

IRRADIATION SERVICES

Neutrons for industry & health

cea

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ADVANCED MATERIALS AND FUELS IRRADIATION SERVICES

CEA delivers an expanded portfolio of irradiation and complementary services designed to support the safe, reliable, and cost-effective deployment of materials and fuels in both current and next-generation nuclear reactors.

Leveraging decades of operational experience and recognized expertise at the highest level, we provide high-quality experimental data tailored to the needs of utilities, fuel vendors, reactor designers, and research organizations.

JHR Irradiation Services

Irradiation of materials

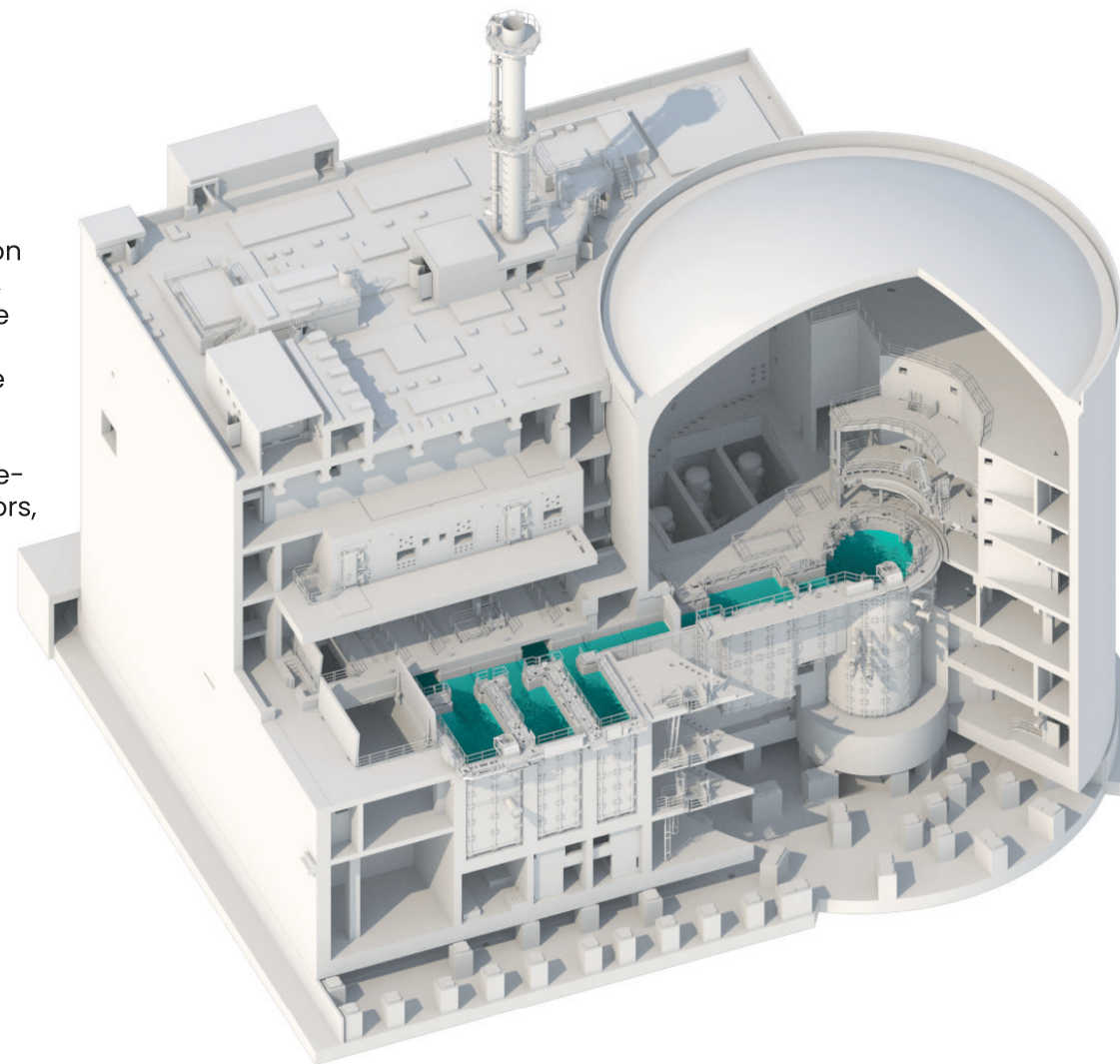
The performance of materials (structural materials and claddings) under neutron irradiation is a key factor in reactor safety, lifetime extension, and economic efficiency. We offer comprehensive materials irradiation programs covering a broad range of neutron fluxes, spectra, and temperature conditions.

Our services support for example lifetime management and ageing assessment of operating reactors, qualification of materials for new nuclear builds, but also screening, development, and validation of advanced materials for new reactor concepts.

Irradiation of fuels

Nuclear fuel behavior under irradiation is central to reactor performance and operational safety. We offer specialized services to investigate and qualify existing and advanced fuel concepts.

Our fuel irradiation programs contribute to continuous fuel performance improvement and enable the development of new fuel types.



