CAMECA®
SCIENCE & METROLOGY SOLUTIONS

AMETEK®

Nuclear Materials





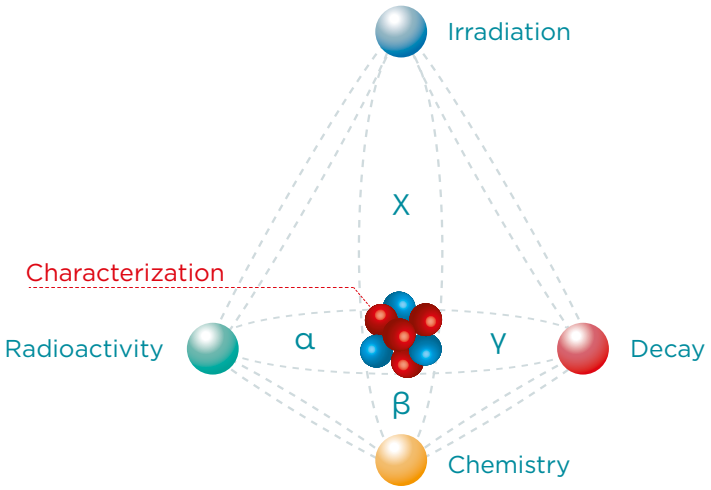
DETECT
ANALYZE
SECURE





The Critical Role of Material Characterization

Radiation is everywhere! From energetic bananas (^{40}K) to colorful fiesta ware (^{238}U paint), from flashy exit signs (^{3}He) to sensitive smoke detectors (^{241}Am), from age determination techniques (^{14}C) to sedimentation chronological studies (^{210}Pb), from cancer treatments (^{60}Co) to nuclear fission (^{235}U), radioactive particles are ubiquitous.



Whether one needs to report radioactivity levels and ratios, follow natural isotopic decays or those induced by man-made irradiation, or understand the chemistry dictating these reactions, a common point resides in the ability to observe, detect, image, probe, identify and quantify changes. This key aspect called characterization is at the heart of CAMECA's expertise.

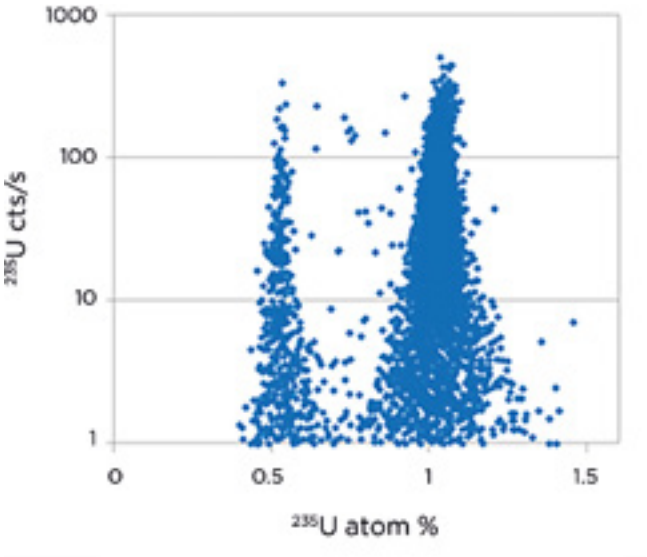
Verifying the Peaceful Use of Nuclear Materials

A challenge to international nuclear safeguards is to verify the absence of undeclared nuclear activities. Analysis of small particles from dust samples that contain elements such as uranium, plutonium, and thorium can give insights into how nuclear materials are handled at a specific location. High precision and low detection limits are required for uranium analysis of these micrometer to sub-micrometer particles.

How can safeguard labs analyze environmental samples to investigate the intended use of a material, as well as its origin? CAMECA has the answer.



Verifying the Peaceful Use of Nuclear Materials



Fast particle screening using CAMECA Automated Particle Measurement software (APM) on a sample containing both depleted and enriched uranium particles (0.5% and 1% ^{235}U). 6653 particles were identified over the central area of the sample (diameter = 16 mm).

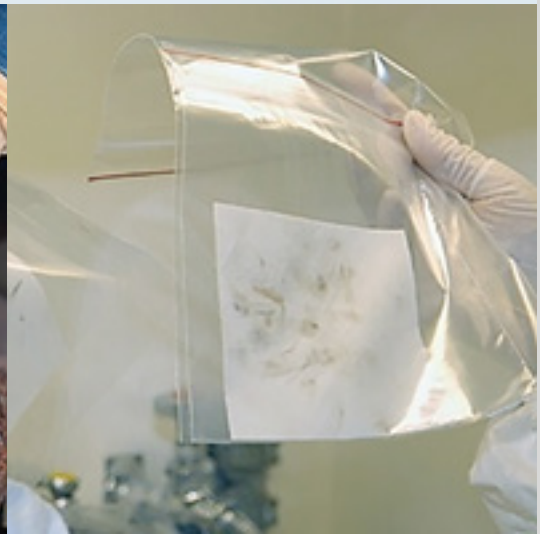
From: P. Peres et al. Surface and Interface Analysis 45, 561 (2013).

CRM U100				
Isotope	^{234}U	^{235}U	^{236}U	^{238}U
Mean	0.0678	10.1954	0.0380	89.6988
SD	0.0004	0.0061	0.0002	0.0062
RSD%	0.54	0.06	0.56	0.01

Uranium isotope measurements of individual uranium particles (certified reference material U100). 51 measurements performed over a period of three months. Excellent precision (0.6 permil) is obtained for ^{235}U.

