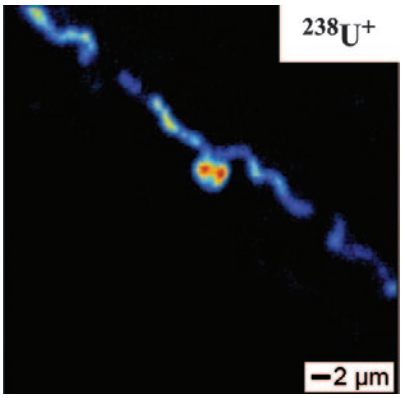
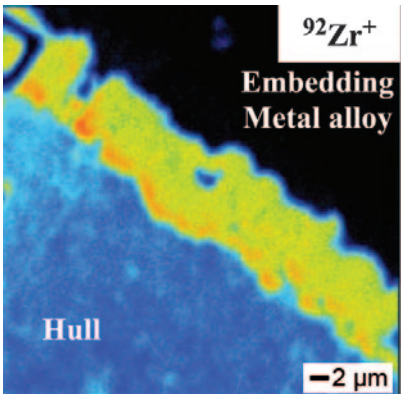
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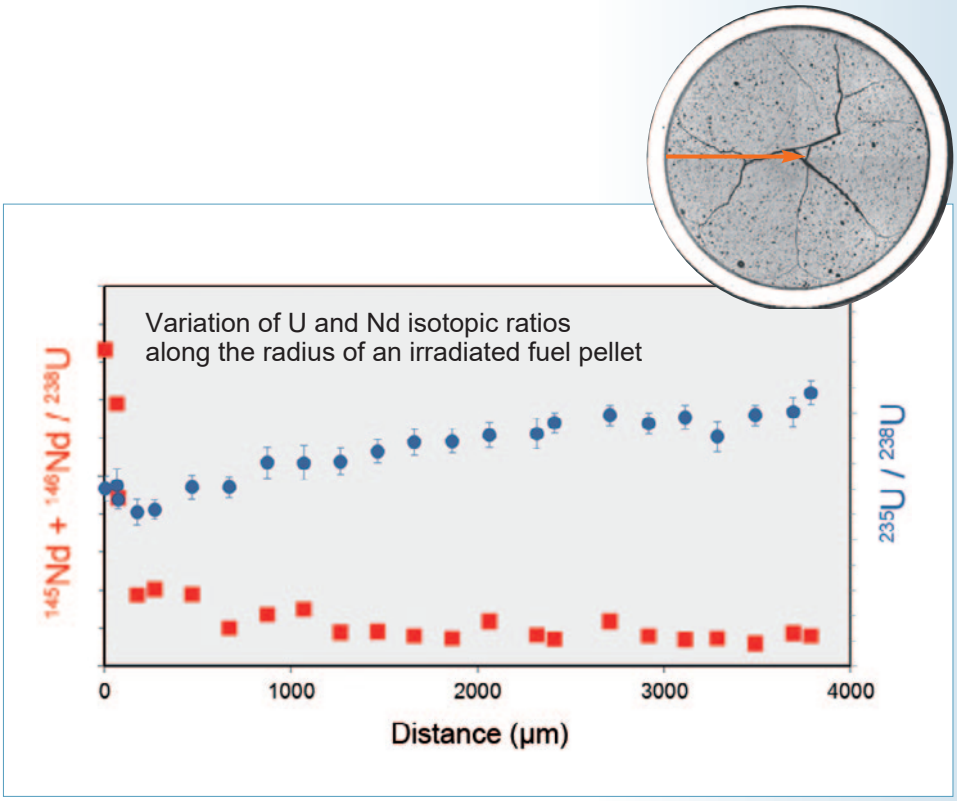
APPLICATION NOTE #SIMS-003

IMS 7f-Auto

SIMS for Materials Analysis in Nuclear Science

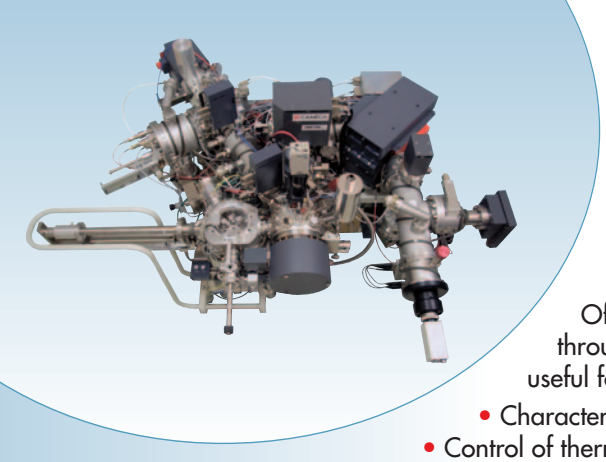






Courtesy of CEA Cadarache (DEN/DEC), France

Fusion & Fission Research
Nuclear Waste Management
Radiological Protection
Irradiated Fuel Analysis



CAMECA IMS 7f-Auto: The versatile SIMS tool for high performance analyses in nuclear materials.

