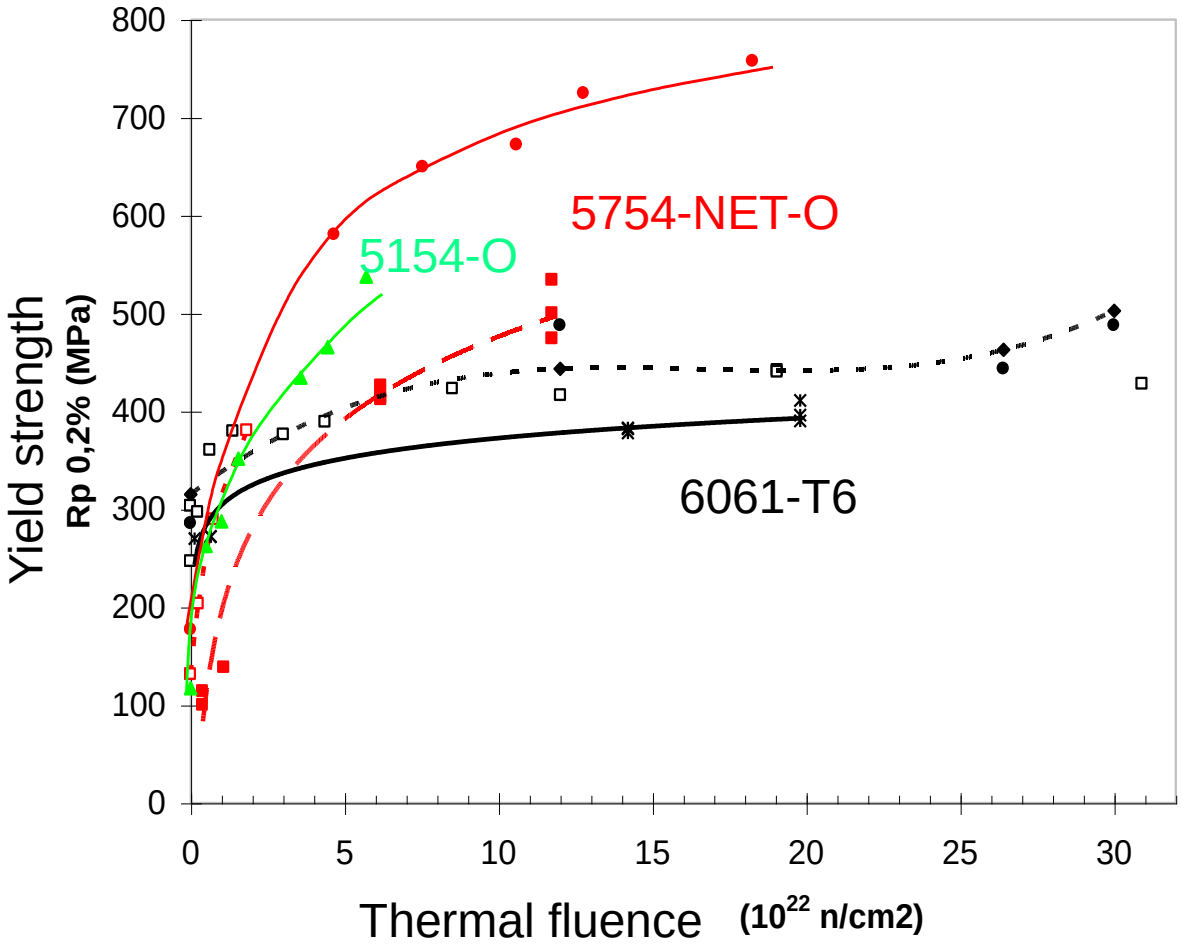
Mechanical Behavior

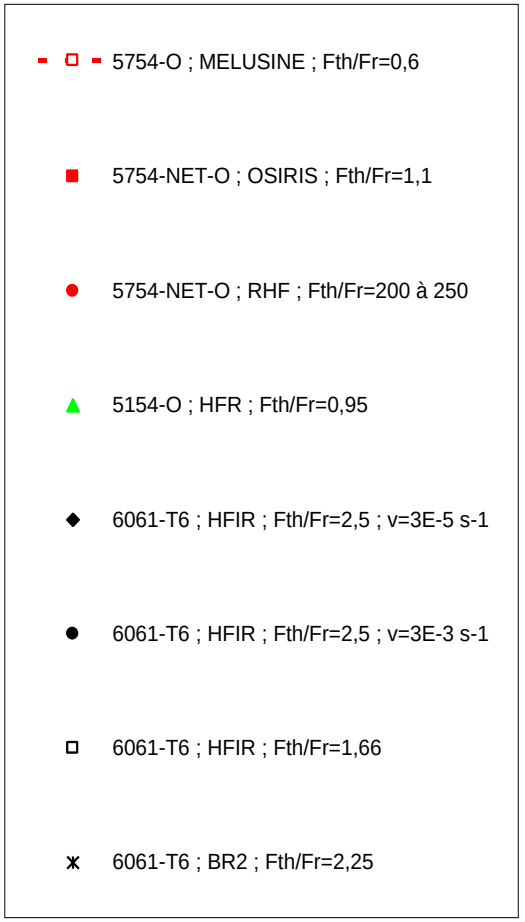
Chemical Analyses

MECHANICAL BEHAVIOR UNDER IRRADIATION (1/2)



Example of hardening of aluminum alloys under irradiation as measured by tensile tests

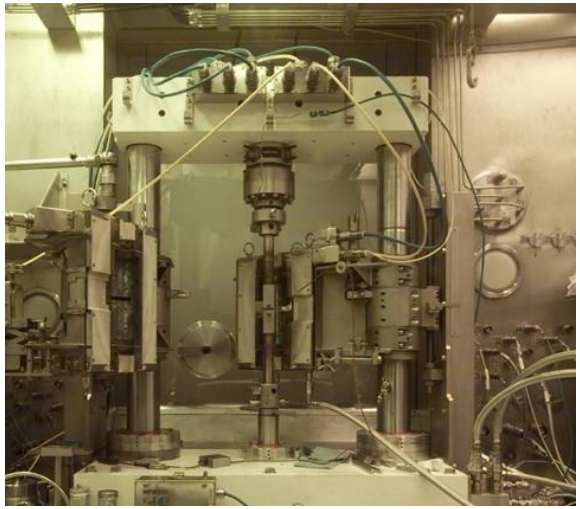




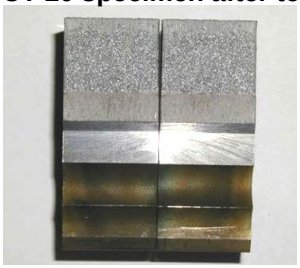
[B.Kapusta, INSTN, Aluminum Behavior Under Irradiation, 2011]

MECHANICAL BEHAVIOR UNDER IRRADIATION (2/2)

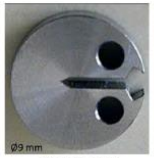