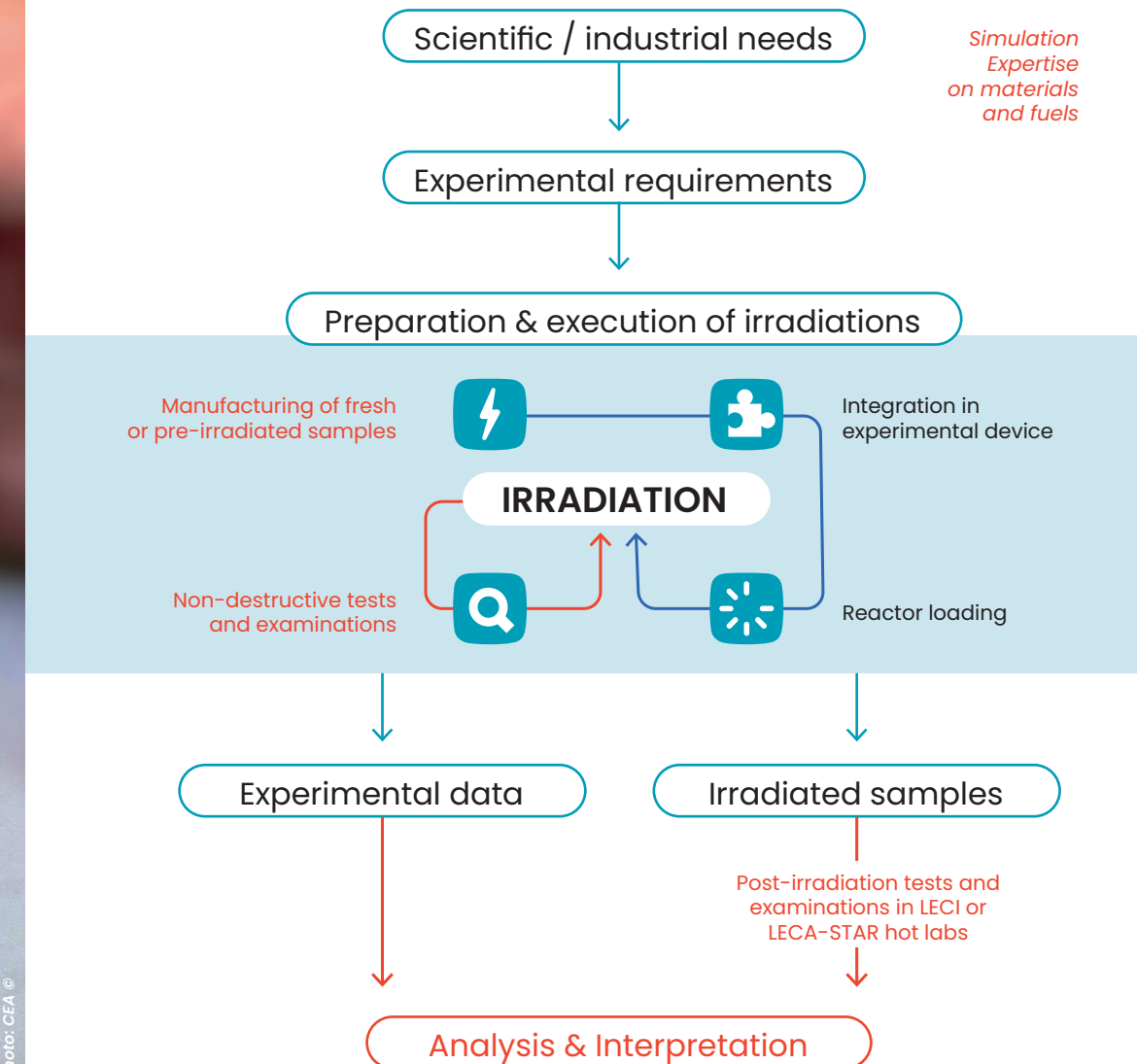
Our capabilities include:

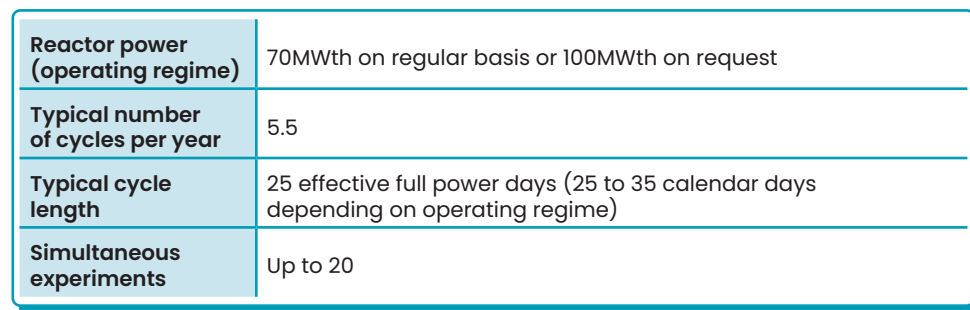
- Safe manufacture, preparation and handling of fuel and material samples, possibly pre-irradiated and instrumented,
- Access to advanced and high-performance irradiation rigs and experimental devices,
- Execution of irradiation campaigns under stable and well-characterized neutron flux and spectrum conditions,
- Precise operation of high-power transient representative of normal operation and off-normal power-reactors conditions,
- Development and deployment of in-pile instrumentation for real-time monitoring of key parameters such as sample temperature, dimensions, crack propagation, fuel power, gas pressure, fission gas release, etc...
- Comprehensive post-irradiation examination and characterization of irradiated material and fuel samples, including 3D imagery, mechanical testing, microstructural analysis and physical property characterization.



TYPICAL IRRADIATION PROCESS AND RELATED SERVICES

Optional services indicated in red can be provided by CEA in addition to irradiation in JHR





The main image shows a scatter plot of blue dots on a white background. The dots are arranged in a grid-like pattern, with some dots missing, creating a sparse, irregular distribution. In the bottom right corner, there is a small inset graph. The graph has a vertical axis labeled $(10^{14} \text{ n/cm}^2/\text{s})$ with tick marks at 2.5, 3.0, 3.5, and 4.0. The horizontal axis is unlabeled. A red line is plotted on the graph, showing a sharp increase from approximately 2.5 to 3.0, followed by a series of peaks and troughs, reaching a maximum of about 3.3 before ending.

