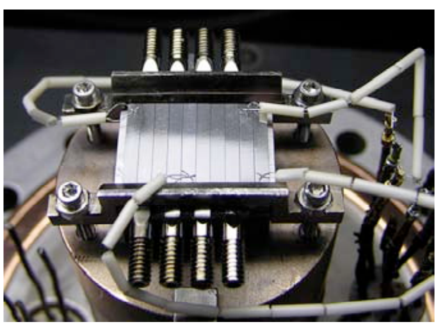
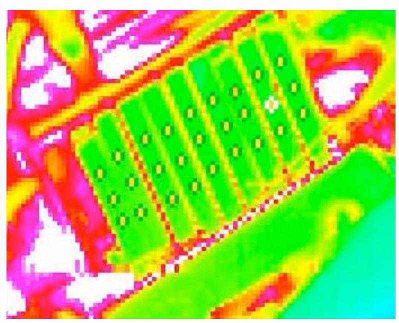
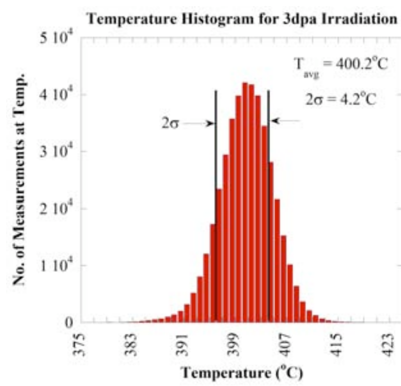
University of Michigan
ATR Partner Facilities Description

Michigan Ion Beam Laboratory (MIBL)

The Department of Nuclear Engineering and Radiological Sciences at the University of Michigan has developed extensive capabilities in the use of accelerators directed towards the study of radiation effects by emulating neutron damage in nuclear reactor materials. Numerous studies on radiation effects have been performed on a variety of materials, including: austenitic stainless steels, ferritic, pressure vessel steels, and Zircaloy-4. The 1.7 MV Tandetron accelerator facility in the Michigan Ion Beam Laboratory (MIBL) has been developed specifically for proton irradiation experiments. The accelerator utilizes a state-of-the art TORVIS ion source from National Electrostatics Corporation to generate up to 100 µA of beam at the target. These currents allow for intermediate dose rate irradiations up to ~ 10 dpa A high current sputter source can produce high dose rates of heavy ions to study very high dose (~200 dpa) irradiation at shallow depths. Irradiations can be conducted over the temperature range 200°C to 600°C. The facility also provides a special sample stage for irradiation under carefully controlled conditions. Irradiations parameters such as dose, dose-rate, and temperature are computer-monitored. The entire irradiated sample area is monitored continuously with 50 nm resolution, 2D, high precision thermal imager, providing unprecedented capability to verify irradiation temperature everywhere on the samples throughout the irradiation.







Samples mounted on the irradiation stage and a thermal image of the samples during an irradiation at 400°C, in which temperature is measured at each spot every few seconds for the entire duration of the irradiation. The histogram shows the temperature distribution for a single spot on the sample during the course of a 3 dpa irradiation. Between 10^5 and 10^6 data points are collected for a typical irradiation, providing a high spatial resolution temperature map.

Irradiation parameters for proton and heavy ion irradiations at MIBL.

Ion	Protons	Heavy ions (Ni, Fe, etc.)
Max. beam current on target	60 µA	10 µA
Dose rate	~10^{-6} dpa/s	~10^{-4} dpa/s
Energy	Up to 3 MeV	Up to 5 MeV (charge state dependent)
Temperature	200-600°C	200-600°C

The MIBL facility has also recently obtained an in-situ cell designed to accommodate proton-irradiation of metals in contact with liquid environments. This system was designed and constructed at ORNL and has been used at ORNL up to temperatures of 288°C and pressures of 1100 psi. Higher temperatures and pressures are possible. The accelerator system provides unparalleled capabilities to conduct irradiation damage studies using ions rather than neutrons, and thus enjoys the advantages of short irradiation times, reduced sample activity and low cost compared to that for the neutron irradiation.