Fracture toughness Testing Servo-Hydraulic Machine (100 kN)



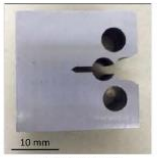
CT 20 specimen after test



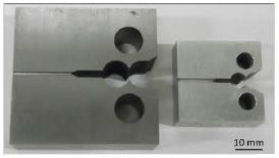
Application to surveillance programs of core components for MTRs and NPPs



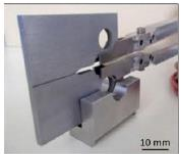
Compact Tension (type CTR5)



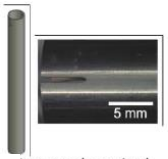
Compact Tension (type CTK)



Compact Tension (type CTJ)

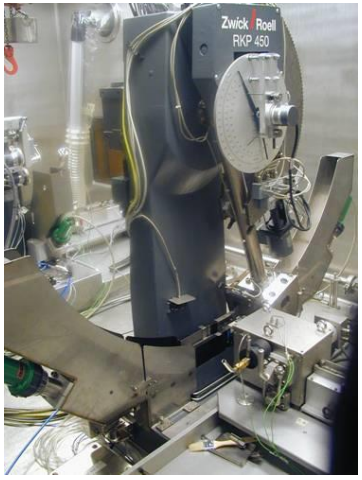


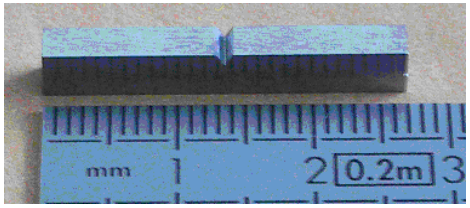
Compact Tension unconventional thickness