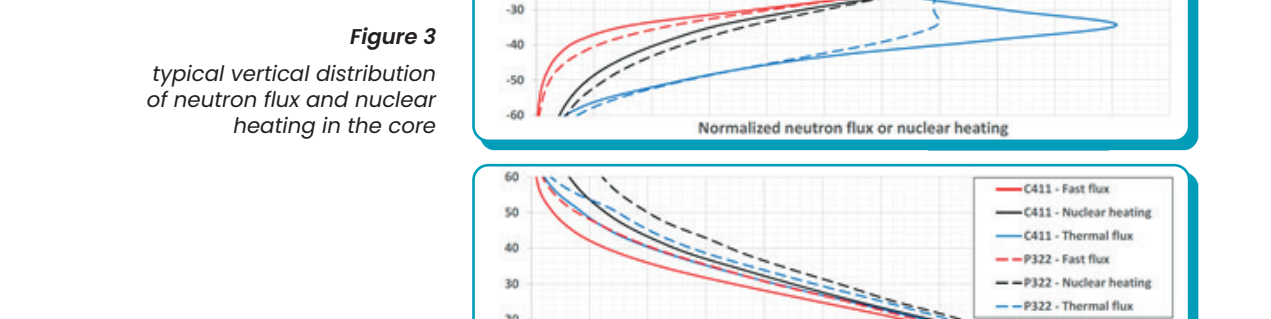
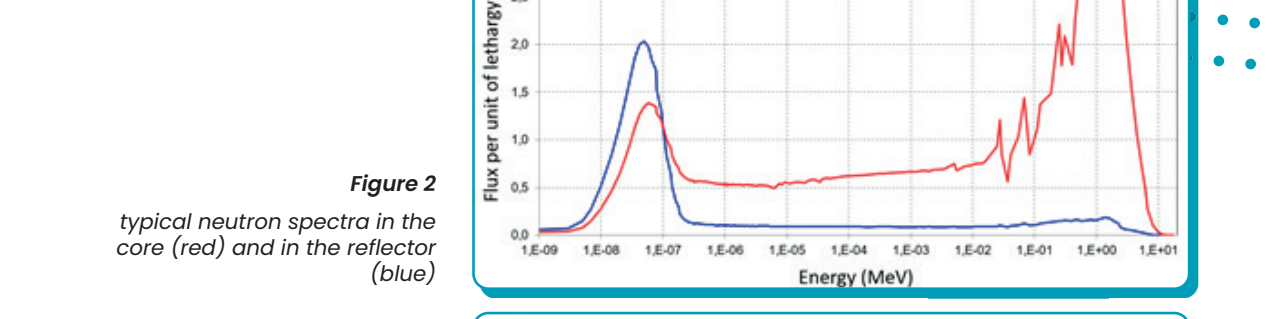


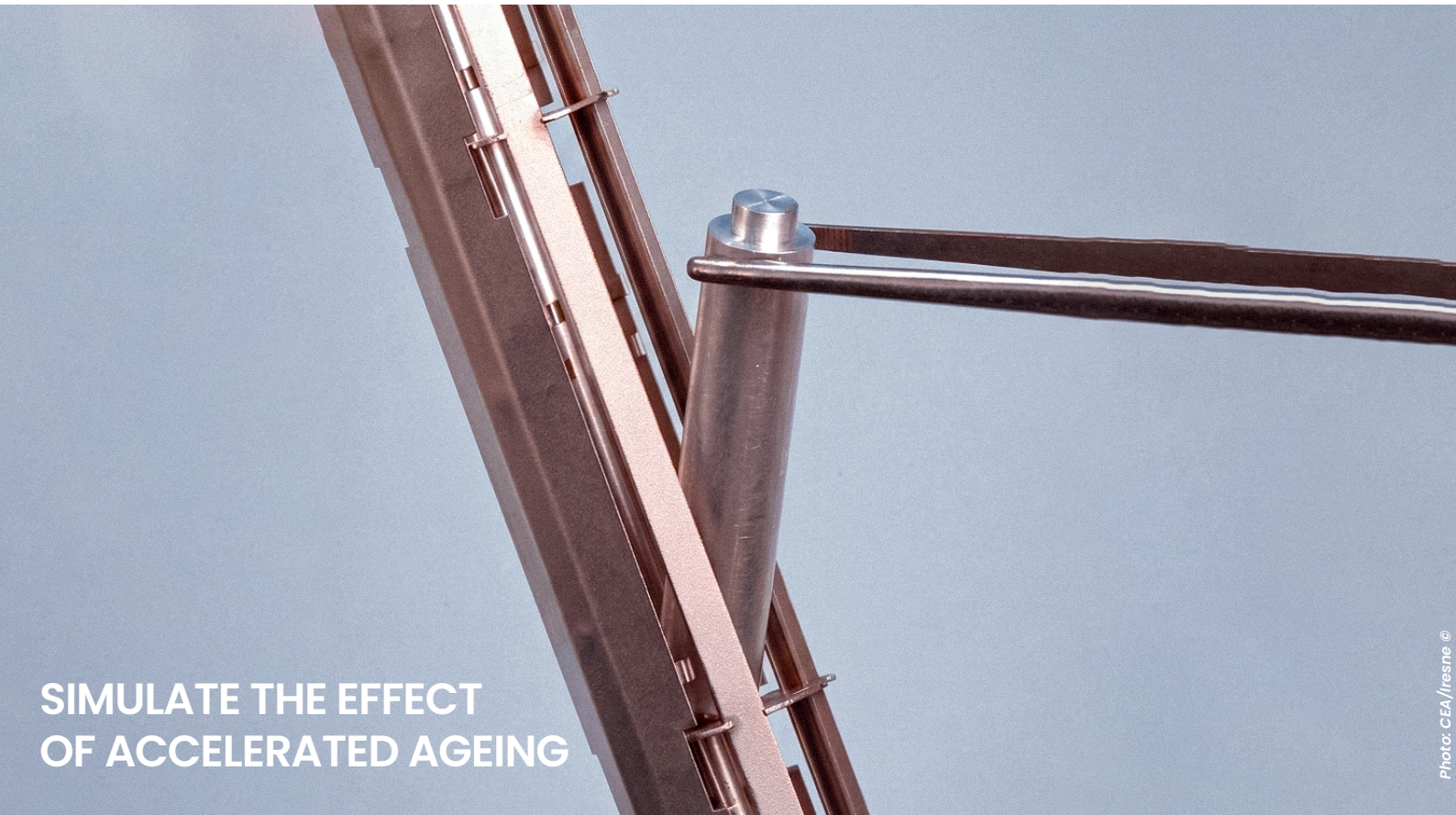
Figure 4
typical vertical distribution
of neutron flux and nuclear
heating in the reflector



MATERIAL EXPERIMENTS IN MICA DEVICES

General objective: Monitoring the evolution of the physical and mechanical properties of non-fissile materials, as a function of parameters such as neutron flux, fluence, irradiation temperature...
The phenomena studied can for example include the tensile properties, fracture toughness, irradiation creep/relaxation rate, irradiation swelling, etc... Depending on the needs, dimensional measurements can be performed online or in hot cells during intermediate unloading of the samples.