From: M. P. Hedberg et al. JVST B 36, 03F108 (2018).





SIMS

IMS 1300-HR^3

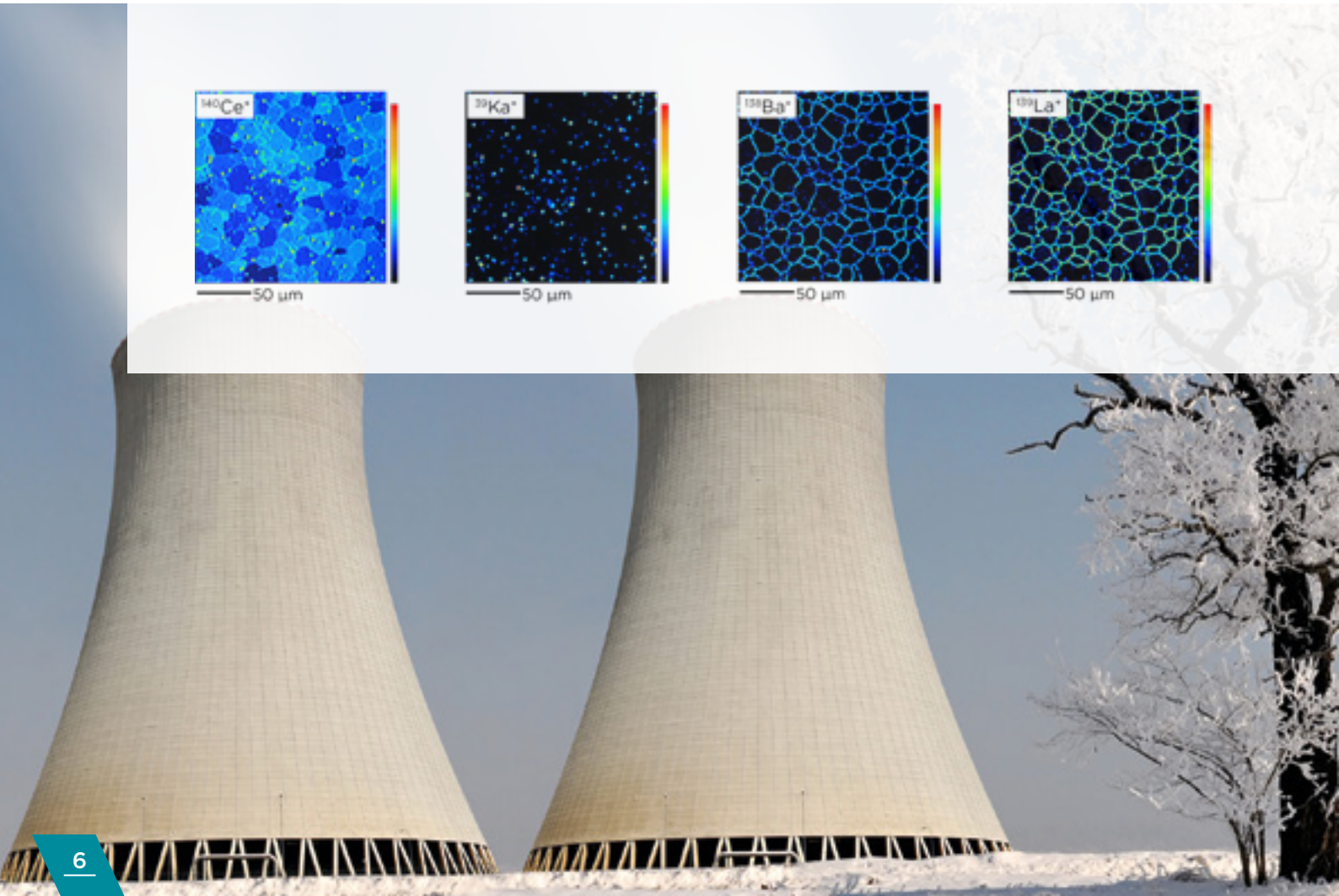


For µm-sized uranium particle analyses, secondary ion mass spectrometry (SIMS) is unique in being the only technique that can both localize the particles of interest and provide the uranium isotopic composition of single particles. Large geometry SIMS instruments, such as **CAMECA's IMS 1300-HR^3**, equipped with multicollection and automated particle mapping software provide the best sensitivity, precision and throughput for such applications.