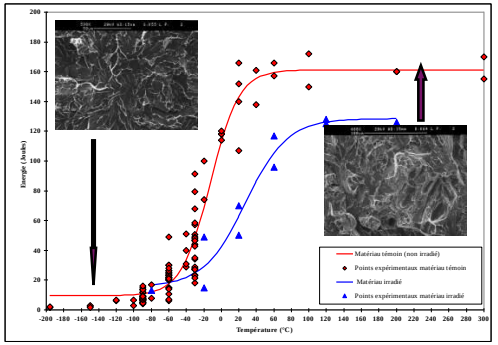
Internal conical mandrel (ICM)

350 J Charpy Impact Testing



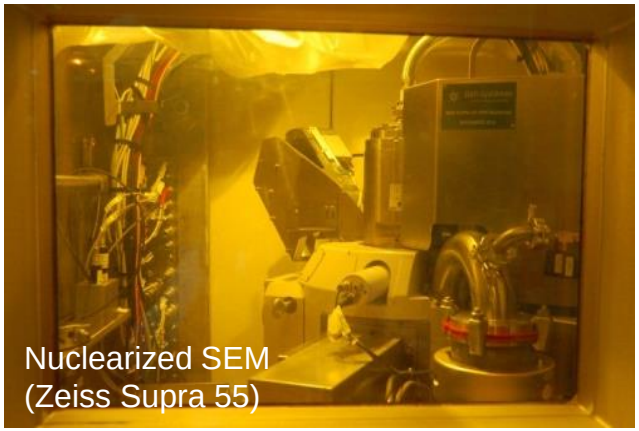


Ductile-Brittle transition (impact tests)

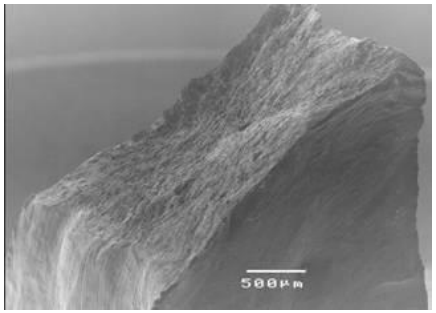


MICROSTRUCTURAL EXAMINATIONS (1/2)

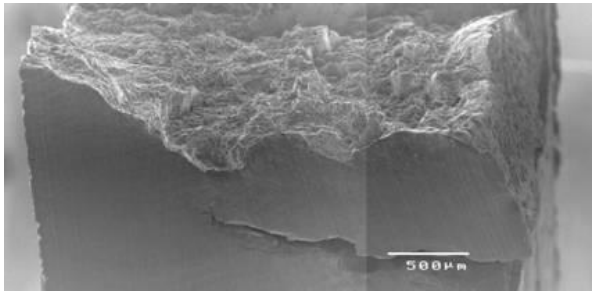
Microscopic characterization



Fractography of broken tensile sample surfaces



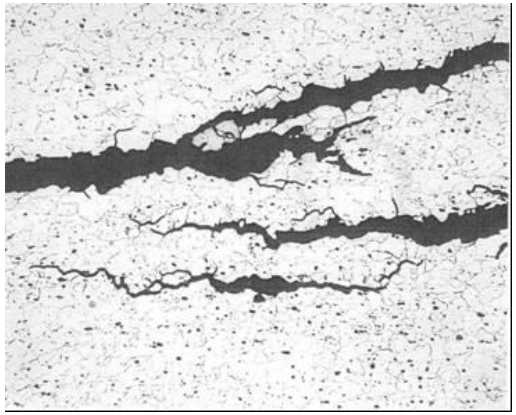
Dose: $4x10^{21}$ n/cm^2
Ductile behavior