- MICA devices include: sample holder, capsule, underwater lines and out-of-pile equipment
- MICA sample holders are specific to each experiment
- MICA capsules, underwater lines and out-of-pile equipment are generic



SIMULATE THE EFFECT
OF ACCELERATED AGEING

Photo: CEA/Iresne ©

Types of samples	Metallic or ceramic non-fissile materials Fresh or pre-irradiated samples Compatible with pressurized samples
Size of samples	Sample load must fit in a cylinder with a diameter of 24mm and a height of ~600mm maximum
Number of samples	Defined by the volume of the load (see above)
Samples environment	NaK (56% K in mass)
Irradiation location	In-core (7 possible locations: 101, 105, 203, 207, 303, 307, 313)
Irradiation conditions at 70MW: Fast neutron flux ($E > 1\text{MeV}$) Fast neutron flux ($E > 0.1\text{MeV}$) Total neutron flux Damage rate	<i>Average flux at the maximum flux level (depending on location)</i> Up to $3.4 \times 10^{14} \text{ n.cm}^{-2}.\text{s}^{-1}$ Up to $6.9 \times 10^{14} \text{ n.cm}^{-2}.\text{s}^{-1}$ Up to $1.5 \times 10^{15} \text{ n.cm}^{-2}.\text{s}^{-1}$ Up to 40 mdpa/day <i>The flux received by samples depends on the samples position relative to the maximum flux level (see Figure 3)</i>
Fast flux stability over 1 cycle	$\leq \pm 5\%$
Accuracy of neutron fluence measurement	$< 5\%$ using activation dosimetry
Nominal sample temperature	From 250°C to 400°C <i>Deviation from target temperature $\leq 20^\circ\text{C}$</i>
Sample temperature gradient	Minimum temperature $\geq$ nominal sample temperature $- 10^\circ\text{C}$ Maximum temperature $\leq$ nominal sample temperature $+ 5^\circ\text{C}$ <i>Over the areas of interest of the samples</i> <i>Depending on sample holder design</i>
Temperature stability over 1 cycle	$\pm 2^\circ\text{C}$ using electric heaters <i>On the areas of interest of the samples</i> <i>Measurement accuracy not included</i>
Accuracy of T° measurement	$\leq \pm 3^\circ\text{C}$ using thermocouples
In-situ instrumentation	Thermocouples (max. 24 TC $\phi 1\text{mm}$), dosimeters, On request: LVDT, diameter gauge, mechanical loading...
On-site non-destructive examination capabilities	Underwater X-ray and gamma spectrometry tomography of MICA device X-ray and gamma spectrometry tomography of sample holder in hot cell Visual inspection + metrology of samples in hot cell (mass, size, etc.)

Types of samples	Metallic or ceramic non-fissile materials Fresh samples only
Size of samples	Sample load must fit in a rectangular volume with a section of 25mm x 60mm and a height of ~600mm maximum
Number of samples	Defined by the volume of the load (see above)
Samples environment	Helium
Irradiation location	Reflector (P611)
Irradiation conditions at 70MW: Fast neutron flux (E > 1MeV) Fast neutron flux (E > 0.1MeV) Damage rate	<i>Average flux at the maximum flux level</i> ~ 5.6 x 10 ¹² n.cm ⁻² .s ⁻¹ ~ 1.5 x 10 ¹³ n.cm ⁻² .s ⁻¹ ~ 0.7 mdpa/day <i>The flux received by samples depends on the samples position relative to the maximum flux level (see Figure 4)</i>
Fast flux stability over 1 cycle	≤ ±5%
Accuracy of neutron fluence measurement	< 5% <i>using activation dosimetry</i>
Homogeneity of fast neutron flux	Max. lateral dispersion < 7% <i>on a horizontal section</i> Max. vertical dispersion < 30% <i>over the height of the sample load</i>
Nominal sample temperature	From 260°C to 330°C <i>Deviation from target temperature ≤ 20°C</i>
Sample temperature gradient	Minimum temperature ≥ nominal sample temperature – 7°C Maximum temperature ≤ nominal sample temperature + 5°C <i>Over the areas of interest of the samples</i> <i>Depending on sample holder design</i>
Temperature stability over 1 cycle	±2°C <i>using electric heaters</i> <i>On the areas of interest of the samples</i> <i>Measurement accuracy not included</i>
Accuracy of T° measurement	≤ ±3°C <i>using thermocouples</i>
In-situ instrumentation	Thermocouples, dosimeters
On-site non-destructive examination capabilities	Underwater X-ray and gamma spectrometry tomography of OCCITANE device X-ray and gamma spectrometry tomography of sample holder in hot cell Visual inspection + metrology of samples in hot cell (mass, size, etc.)

MATERIAL EXPERIMENTS IN OCCITANE DEVICE

General objective: Monitoring the evolution of the physical properties of non-fissile materials, e.g. pressure vessel steels, as a function of parameters such as neutron flux, fluence, irradiation temperature...
The physical phenomena studied can for example include the tensile properties to measure the hardening and the fracture/impact toughness to quantify the embrittlement, etc. OCCITANE offers a large irradiation volume. It is not re-loadable thus samples can only be unloaded at the end of the irradiation

OCCITANE device include: sample holder, capsule, underwater lines and out-of-pile equipment
OCCITANE sample holders are specific to each experiment
OCCITANE capsule, underwater lines and out-of-pile equipment are generic

STUDY THE BEHAVIOUR
OF REACTOR VESSEL STEELS



Photo: CEA/resne ©

MATERIAL EXPERIMENTS IN CLOE DEVICE

General objective: Monitoring irradiation-assisted stress corrosion cracking (IASCC) phenomena (crack initiation and propagation) and oxidation kinetics (Zr alloys) in metallic samples as a function of parameters such as neutron flux, fluence, irradiation temperature and chemical conditions, etc. CLOE is a pressurized water loop working under PWR or BWR conditions

CLOE includes an in-pile section and an out-of-pile section sharing the same water conditions. This allows to test similar samples simultaneously with and without irradiation.
CLOE in-pile section includes: sample holder, pressure tubes, underwater lines and out-of-pile equipment. **CLOE** sample holder is specific to each experiment. Pressure tubes, underwater lines and out-of-pile equipment are generic.