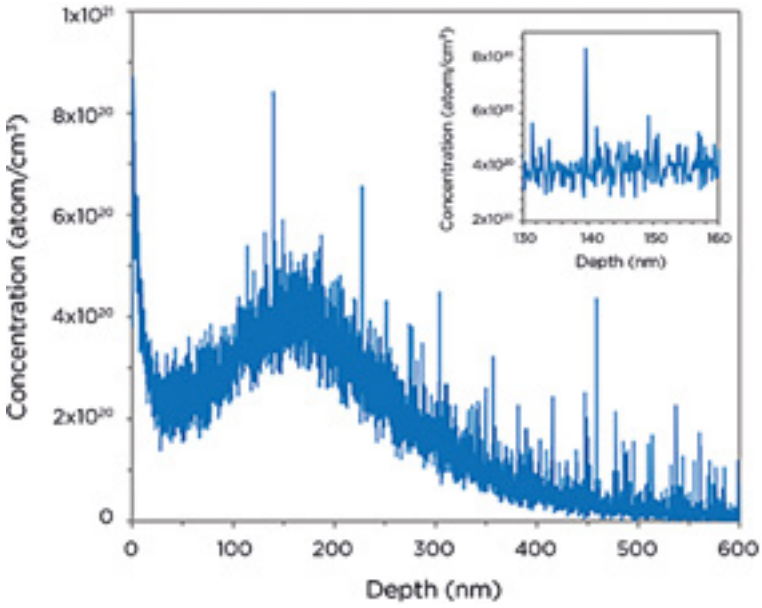
Controlling the Behavior of Fission Products

Radioactive fuel used in nuclear power reactors is manufactured in rods containing cylindrical UO_2 pellets, or $(U,Pu)O_2$ in MOx fuel, which are stacked in a long cladding made of a zirconium-based alloy. During irradiation, uranium (and plutonium) atoms are transformed by nuclear reaction into fission products (e.g., Xe, I, Mo), or other actinides. Release of rare gases can induce pellet swelling and increase the pressure within the cladding.

How can nuclear scientists detect the fission-induced gas bubbles responsible for cladding stress and creating the underlying safety issue? CAMECA has the answer.



Controlling the Behavior of Fission Products



SIMS-quantified Xe depth profile obtained in ^{129}Xe-implanted CeO_2 sample (surrogate of UO_2 ceramics). The baseline signal corresponds to dissolved Xe, whereas the signal spikes indicate the presence of gas bubbles.

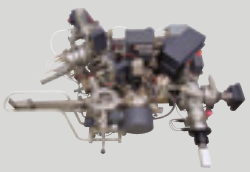
From: P. Peres et al. JVST B 36, 03F117 (2018).



SIMS ion imaging data obtained in Xe implanted CeO_2 sample for Ce matrix species and K, Ba contaminants. Field of view: 175 x 175 µm².

SIMS

IMS 7f-Auto



Offering high sensitivity, depth profiling and ion imaging capabilities together with high throughput, dynamic secondary ion mass spectrometry (SIMS) is extremely useful for a wide range of nuclear science applications. The **IMS 7f-Auto** delivers depth profiling with excellent detection limits and high lateral resolution imaging capabilities (down to sub-micron scale), allowing to visualize the distribution of elements or isotopes in two or three dimensions. A shielded version, **ACTINIS** is dedicated to the analysis of irradiated nuclear fuels.

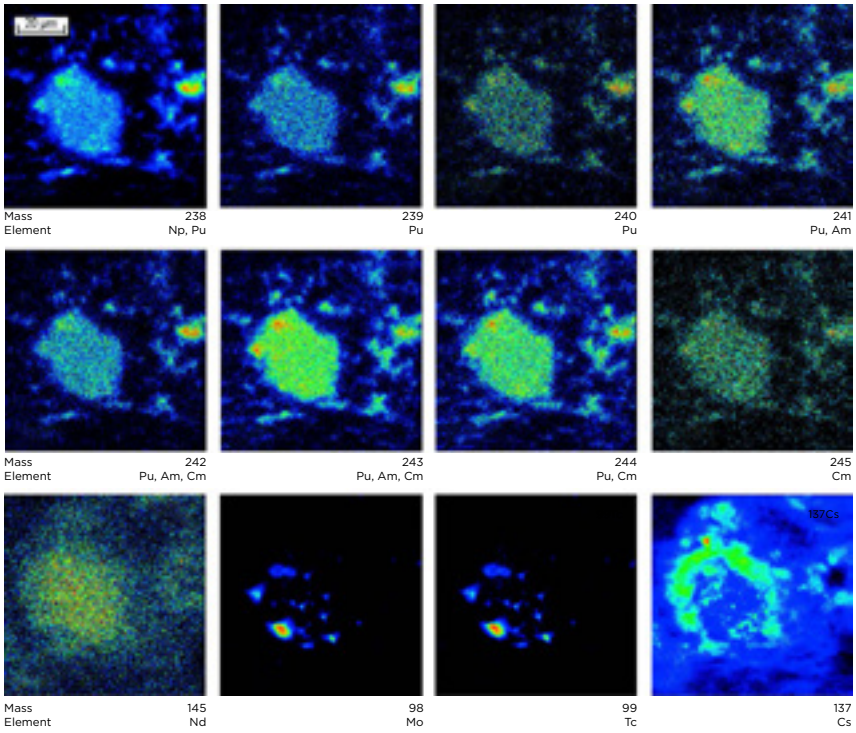
Optimizing the Nuclear Fuel Cycle

The nuclear fuel cycle consists of front-end steps that prepare fuel for use in reactors and back-end steps to safely manage and dispose of spent—but still highly radioactive fuel. Numerous concepts are tested with the objective of reducing the radiotoxicity of spent nuclear fuels.

How can scientists expermimentally determine transmutation processes and the amount of actinides dispersed in the target? CAMECA has the answer.