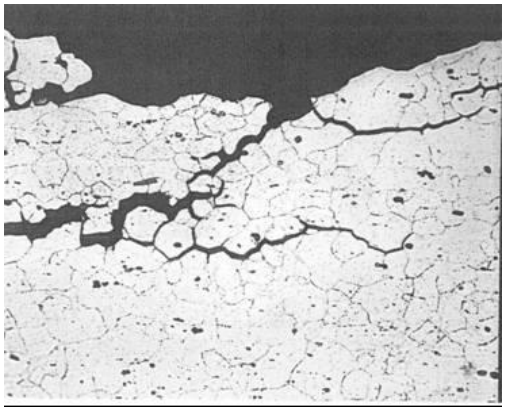


Dose: $11.7x10^{22}$ n/cm^2
Brittle behavior

[B.Kapusta, INSTN, Aluminum Behavior Under Irradiation, 2011]

Example of foiling corrosion on 5754-NET-O alloy with important hardening

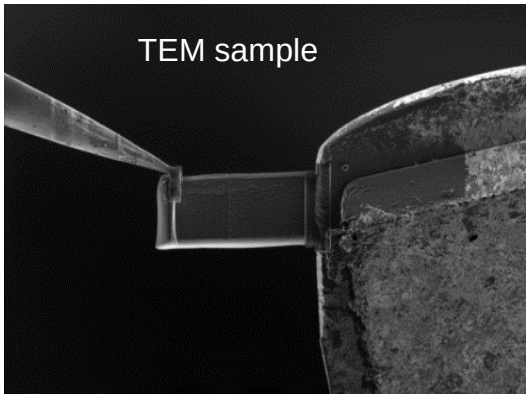


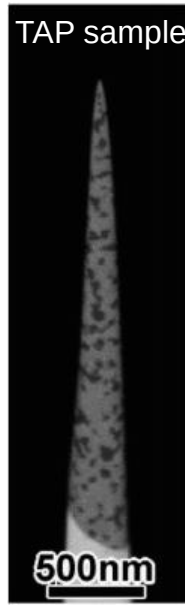


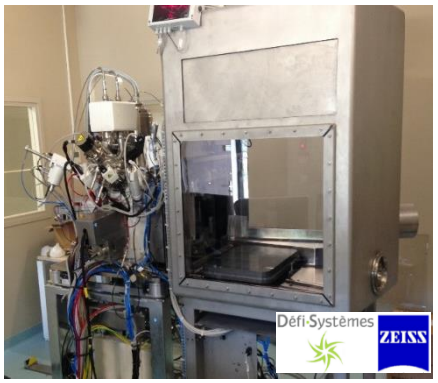
MICROSTRUCTURAL EXAMINATIONS (2/2)

Nano-characterization

Sample preparation by nuclearized FIB or electropolishing



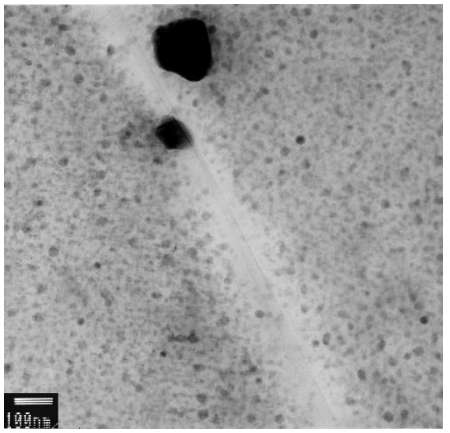




Nuclearized FIB-SEM (Zeiss Auriga 40)

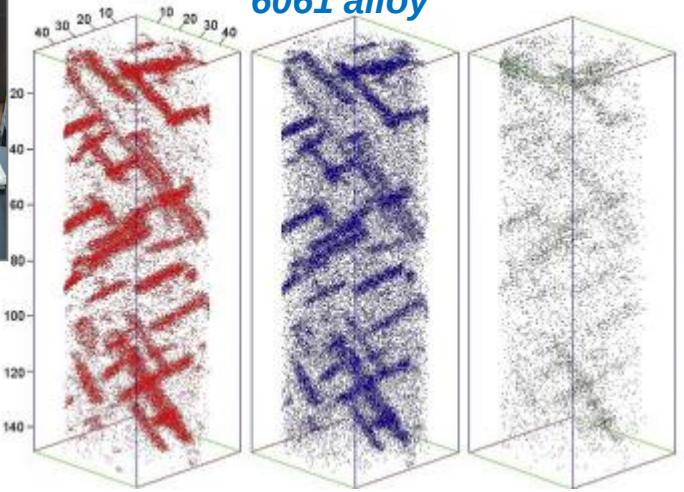
Nuclearized Atom Probe

Precipitate-free zone in heavily irradiated 6061-T6 ($2x10^{23}$ n_{th}/cm^2)