STUDY THE CORROSION OF MATERIALS UNDER STRESS



Photo: CEA/Iresne ©

Types of samples	Metallic non-fissile materials (steels, Ni or Zr alloys...) Fresh or pre-irradiated samples	
Size of samples	Sample load must fit in a cylindrical volume with a diameter of 48mm maximum and a height up to ~600mm	
Number of samples	Defined by the volume of the load (see above)	
Samples environment	PWR water chemistry conditions: LiOH content: 0.2 to 6 ppm H ₃ BO ₃ content: 0 to 2000 ppm H ₂ content: 1 to 10 ppm O ₂ : < 1 ppb	BWR water chemistry conditions: BWR-NWC: O ₂ content: 300 to 400 ppb BWR-HWC: H ₂ content: 100 to 3000 ppb O ₂ content: Few ppbs
	For PWR & BWR: impurities < 10 ppb (Cl ⁻ , FI ⁻ , SO ₄ ⁻ , Na ⁺ < 50 ppb)	
Irradiation location	Reflector (C313)	
Irradiation conditions at 70MW: Fast neutron flux (E > 1MeV) Fast neutron flux (E > 0.1MeV) Thermal flux (E < 0.625eV) Damage rate	Average flux at the maximum flux level ~ 1.9 x 10 ¹³ n.cm ⁻² .s ⁻¹ ~ 2.7 x 10 ¹³ n.cm ⁻² .s ⁻¹ ~ 3.7 x 10 ¹³ n.cm ⁻² .s ⁻¹ ~ 3.0 mdpa/day The flux received by samples depends on the samples position relative to the maximum flux level (see Figure 4)	
Fast flux stability over 1 cycle	≤ ±5%	
Accuracy of neutron fluence measurement	< 5% using activation dosimetry	
Nominal sample temperature	260°C to 360°C during reactor cycle > 200°C during reactor shutdown	
Temperature stability over 1 cycle	±3.5°C on the areas of interest of the samples Measurement accuracy not included	
Accuracy of T° measurement	≤ ±3°C using thermocouples	
Nominal water pressure	190bars	
Nominal water flow	1050kg/h around samples	
Controlled chemical parameters	pH, electrical conductivity, redox potential, electrochemical potential... Contents of O ₂ , H ₂ , F ⁻ , Na ⁺ , LiOH, H ₃ BO ₃ , impurities	
In-situ instrumentation	Thermocouples, dosimeters, ECP probe, DCDP, LVDT... Mechanical loading	
On-site non-destructive examination capabilities	Underwater X-ray and gamma spectrometry tomography of CLOE device	

Types of samples	PWR UO ₂ fuel (²³⁵ U enrichment ≤ 5%) or MOX fuel (Pu content ≤ 12%) Advanced fuel on request Fuel burn-up from 0 to 90GWd/t Fresh or pre-irradiated samples
Size of samples	Fissile length ≤ 500mm Rod length ≤ 900mm Diameter ≤ 14mm
Number of samples	1 fuel rod (possibly instrumented)
Samples environment	Pressurized water (PWR conditions)
Irradiation location	Reflector with displacement system (T05)
Irradiation conditions at 70MW:	<i>Average flux at the maximum flux level</i>
Fast flux (E > 1MeV)	Up to 2.1 x 10 ¹³ n.cm ⁻² .s ⁻¹
Fast flux (E > 0.1MeV)	Up to 5.4 x 10 ¹³ n.cm ⁻² .s ⁻¹
Thermal flux (E < 0.625eV)	Up to 3.4 x 10 ¹⁴ n.cm ⁻² .s ⁻¹
Nuclear heating	Up to 2.2 W/g
Fuel sample linear power	Up to 620W/cm <i>depending on fuel enrichment and burn-up</i> ±10W/cm <i>deviation from power target</i>
Constant power levels	100 to 200W/cm during a few days (conditioning phase) High power plateau during up to 24h after transient
Power transient speed	10 to 700W/(cm.mn)
Accuracy of linear power evaluation	5.6% (2σ) <i>through thermal balance measurement</i>
Nominal water temperature	260°C to 345°C around sample depending on rodlet linear power
Nominal water pressure	155 to 160bars around samples ±2bars
Controlled chemical parameters	pH, electrical conductivity Concentrations of O ₂ , H ₂ , chloride, fluoride...
In-situ measurements	Coolant temperature, pressure and flow around the sample Thermal neutron flux Detection of clad failure, identification and quantification of released fission products in the coolant, release kinetics On request: fuel temperature, clad temperature, sample internal pressure, clad elongation
On-site non-destructive examination capabilities	Neutron imagery of the sample X-ray and gamma spectrometry tomography (underwater or in hot cell) Metrology, visual examination, Eddy Current and gamma spectrometry of the sample in JHR hot cell

FUEL EXPERIMENTS IN ADELIN DEVICE

General objective: irradiation of standard and innovative PWR fuel samples under thermohydraulic and chemical conditions representative of PWR conditions, including power transient representative of normal and incidental PWR conditions with possibility of fuel cladding failure and partial fuel melting.

ADELIN is a pressurized water loop working under PWR conditions (with possible upgrade to BWR and VVER conditions).
ADELIN includes an in-pile section installed on a displacement system. This allows to perform power transients on samples at constant reactor power.
ADELIN device includes generic equipment: sample holder, pressure tubes, device holder, underwater lines and out-of-pile equipment.