Offering extreme sensitivity, high depth and lateral resolution together with high throughput, Dynamic SIMS (Secondary Ion Mass Spectrometry) proves extremely useful for a wide range of nuclear science applications:

- Characterization of plasma facing materials in fusion devices
- Control of thermal and irradiation effects on fission products
- Investigation of long-term behavior of nuclear materials for safe waste disposal
- Study of uranium accumulation processes in human tissues and cells.

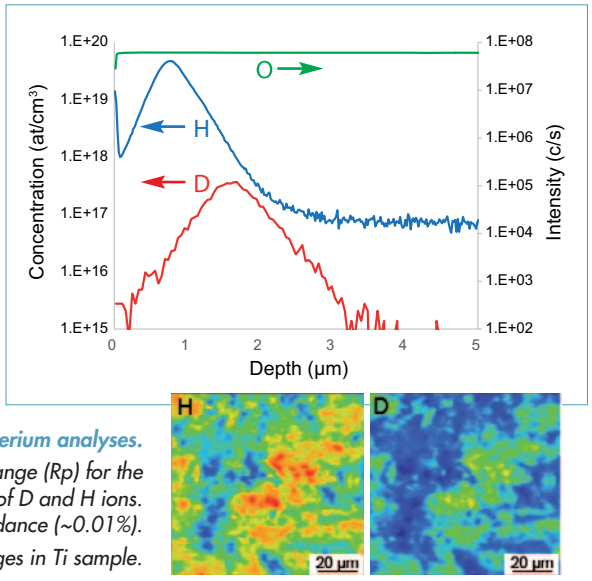
The CAMECA IMS 7f-Auto magnetic sector SIMS is the tool of choice for these applications. It offers:

- Depth profiling with excellent detection limits (ppb to ppm) and high depth resolution
- Elemental as well as isotopic information ranging from low mass (H) to high mass species (Pu and above)
- Unique sub-µm resolution 2D and 3D imaging capabilities
- Benchmark throughput and automation.

Fusion research

The erosion of plasma facing materials in magnetically confined fusion devices is a key issue with respect to component lifetime. ITER (International Thermonuclear Experimental Reactor) will be operated with mixtures of deuterium and tritium, therefore tritium retention in plasma facing components must be as low as possible as it may lead to an unacceptable inventory of radioactive tritium. In addition, safe management and accounting of tritium in ITER and future fusion power reactors will be crucial for their reliable operation.

SIMS analyses of the wall tiles of the fusion device allow the study of erosion, deposition, and transport of materials. SIMS is particularly well suited for analyzing light elements such as hydrogen or deuterium with good detection limits.



Hydrogen and deuterium analyses.

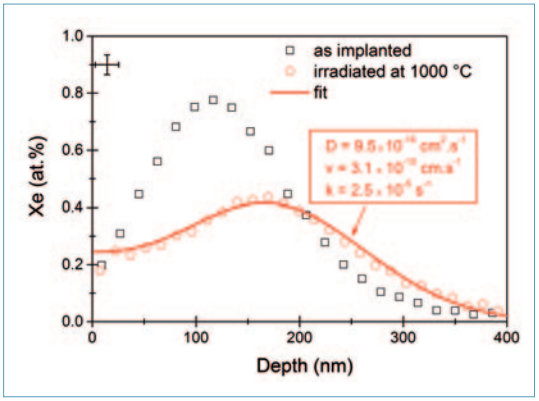
Top: Depth profiles in an implanted Al_2O_3 sample. The projected range (Rp) for the D profile is about twice the one for the H profile, indicating a co-implantation of D and H ions. The D relative dose is 1.1 %, well above the naturally occurring abundance (~0.01%).

Bottom: Scanning ion images in Ti sample.

Study of fission mechanisms

The behavior of rare gases produced by fission is of great importance for nuclear fuel in operation. For instance, low solubility fission products such as xenon and krypton can either agglomerate into bubbles which induce mechanical stress in the fuel pellets, or be released from the pellets, increasing the pressure within the cladding.

Due to their outstanding depth profiling capabilities the IMS 7f series instruments are routinely used to study thermal & irradiation effects and to investigate the migration behavior of fission products in nuclear fuel.