[B.Kapusta, INSTN, Aluminum Behavior Under Irradiation, 2011]

Mg-Si needles in Si-enriched 6061 alloy



[K. Buchanan et al. Acta Materialia, v132, 2017]

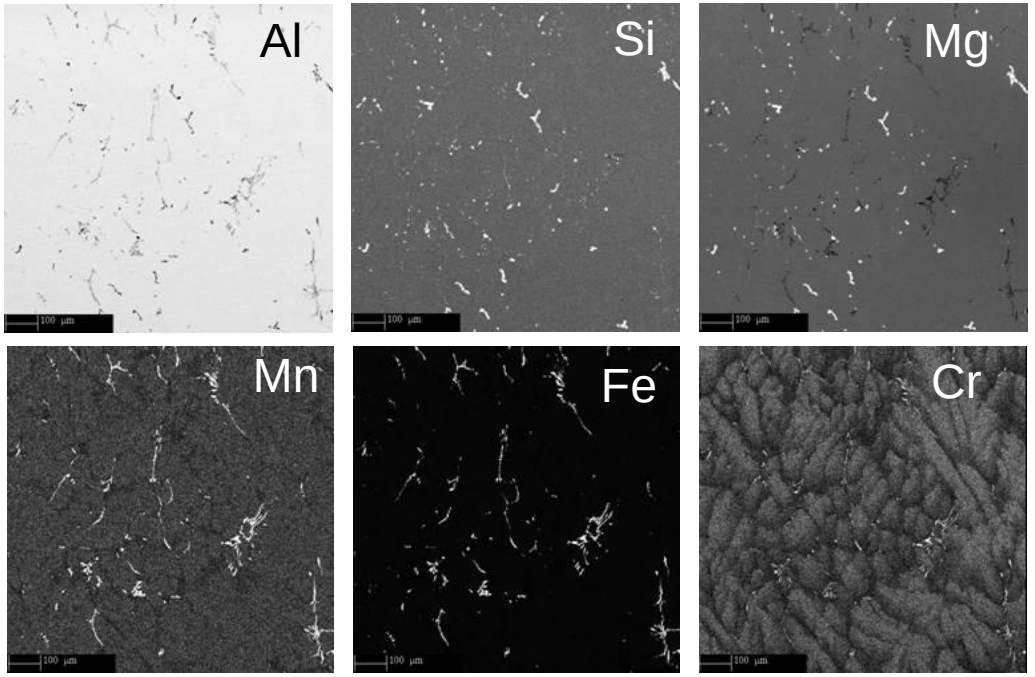
Nota :This work profited from a French government grant managed by the National Agency of Research under the program "Investments for the future" (ref. ANR-11-EQPX-0020

CHEMICAL ANALYSES (1/2)

Nuclearized Electron Probe Micro-Analyzer

Examples of EPMA analyses on 5754-NET-O

Observation of precipitation and radiation-induced migration of chemical elements