FUEL EXPERIMENTS IN MADISON DEVICE

General objective: irradiation of standard and innovative PWR fuel samples under thermohydraulic and chemical conditions representative of PWR conditions, including power transient representative of normal PWR operating conditions, without cladding failure. Up to 4 fuel rods can be irradiated simultaneously for screening test, burn-up acquisition test or transient test.

MADISON is a pressurized water loop working under PWR conditions (with possible upgrade to BWR and VVER conditions).
MADISON includes an in-pile section installed on a displacement system. This allows to perform power transient on samples at constant reactor power.
MADISON device includes generic equipment: sample holders, pressure tubes, device holder, underwater lines and out-of-pile equipment.



FUEL TESTING
IN NORMAL
CONDITIONS

Photo: CEA/IRESNE ©

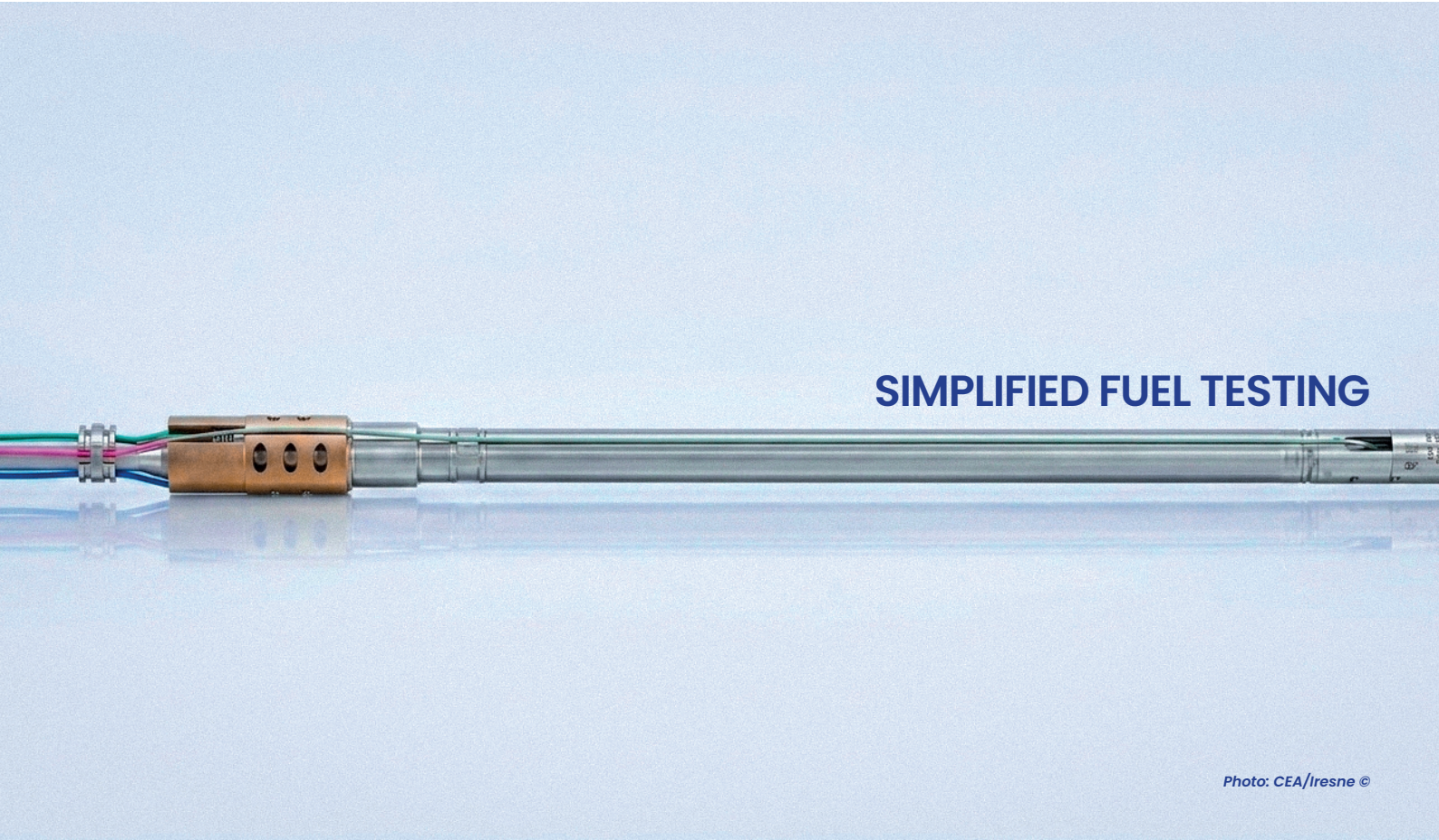
Types of samples	PWR UO2 fuel (²³⁵ U enrichment ≤ 5%), standard MOX fuel (Pu content ≤ 12.7%), advanced MOX fuel for Multiple Recycling in PWR, advanced fuel and ATF type fuel (²³⁵ U enrichment ≤ 10%) Fuel burn-up from 0 to 80GWd/t Fresh or pre-irradiated samples
Size of samples	Fissile length ≤ 600mm Rod length ≤ 1100mm Diameter ≤ 20mm
Number of samples	Up to 4 fuel rods (possibly instrumented)
Samples environment	Pressurized water (PWR conditions)
Irradiation location	Reflector with displacement system (T12)
Irradiation conditions at 70MW:	<i>Average flux at the maximum flux level</i> Fast flux (E > 1MeV) Up to 1.0 x 10 ¹³ n.cm ⁻² .s ⁻¹ Fast flux (E > 0.1MeV) Up to 2.9 x 10 ¹³ n.cm ⁻² .s ⁻¹ Thermal flux (E < 0.625eV) Up to 2.7 x 10 ¹⁴ n.cm ⁻² .s ⁻¹ Nuclear heating Up to 1.2 W/g
Fuel sample linear power	Up to 450W/cm <i>depending on fuel enrichment and burn-up</i> ±10W/cm <i>deviation from power target</i>
Power transient speed	10 to 50W/(cm.mn)
Accuracy of linear power evaluation	5.6% (2σ) <i>through thermal balance and gamma spectrometry measurements</i>
Nominal water temperature	280°C to 345°C around sample depending on rodlet linear power
Nominal water pressure	155bars around samples ±2bars
Controlled chemical parameters	pH, electrical conductivity Concentrations of O ₂ , H ₂ , chloride, fluoride...
In-situ measurements	Water temperature, pressure and flow around the samples Thermal neutron flux On request: fuel temperature, clad temperature, sample internal pressure and gas composition (acoustic sensor), clad elongation, fuel stack elongation, fission gas release (through pressure and composition measurements)
On-site non-destructive examination capabilities	Neutron imagery of the samples X-ray and gamma spectrometry tomography (underwater or in hot cell) Metrology, visual examination, Eddy Current and gamma spectrometry of samples in JHR hot cell