Optimizing the Nuclear Fuel Cycle



Americium is a radioactive element that greatly contributes to the radiotoxicity of spent nuclear fuels. Shown here are ion maps acquired from the $AmO_{1.62}$ partide at 400µm from the periphery of the pellet. The same pellet cross-section was analysed by EPMA and SIMS. The volatile fission product behavior is studied using Shielded SIMS. Detailed SIMS ion maps show:

- the perfect co-location of masses 238–245
- the Am distribution is homogeneous in the particles, as is illustrated by SIMS map for masses 241–243
- a low Cs content in the $AmO_{1.62}$ particle, and the clear existence of a higher Cs content in the matrix within the 10 µm closest to the $AmO_{1.62}$ particle.

From: J. Lamontagne et al. Determining the americium transmutation rate and fission rate by post-irradiation examination within the scope of the ECRIX-H experiment. Nuclear Materials 440, 366-376 (2013).



SIMS

ACTINIS

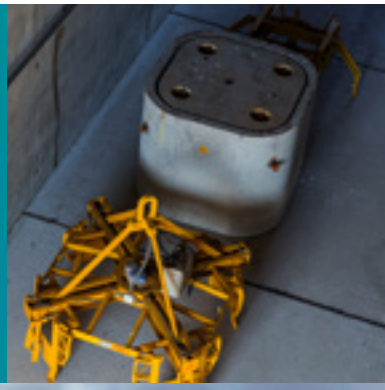


Dynamic Secondary Ion Mass Spectrometers (SIMS) are valuable for nuclear science, but analyzing highly radioactive materials like irradiated nuclear fuel demands specialized equipment. The **ACTINIS** shielded SIMS facilitates precise elemental and isotopic analysis within a secure environment. It features biological safeguards to shield operators from contamination and radiation during sample transfer and analysis, with adaptations to minimize manual handling. This innovation enhances both accuracy and safety in radioactive material investigation.

Securing Nuclear Waste Storage

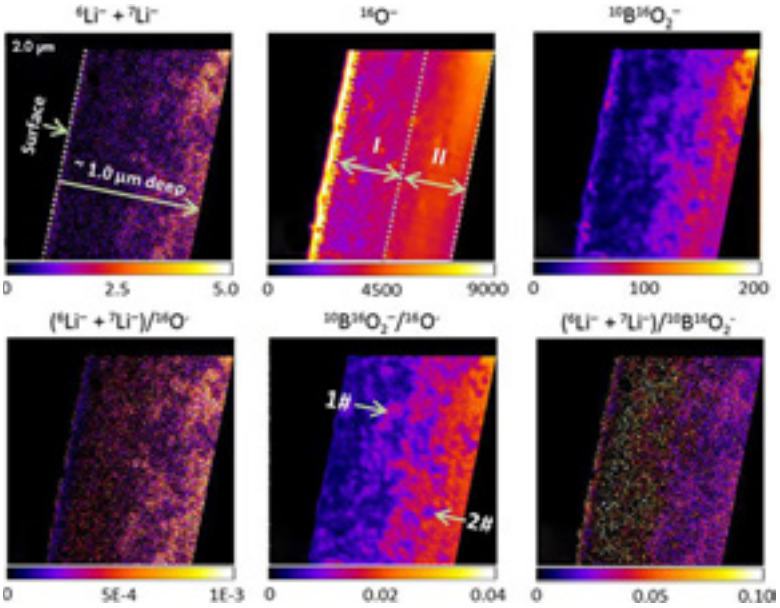
The long-term behavior of glasses used to confine nuclear waste is of prime interest to ensure safe geological disposal. In order to understand glass alteration mechanisms and to optimize its strength, it is crucial to accurately characterize the micro-crystals formed in the glass matrix.

How can you best characterize micro-phases in nuclear glass? CAMECA has the answer.



Nuclear waste containers confined in long-term repository.

Securing Nuclear Waste Storage



Nanoscale secondary ion mass spectrometry negative secondary ion images, showing distribution of Li, B, and O in the focus ion beam-prepared wedge at the surface of the corroded Advanced Fuel Cycle Initiative glass sample.

From: Z. Wang et al. Surface and Interface Analysis, Vol. 48, (2016).



SIMS

NanoSIMS 50L



The **CAMECA NanoSIMS 50L** is a dynamic SIMS using a ~50nm spot size for both negative and positive secondary ions to produce high spatial resolution imaging capability. It has parallel detection of up to seven elements or isotopes and ultra-high sensitivity, combined with high mass resolving power and excellent lateral imaging resolution.

Improving Corrosion Resistance of Alloys

Zirconium alloys have found extensive use in the nuclear industry, primarily as fuel cladding elements, due to their low neutron capture cross section. Their reasonable mechanical properties and acceptable corrosion resistance to primary coolant water bring additional value when designing power plants. Such properties are often dependent on the sub-µm scale chemistry of the Zr-based alloys.

How can complex oxidation and hydrogen pickup mechanisms be better understood in Zirconium alloys at the sub-µm level in nuclear-type environments? CAMECA has the answer.

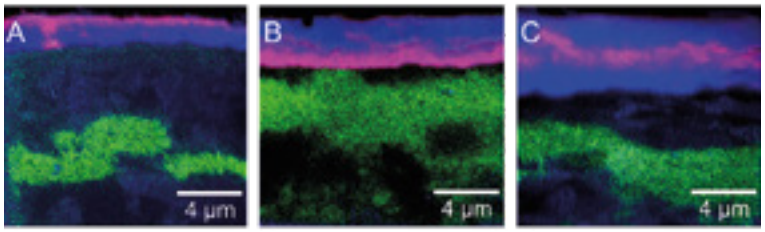
The development and optimization of materials used in a pressurized nuclear reactor require detailed understanding of the surface reactions.