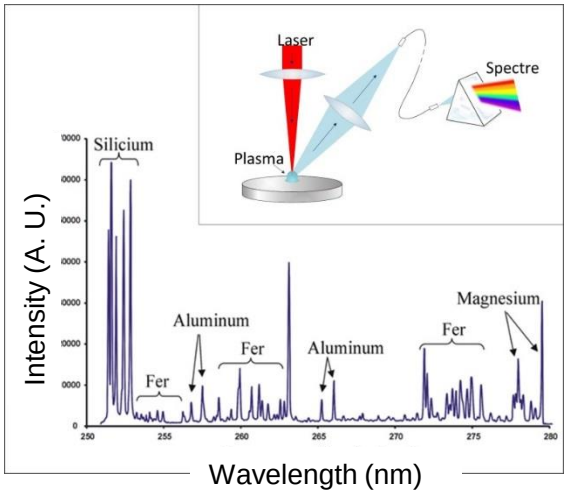


Φ_{th} (0,0254 eV) = 8,2 x10^{22} n/cm^2 ΔSi_{wt} = 2,1%

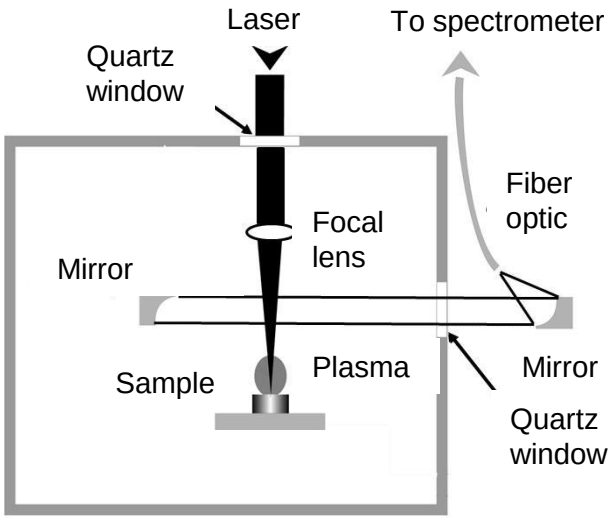
[B.Kapusta, INSTN, Aluminum Behavior Under Irradiation, 2011]

CHEMICAL ANALYSES (2/2)

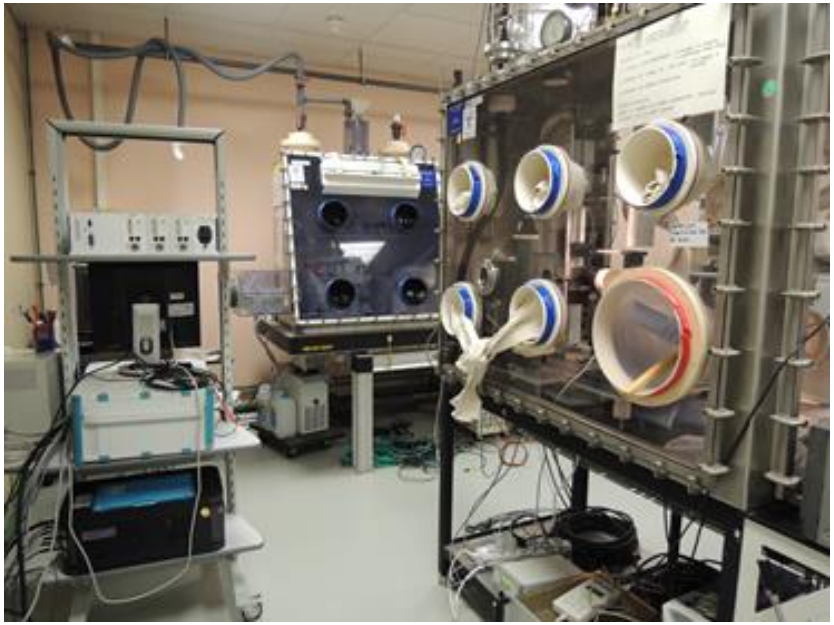
Nuclearized Laser-Induced Breakdown Spectrometer