Xenon migration in UO_2 under irradiation.

Samples were first implanted with ^{136}Xe at 800 keV. They were then either annealed or irradiated with swift heavy ions at different temperatures. Depth profiles show that xenon is mobile during irradiation at 1000°C, indicating a synergistic effect of both temperature and irradiation (Radiation Enhanced Diffusion).

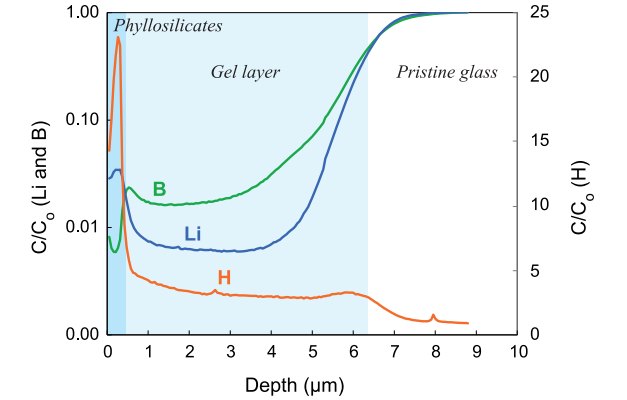
Data from: B. Marchand et al, Journal of Nuclear Materials 440 (2013) p.562.

Nuclear waste management

The long-term behaviour of glasses used to confine nuclear waste is of prime interest to ensure their safe geological disposal. In order to understand glass alteration mechanisms, it is crucial to study the formation of altered layers (e.g. gel and phyllosilicates for silicate glasses) that develop in contact with acqueous solution.

This requires elemental in-depth characterization as well as the use of isotopic tracers which is a powerful method to study the exchanges between the solution and the glass.

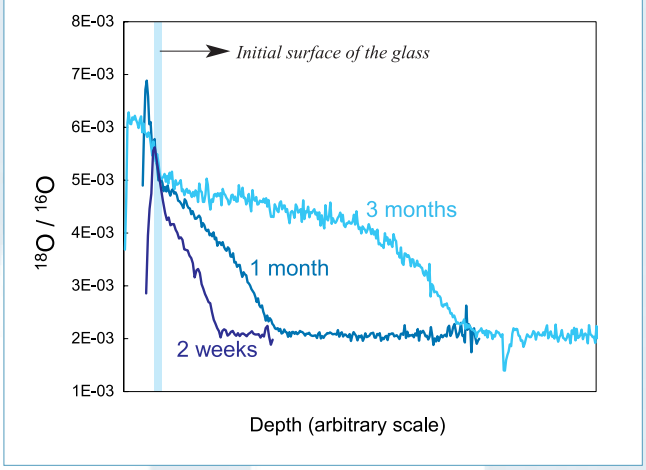
Offering excellent depth profiling capabilities for low concentration elements and high precision isotopic ratio analysis, the IMS 7f-Auto is the best suited tool for analyzing nuclear glasses and investigating glass alteration mechanisms.



Elemental in-depth profiles (B, Li, H) for a glass altered after 3 months.

The pristine glass displays high B and Li concentrations and a low H content. The gel layer is depleted in B and Li. Close to the free surface, H and Li enrichments are observed together with a B depletion. Concentrations are normalized to the pristine glass composition (C/C_0).

Data from: N. Valle et al, GCA 74 (2010), p.3412.



Isotopic depth profiles ($^{18}O/^{16}O$) performed in a glass at different alteration times with ^{18}O-labelled leaching solution ($^{18}O/^{16}O$ ~ 0.011).

Whatever the duration of alteration, the variations of $^{18}O/^{16}O$ vs depth follow a sigmoidal profile. The outermost part of the gel layer has a $^{18}O/^{16}O$ ratio around 5E-03 after two weeks of alteration. These profiles indicate a ^{18}O incorporation via condensation reactions.

Radiological protection

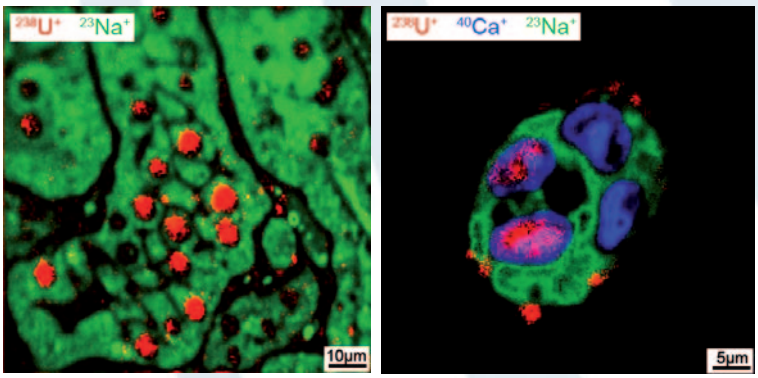
Uranium is a radionuclide but also a heavy metal to which humans can be exposed due its natural presence in the earth's crust or human activities. The acute effect and notably the uranium nephrotoxicity are well known but knowledge about the effect of chronic uranium exposure is less clear. It is therefore important to study the uranium bioaccumulation processes at tissue and cell level.