Portion of a nuclear fuel assembly made of Zr alloy.

Improving Corrosion Resistance of Alloys



From left to right: cross-section images of a zirconium alloy exposed with increasing times to isotopically labelled high-pressure high-temperature water, mimicking nuclear reactor vessel conditions. A Zr-oxide layer (in blue and magenta) is growing progressively on top of the original metal below. The multi-step growth mechanism, the kinetic, the cracking of the different oxide layers can be studied and visualized with the NanoSIMS through the incorporation of the oxygen isotopes of water (^{16}O in blue and ^{18}O in red) into the oxides. The formation of hydrides, found below the metal/oxide interface can be visualized through the incorporation of water's ^{2}H isotope (in green) ~ one µm below the surface.

From: Sean S. Yardley et al. An investigation of the oxidation behaviour of zirconium alloys using isotopic tracers and high resolution SIMS. Journal of Nuclear Materials 443 (2013) 436–443.



SIMS

NanoSIMS 50L



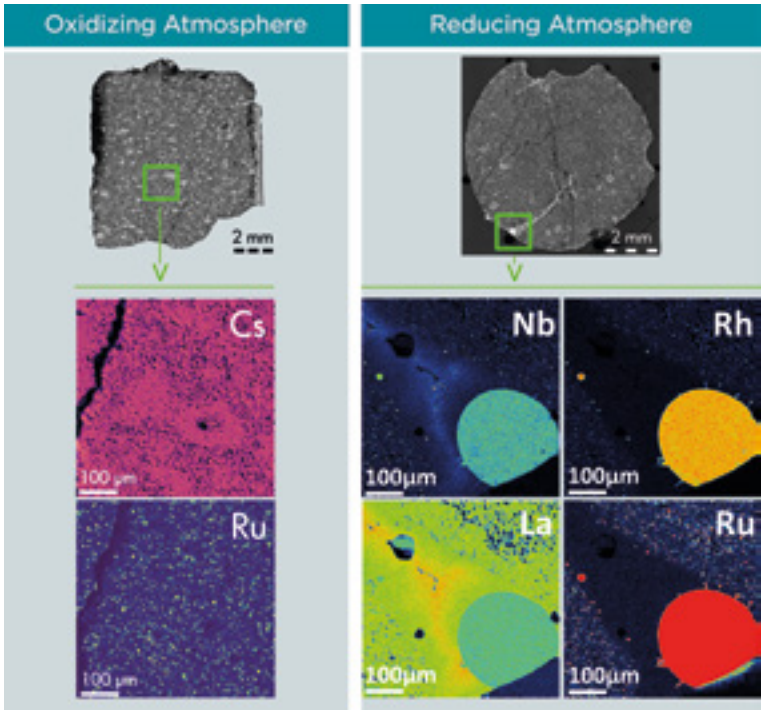
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Characterizing Irradiated Fuels

Safety is critical for operating a nuclear reactor, and scientists rely on both computational simulations and laboratory experiments in order to improve their understanding of various undesirable conditions. Such scenarios include failure of the reactor containment due to core temperature increase and different atmospheric conditions around the fuel.

From an experimental standpoint, how can microstructure and chemical composition of the fuel ultimately help nuclear engineers predict the consequences of a nuclear accident? CAMECA has the answer.





Evolution of metallic precipitates in oxidizing and reducing atmospheres.

Sample courtesy of Dr. Karine Hanifi and her team at CEA Cadarache, France.



EPMA

SKAPHIA



The **CAMECA SKAPHIA** is a shielded Electron Probe MicroAnalyzer that provides a safe environment for manipulating and analyzing radioactive samples. SKAPHIA delivers high quality trace and minor element analysis for a wide range of nuclear applications: study of the radiation damage process, analysis for the nuclear fuel, R&D of advanced alloys etc. It can be fitted with up to five wavelength dispersive spectrometers and one energy dispersive spectrometers for high reliability and reproducibility.

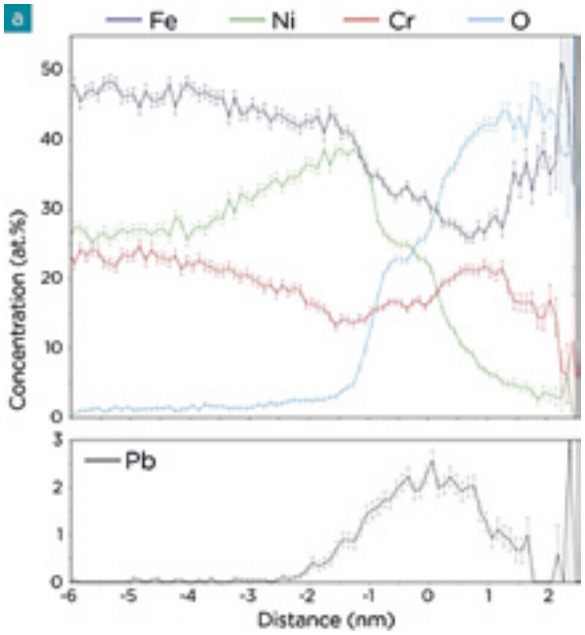
Making Nuclear Energy Production Safer

Materials used in nuclear reactors are subject to extreme temperature, pressure, and ion bombardment. This can lead to a structural failure known as stress corrosion cracking. Nuclear reactor materials must maintain structural stability for long-term use to minimize the risk of catastrophic accidents.