Courtesy of N. Coulon
CEA, DPC/SEARS

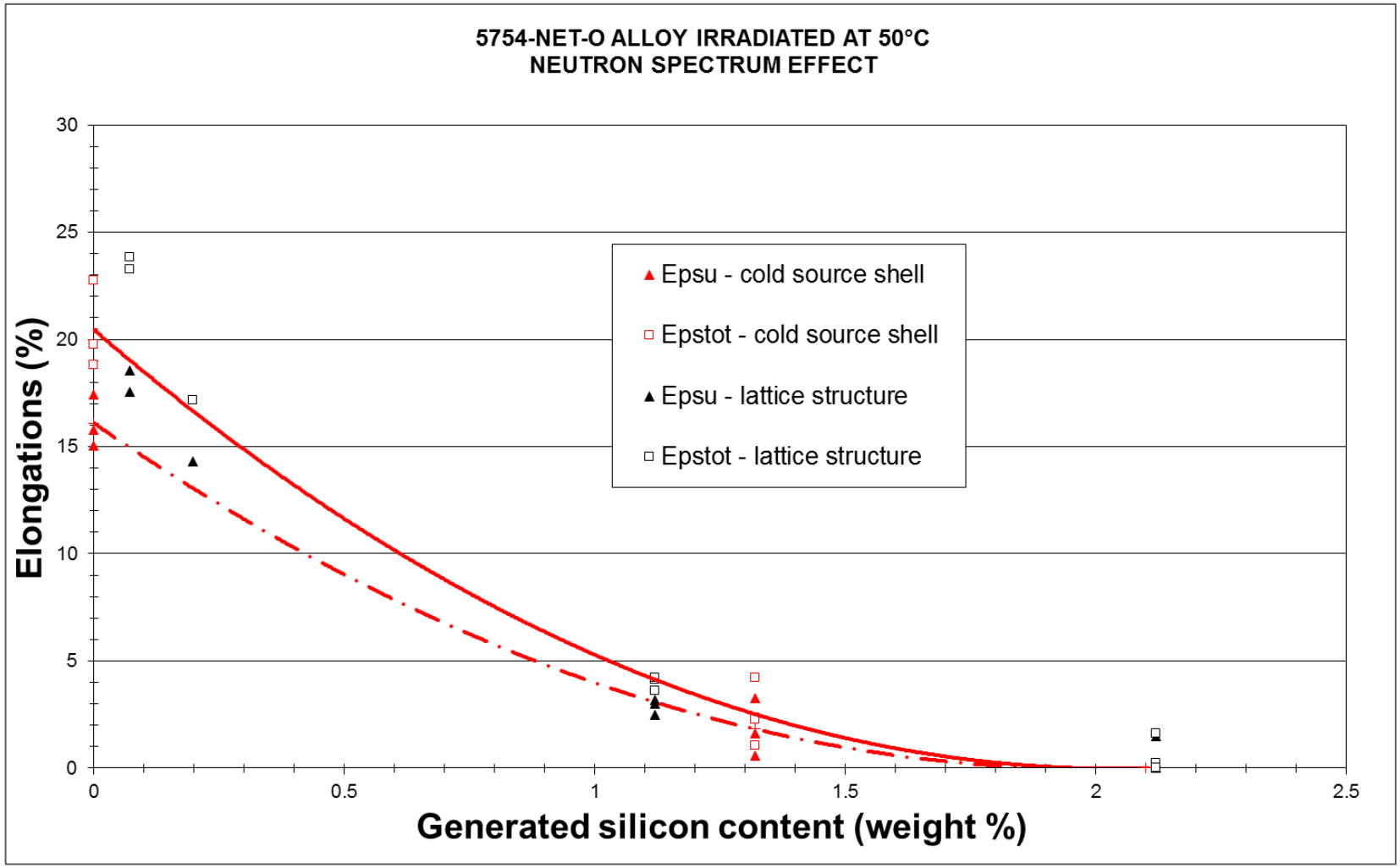


- **LIBS technique:** measurement of Si content on centimeter size samples
  →information on received dose (transmutation Al-Si)
- Also available **ICP-AES technique** on Al shavings from massive components
  →information on Mg, Fe, Si contents