Due to the unique, high resolution imaging capabilities of the IMS 7f series instruments, SIMS data make it possible to observe soluble uranium within the nuclei of cultured cells and, more recently, in vivo in chronically exposed rats.

Uranium bioaccumulation in tissue.

Left: Superimposed ionic images of $^{238}U^+$ and $^{23}Na^+$ of proximal convoluted tubules in the renal cortex of rat after 9 months of contamination by uranium in the drinking water (120 mg/L). The Na image shows the morphology of the analyzed area. U is mainly localized in the proximal tubule cells.

Right: Superposed ionic images of $^{238}U^+$, $^{40}Ca^+$ and $^{23}Na^+$ of hepatocyte cell cultures (HepG2) after 30 minutes of U exposure at 100 µmol/L. The Ca and Na images show respectively the nucleus and the cytoplasm.



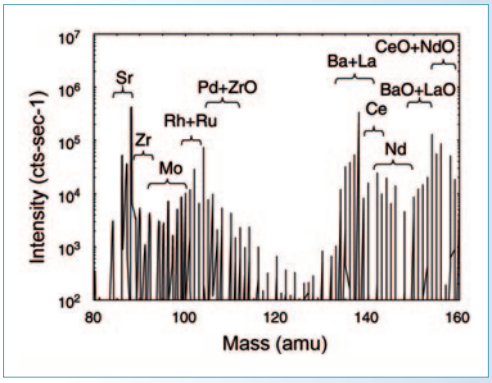
Data from: C. Poisson C. et al. Free Radic Res. 48 (2014) p.1218, and Y. Gueguen, et al. Toxicology in Vitro (epub Sep. 2015).

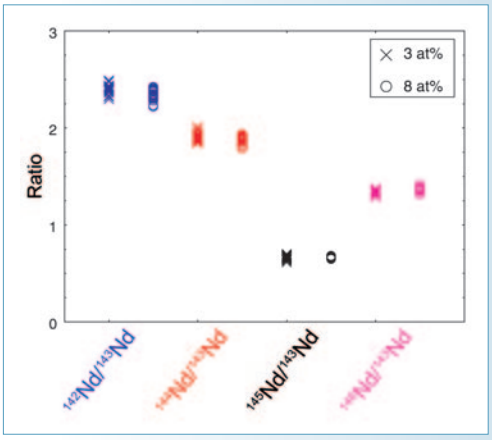
CAMECA also offers a ACTINIS specifically developed for the analysis of highly radioactive samples.

Irradiated nuclear fuel

Derived from the IMS 7f-Auto, the ACTINIS is dedicated to the analysis of irradiated nuclear fuel. It offers all necessary protection against radiation and alpha contamination while ensuring excellent analytical performance: high sensitivity for detecting low concentrations, excellent depth resolution, high mass resolution, precise measurement of isotopic ratios, unique imaging capabilities...

Combining mass spectra, isotopic ratios and scanning ion imaging, the Shielded IMS delivers comprehensive analyses of complex nuclear fuel samples.





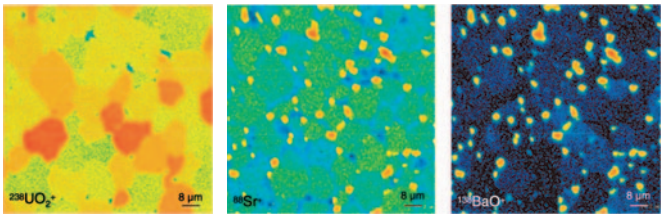
Courtesy of JRC-ITU, Karlsruhe, Germany

SIMS study of simulated nuclear fuel.

Two samples, simulating burn-ups of 3 and 8 at%, obtained by doping non-irradiated UO_2 with a known concentration of elements representing fission products.

Mass spectra on the 3 at% sample (top), isotope measurements for four Nd ion ratios (bottom right), ion maps on the 3 at% samples (bottom left).

Data from: S. Portier et al. Microchim Acta 161 (2008), p.479.



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