Types of samples	PWR UO2 fuel (²³⁵ U enrichment ≤ 5%), standard MOX fuel (Pu+Am content ≤ 12.5%), advanced MOX fuel for Multiple Recycling in PWR, advanced fuel and ATF type fuel (²³⁵ U enrichment ≤ 10%) Fuel burn-up from 0 to 80GWd/t Fresh or pre-irradiated samples
Size of samples	Fissile length ≤ 600mm Rod length ≤ 1100mm Diameter ≤ 14mm
Number of samples	1 fuel rod (possibility of segmented rod)
Samples environment	Pressurized water (PWR conditions)
Irradiation location	Reflector (C411)
Irradiation conditions at 70MW: Fast flux (E > 1MeV) Fast flux (E > 0.1MeV) Thermal flux (E < 0.625eV) Nuclear heating	<i>Average flux at the maximum flux level</i> Up to 1.9 x 10 ¹³ n.cm ⁻² .s ⁻¹ Up to 5.0 x 10 ¹³ n.cm ⁻² .s ⁻¹ Up to 3.6 x 10 ¹⁴ n.cm ⁻² .s ⁻¹ Up to 2.0 W/g
Fuel sample linear power	100 to 400W/cm depending on fuel enrichment and burn-up ±10W/cm deviation from power target
Accuracy of linear power evaluation	8% (2σ) through thermal balance measurement
Nominal water temperature	Up to 345°C around samples depending on rodlet linear power
Nominal water pressure	155bars around sample ±2bars
Controlled chemical parameters	pH, electrical conductivity Concentrations of O ₂ , H ₂ , chloride, fluoride...
In-situ measurements	Water temperature and pressure around the sample On request: fuel temperature, sample internal pressure
On-site non-destructive examination capabilities	Neutron imagery of the sample Underwater X-ray and gamma spectrometry tomography of the whole FUICA in-pile section X-ray and gamma spectrometry tomography of the sample in hot cell Metrology, visual examination, Eddy Current and gamma spectrometry of the sample in JHR hot cell

FUEL EXPERIMENTS IN FUICA DEVICE

General objective: irradiation of standard and innovative PWR fuel samples under thermohydraulic and chemical conditions close to PWR conditions, at constant power, without cladding failure.

FUICA is a pressurized water capsule working under PWR conditions (with possible upgrade to BWR and VVER conditions).
FUICA device includes generic equipment: sample holder, pressure tubes, underwater lines and out-of-pile equipment.



SIMPLIFIED FUEL TESTING

Photo: CEA/Iresne ©

GENERAL CAPABILITIES OF NON-DESTRUCTIVE EXAMINATION BENCHES IN THE JHR FACILITY

Objectives	Measured parameters	Examination techniques	Examination benches	Expected accuracy / resolution
Fissile power history of fuel samples Axial distribution of fissile power in fuel samples	Linear concentration of fission products with short and medium half-lives	Gamma spectrometry scanning	Under-water benches (x2)	Linear activity (at/mm) of fission products: accuracy $\pm 6\%$ (2σ)
			JHR hot-cell bench (x1)	Linear activity (at/mm) of fission products: accuracy $\pm 4\%$ (2σ)
Local burn-up of the fuel samples	Linear concentration of fission products with long half-lives, particularly ^{137}Cs	Gamma spectrometry scanning	Under-water benches (x2)	Linear activity (at/mm) of ^{137}Cs : accuracy $\pm 6\%$ (2σ)
			JHR hot-cell bench (x1)	Linear activity (at/mm) of ^{137}Cs : accuracy $\pm 4\%$ (2σ)
Dimensions of fuel samples	Length and diameter of fissile column, space between pellets...	Gamma spectrometry scanning	Under-water benches (x2)	Accuracy $\pm 0,5$ mm (typical value for a slit of 1mm and a step ≤ 0.5 mm)
			JHR hot-cell bench (x1)	
Images of fuel samples	Forms, positions, fissile column, structure components and instrumentation dimensions, defects... (X emission)	2D or 3D gamma emission tomography	Under-water benches (x2)	Accuracy $\pm 0,5$ mm (typical value for a slit of 1mm and a step ≤ 0.5 mm)
			JHR hot-cell bench (x1)	
	Forms, positions, fissile column, structure components and instrumentation dimensions defects... (low-Z materials)	Neutron imaging	Under-water Neutron Imaging System (x1)	Resolution $\leq 0.35\text{mm}$

Objectives	Measured parameters	Examination techniques	Examination benches	Expected accuracy / resolution
High resolution images of material or fuel samples	Forms, positions and fissile column, structure components and instrumentation dimensions, defects... (high-Z materials)	2D or 3D X-ray transmission tomography	Under-water benches (x2)	Resolution $\leq 0.1\text{mm}$
			JHR hot-cell bench (x1)	Resolution $\leq 0.07\text{mm}$
Non-Destructive Examinations of fuel samples*	Visual examination	Recording of photographs or films	Fuel measurement devices on JHR hot-cell bench (x4)	Resolution $\leq 0.1\text{mm}$
	Dimensions: Length and diameter	Profilometry or diameter measurements		Length: accuracy $\pm 0.2\text{mm}$ (2σ) Diameter: accuracy $\pm 0.01\text{mm}$ (2σ)
	Zirconia thickness measurements	Eddy current measurements (punctual probe)		Accuracy $\pm 0.01\text{mm}$ (2σ)
	Cladding defects	Eddy current measurements (coil probe)		Qualitative, complementary to other examinations
Metrology of material samples	Visual examination Dimensions Mass Etc.	Metrology	JHR hot-cell bench (x1)	<i>To be defined depending on customer needs</i>