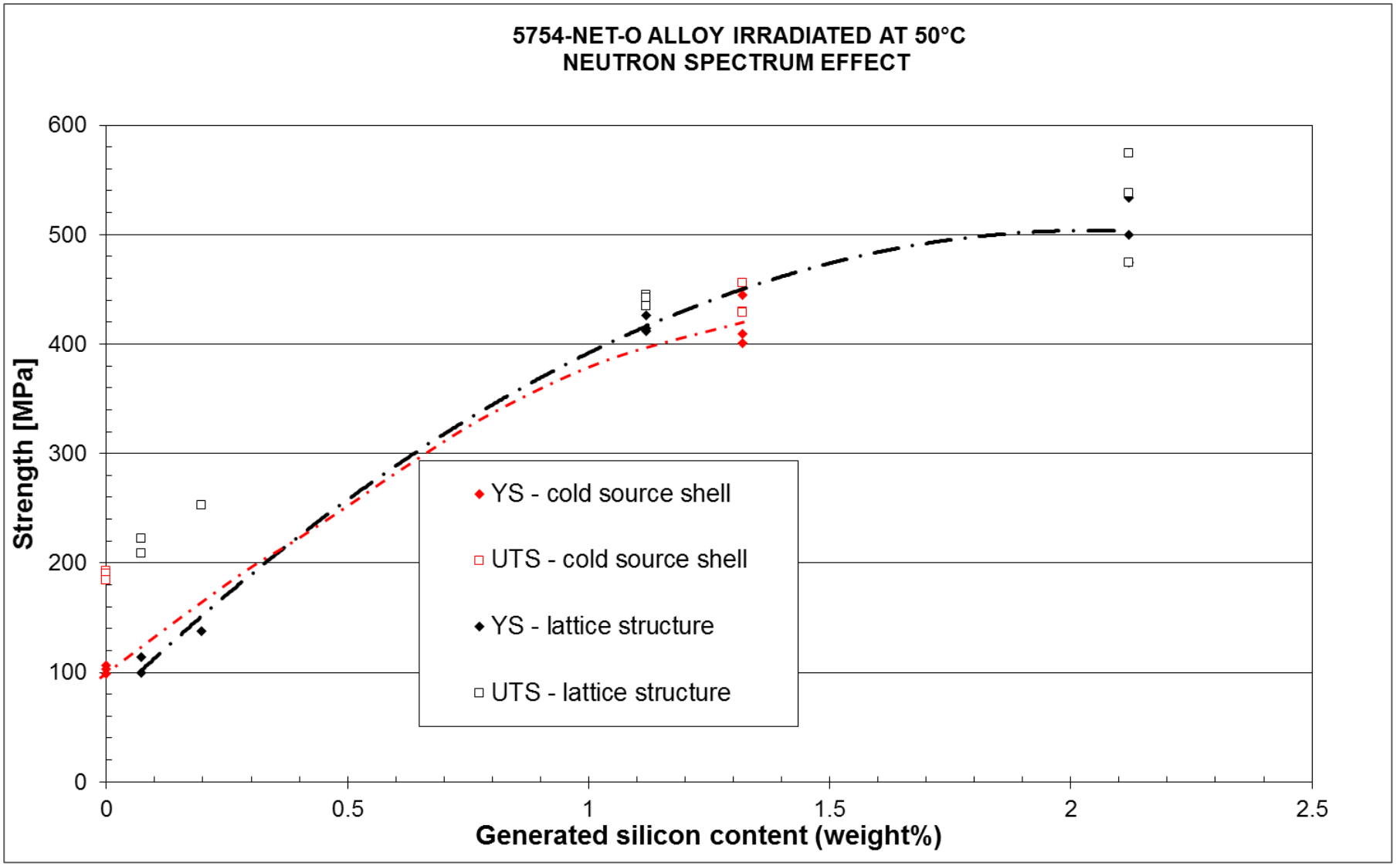
CORRELATION SI CONTENT AND MECHANICAL BEHAVIOR (2/2)

Generated Si content (from Al transmutation) is directly linked to embrittlement and hardening of the components of MTRs



[B.Kapusta, IGORR, 2005]

CORRELATION SI CONTENT AND MECHANICAL BEHAVIOR (2/2)



[B.Kapusta, IGORR, 2005]

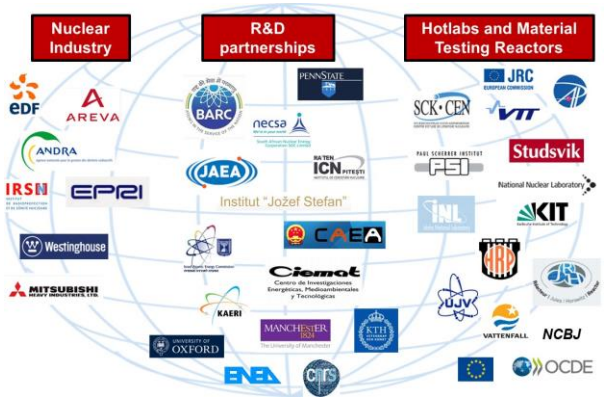
CONCLUSIONS

- Methods and experimental capacities have been developed over the years at the LECI facility in order to characterize non-fissile materials.

- These means can be applied to MTRs core components such as pressure vessels, experimental racks, neutron guide tubes for example.

- Several aspects of the impact of irradiation on aluminum components can be studied:
  - Degradation of mechanical properties (hardening, embrittlement)
  - Microstructure evolution (radiation-induced segregations, precipitation)
  - Enhanced corrosion
  - Swelling

- Application to
  - Surveillance programs of MTRs
  - Prediction of component lifetime/replacement



- LECI is open to national and international clients through direct contracts or international scientific collaboration

Commissariat à l'énergie atomique et aux énergies alternatives
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