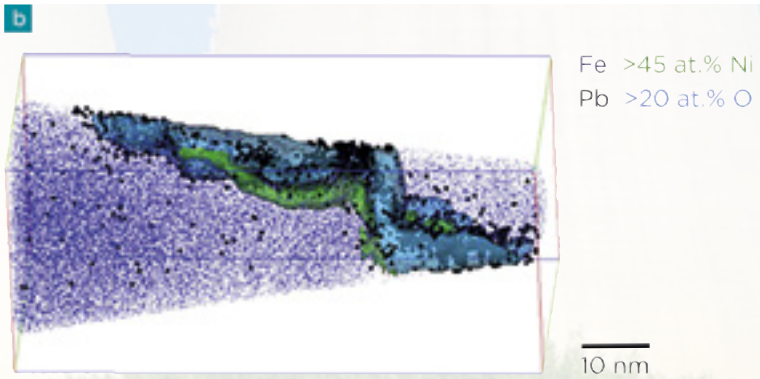
How can you measure the changes in structural materials with use over time? CAMECA has the answer.



Making Nuclear Energy Production Safer



Investigation of failure regions in alloy 800 which has been treated to simulate extreme conditions. a) Concentration profiles showing the interface between the oxide and the alloy at the crack interface.



b) Atom map showing isoconcentration surface of Fe and Pb.

From: Persaud et al. An Atom Probe Tomography study of Pb-caustic SCC in alloy 800. Corrosion Science 140, 159–167 (2018).



APT

LEAP®

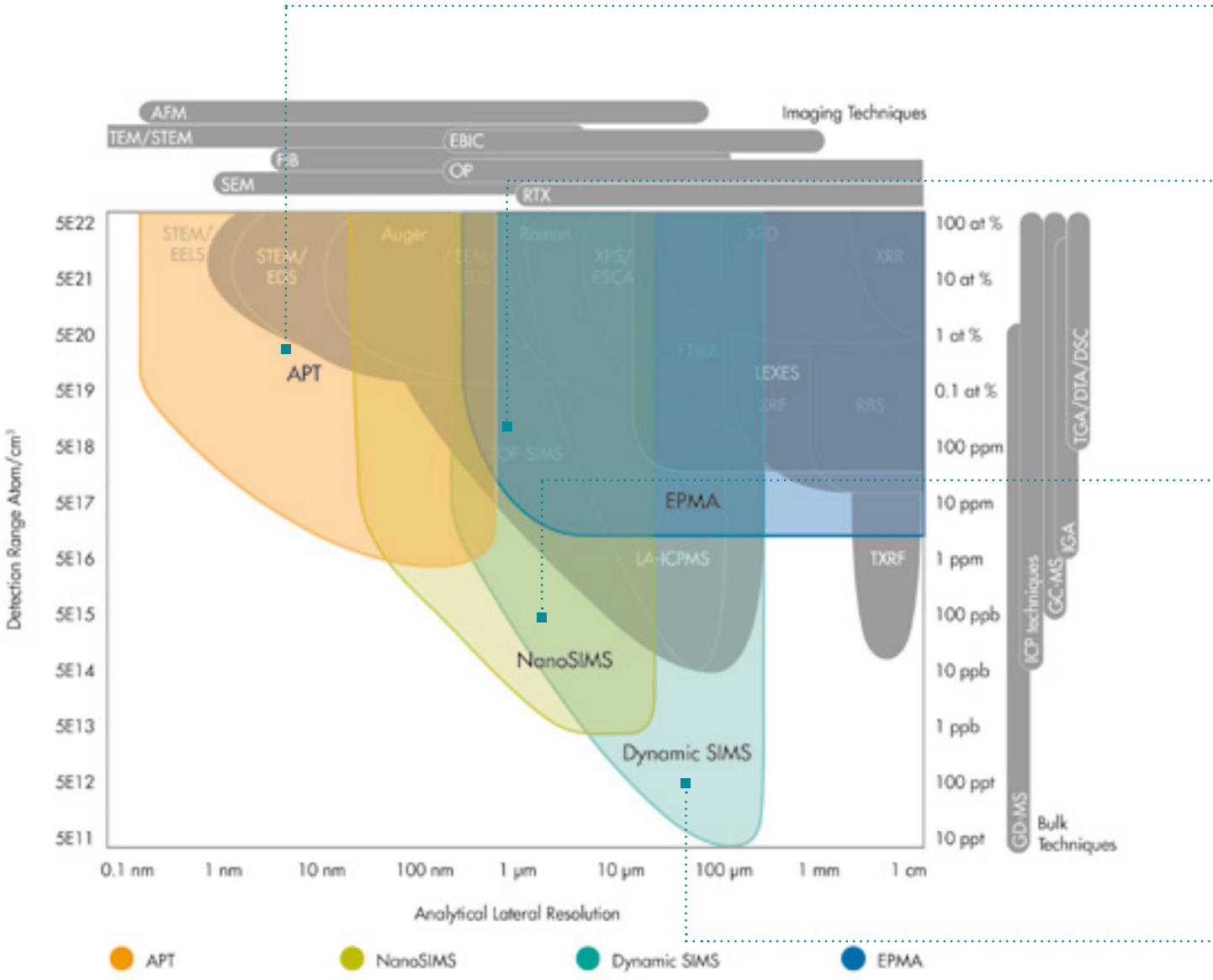


Atom Probe Tomography (APT) provides quantitative compositional analysis with sub-nanometer spatial resolution in three dimensions. It is especially suited for characterizing composition variations from microscale to sub-nanoscale.