*Only on fuel samples without cladding failure

GENERAL CAPABILITIES OF NON-DESTRUCTIVE AND DESTRUCTIVE EXAMINATION BENCHES IN CEA HOT LABS

Examination of irradiated material samples (LECI facility, Saclay)

Type of examination	Expected accuracy / resolution
Visual examination and optical microscopes	Few micrometers
Diameter measurement (external and internal)	1 micrometer (laser)
Mass measurement	10 ⁻⁵ g
Profiles measurement	Few micrometers
Density measurement	10 ⁻⁴ or 10 ⁻⁵
SEM-FIB (scanning electron microscope / focused ion beam) fitted with EBSD (electron backscatter diffraction), and Nanomechanical Testing System	Few nanometers
SEM (scanning electron microscope) fitted with EDS (energy dispersive x-ray spectroscopy), EBSD (electron backscatter diffraction), and WDS (wavelength dispersive spectroscopy)	Few nanometers; atomic detection < 0,2 at.%
TEM-EDX-EELS (transmission electron microscopy - energy dispersive X-ray spectroscopy - electron energy loss spectroscopy)	0,14 nanometer atomic detection < 1 at.%
APT (atom probe tomography)	One nanometer atomic detection of few ppm
Micro-hardness measurement	-
Gas extraction and quantification (hydrogen measurement)	10% under 200ppm or 4% above
Tensile testing (10, 25 and 100 kN, -140°C to 900°C), 10-5 to 50s-1, dynamic heat rate up to ~500°C/s	-
Fracture toughness (100 a kN, -140°C to 900°C)	-
Charpy testing (50 J and 350 J, -140°C to +600°C)	-
Axial creep tests (up to 1000°C)	-
Internal Pressure creep test (up to 900°C)	-
Thermoelectric power measurement	-

Examination of irradiated fuel samples (LECA-STAR facility, Cadarache)

Type of examination	Expected accuracy / resolution
Non-Destructive visual examination	Resolution ≤ 0.1mm
Dimensions (length and rod diameter)	Length: accuracy ±0.5mm (2σ) Diameter: accuracy ±0.01mm (2σ)
Non-Destructive zirconia thickness measurement (Eddy current)	Accuracy ±0.01mm (2σ)
Health control (Eddy current) of rods	Qualitative control
Gamma spectrometry	Linear activity (at/mm) of ¹³⁷ Cs: accuracy ±6% (2σ) Other Fission products: > ±6% (2σ) depending on customers' needs
Internal pressure	5% (2σ)
Free volume	< 10% (2σ)
Gas composition (release of fission products)	5% (2σ)
Metallography (sample preparation, density measurement, macroscopy and optical microscopy)	Microscopy: 1 μm
SEM-FIB-EBSD (electron backscatter diffraction with nanoindenter using scanning electron microscope / focused ion beam, a gas injection system, and a μ-telemanipulator)	Resolution of 10 nm
TEM-EDX-EELS (transmission electron microscopy - energy dispersive X-ray spectroscopy - electron energy loss spectroscopy)	Point to point resolution 0,19 nm. Atomic detection ≈1 at.%
SIMS (secondary ion mass spectrometry) <i>Elemental and isotopic surface analysis technique from Hydrogen to Uranium and beyond</i>	Depth profiling: depth resolution ~ 15 nm down to 2 nm Imaging: from 10 μm to 500 μm square with lateral resolution ~ 1 μm Very high sensitivity detection limit from ppm to ppb level Isotopic composition: isotope ratio analyses with high precision (better than 2 permil) Quantification: standard required
XRD (X-ray diffractometry)	Resolution: adapted to the needs of the experiment (0.01-0.1°/step) Accuracy: between 1x10 ⁻² and 1x10 ⁻³ Å depending on the quality of the diffractogram
EPMA (Electron Probe Micro Analysis) <i>Elemental Quantitative et qualitative analysis technique from Oxygen to Americium</i>	Resolution of 1 μm Imaging: from 50 μm to 1 mm (stage) square with lateral resolution ~ 1 μm Quantification: standard required

GENERAL CAPABILITIES OF MANUFACTURING PRE-IRRADIATED SAMPLES AT CEA

Type of samples	Manufacturing benches / Facility	Characteristics of initial pre-irradiated objects	Characteristics of manufactured samples
Material samples using pre-irradiated materials	LECI / EDM (electrical discharge machining)	Irradiated metallic materials (without fuel traces) Maximum activity: >> GBq Maximum weight: 5 kg Maximum dimensions: L.100mm x W.100 mm x Th.13mm	Wire size: 0.25 mm Overall accuracy of machining: +/- 0,05 mm Type of samples manufactured: – round and plate tensile specimen – C-ring – O-ring – Two-leg tensile specimen – Charpy specimen – CT-xT specimen – SENB specimen – Creep specimen – miniaturized specimens...
Fuel samples using pre-irradiated fuels	LECA-STAR / CORALIE 2 LECA-STAR / CRISTAL	PWR and FBR fuel rods: - Type: cylindrical - Dimensions: < 2m - Burn-up: no limitation	Fuel rod non instrumented Fuel rod with instrumentation: - thermocouple type C - pressure sensor (LVDT type) - gas composition sensor (acoustic sensor)

CEA capabilities also include the manufacture of experimental samples using unirradiated materials and fuels



CONTACT AND INFORMATION

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Irradiation services described in this brochure correspond to the target for the experimental fleet available at the start-up of the RJH. Additional experimental capabilities will be developed and commissioned later upon request.

Disclaimer: the figures indicated in this brochure are non-binding. Actual performance will depend on parameters such as the nature and geometry of the samples, experimental specifications, in-pile instrumentation, system configuration, and other factors. Definitive capabilities will be assessed and specified based on a detailed service request.