- **EIKOS-UV™**, the Atom Probe for core APT applications;
- **LEAP 6000 XR™**, with a deep UV laser, that enables high productivity and a wide variety of applications;
- **Invizo 6000™**, the wide field-of-view atom probe.

Broad Solutions to your Analytical Needs

CAMECA makes products tailored to the characterization of materials at all length scales, from millimeters to nanometers, and can provide a complete solution to your materials characterization challenges. From bulk composition with ppm sensitivy to nanometer scale atom clusters, you can find your characterization solution at CAMECA.



Broad Solutions to your Analytical Needs



LEAP 6000 XR™



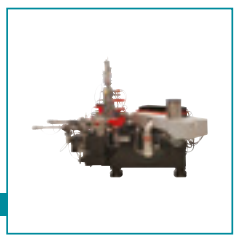
Invizo 6000™



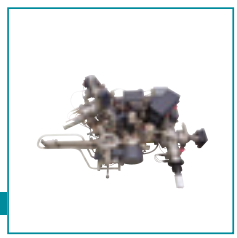
EIKOS-UV™



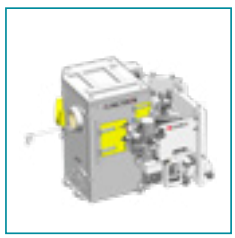
SKAPHIA



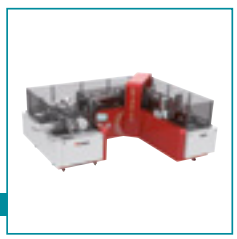
NanoSIMS 50L



IMS 7f-Auto



ACTINIS



IMS 1300-HR^3

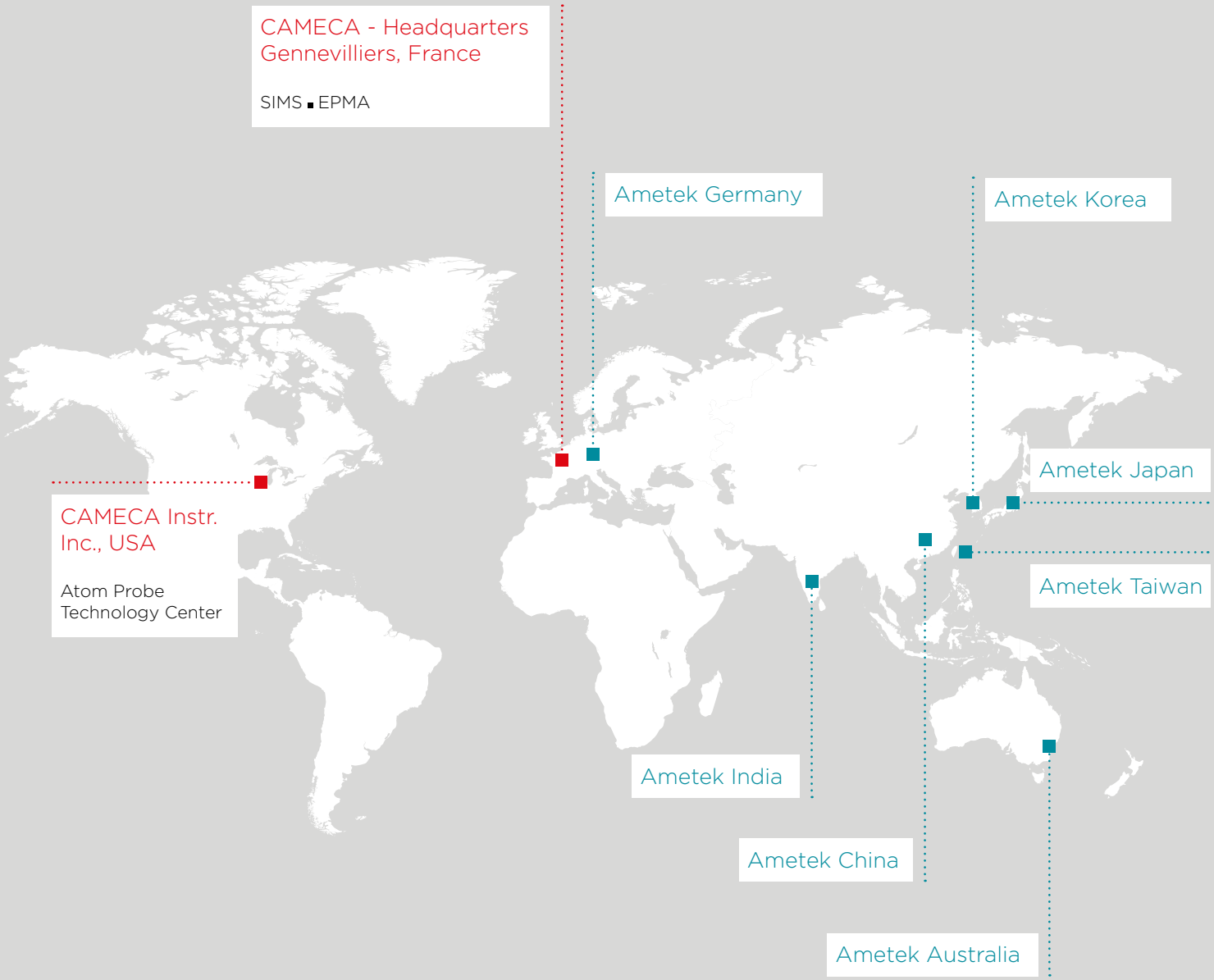
About CAMECA

CAMECA started in France in 1929 as a manufacturer of movie theater projectors, before rapidly evolving into a provider of scientific instrumentation for the international research community and in-fab / near-fab metrology solutions for the semiconductor manufacturing industry. From its inception, CAMECA has been renowned for its precision mechanics, optics and electronics.

Since pioneering Electron Probe MicroAnalysis (EPMA) in the 1950's and Secondary Ion Mass Spectrometry (SIMS) in the 1960's, CAMECA has remained the undisputed world leader in these techniques while achieving numerous breakthrough innovations in complementary techniques such as Atom Probe Tomography (APT).

Operating under ISO 9001 certification, CAMECA controls not only the technology, but all aspects in the design, manufacture, installation, and servicing of products. Located near Paris, France (CAMECA headquarters) as well as in Madison, Wisconsin, USA, our plants are state of the art facilities, using best practices for clean room production, computer networking, electron and ion optics simulation, and advanced CAD.

CAMECA is a business unit of AMETEK, Inc., a leading global provider of electronic instruments and electromechanical devices, as part of the AMETEK Materials Analysis Division.



R&D and production center, Sales and service

Sales and service

User Testimonials

Our IMS 7f gives us analytical capabilities for highly sensitive quantitative analysis of light elements, particularly Oxygen and Hydrogen, in Zr alloys after exposure in high temperature steam environment simulating conditions in VVER nuclear reactors. In combination with the CAMECA APM software we can use our IMS 7f for fast search, identification, and isotopic analysis of micrometer size dust particles containing nuclear material – a capability that we never had before.

Dr. Jan Lorincik, Research Center Rez, Czech Republic

Since 1999 CAMECA IMS 6f has been used for the research on isotope ratio analysis of uranium in individual particles in the environment at JAEA (Japan Atomic Energy Agency). These analysis data are regularly provided to IAEA (International Atomic Energy Agency) and are highly evaluated by IAEA. End of 2017 we have newly introduced a CAMECA IMS 1300-HR³, which realizes more precise isotope ratio measurements, and have started new researches. It is impossible to perform without using CAMECA's SIMS instruments with high performance and reliability. They continue to be widely utilized in the field of nuclear sciences and environmental sciences.

Dr. Fumitaka Esaka, Japan Atomic Energy Agency, Ibaraki, Japan

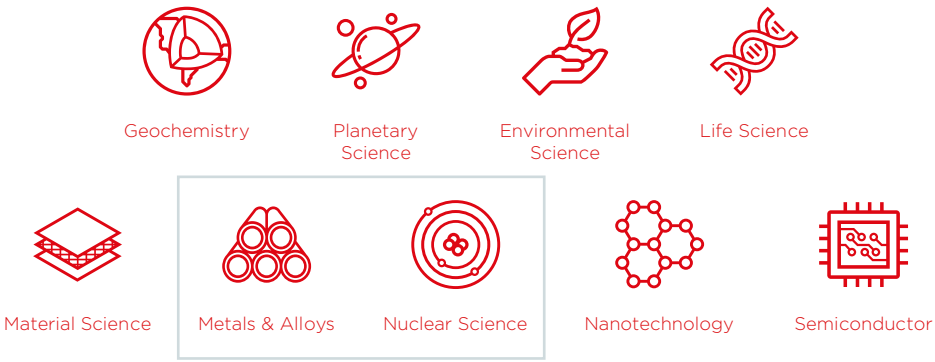
The CEA Cadarache uses an SX100-R EPMA from CAMECA. [...] It is the second shielded CAMECA EPMA employed here since 1984. The instrument's measurements are specially shielded against the background X-rays, gamma rays, and beta particles that radioactive samples emit, which would otherwise prevent precise microanalysis. So even on irradiated fuel pellets or cladding, this advanced analyzer can map the distribution of elements at or near the sample surface, while also accurately measuring each element's concentration with excellent detection limits. The EPMAS's shielding and hot cell also ensure optimum safety for our operators [...]. In late 2020, CEA Cadarache installed a CAMECA ACTINIS Shielded Ion Microrobe. Like our shielded CAMECA EPMA, it's a good investment!

Karine Hanifi, CEA Cadarache, France

Predicting the in-service structural integrity of components in nuclear reactors is immensely challenging but essential from both safety and economic perspectives. The CAMECA LEAP provides an unrivalled capability to characterise the 3D atomic-scale irradiation damage caused by the interaction between energetic neutrons and atoms in structural components. The resultant microstructural data are used to underpin mechanistic models of the degradation processes and hence support safety cases for continued operation of nuclear reactors world-wide.

Prof. Jonathan Hyde, National Nuclear Laboratory, U.K.

World Leader in Elemental & Isotopic Microanalysis



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