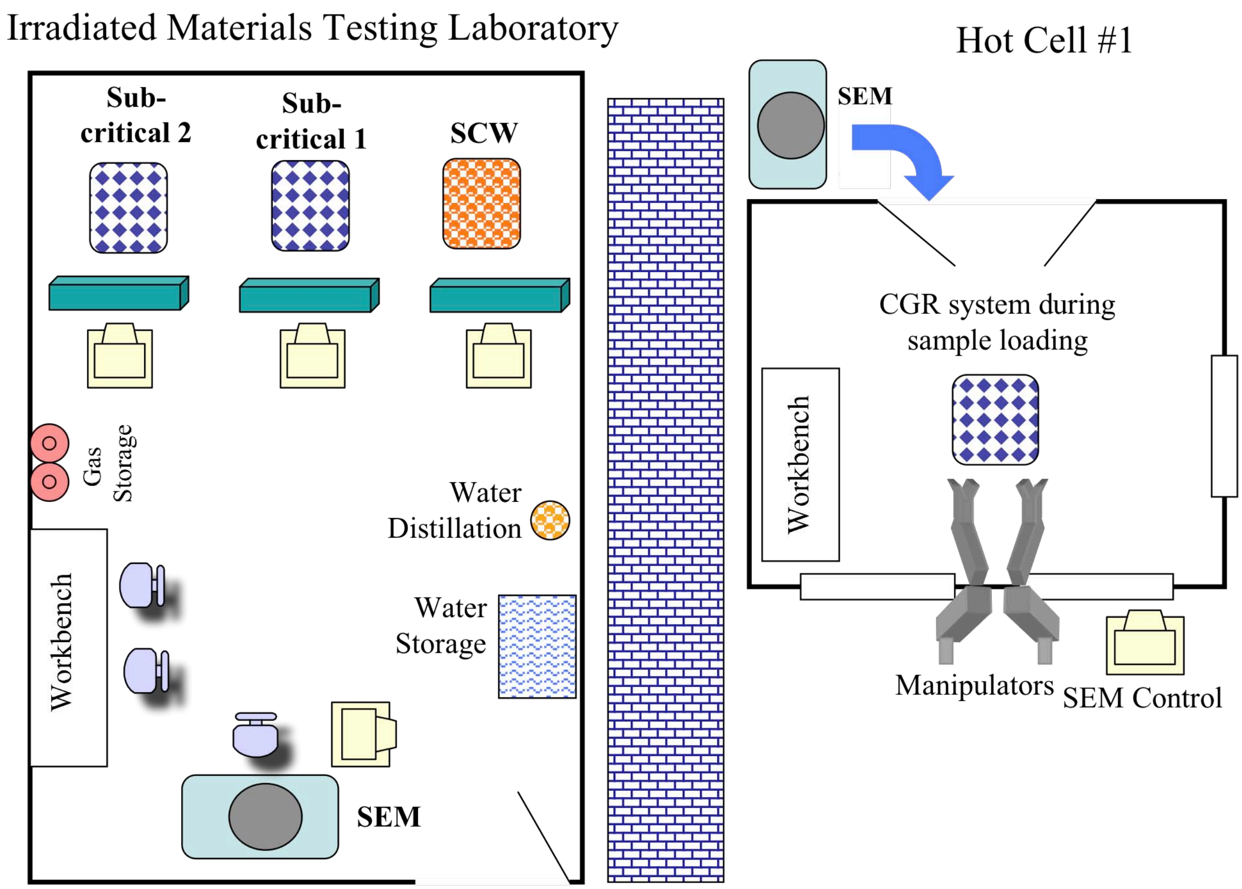
A National Electrostatics Corporation (NEC), 400 kV implanter is capable of delivering beams with energies between 10 and 400 keV from potentially any element in the periodic table. The ion source was designed for production of ion beams with currents ranging from several microamperes to more than a milliampere. It is capable of ionizing elements that have low vapor pressure, and producing ions by sputtering solid targets or by ionizing gases. Beam fluences of up to 10^{20} atoms/cm^2 could be achieved in an area of a square inch in a few hours. Double ionization states for some elements (Ar^{2+}, O^{2+}, etc) allow for implants at energies of up to 800 keV. The target chamber provides an implant area of up to 6 inches in diameter, and temperature control from 77K to 1073K. A rotating carousel permits simultaneous loading of twelve 2-inch wafers, five 4-inch wafers or four 6-inch wafers for sequential implantation. The target chamber is equipped with a 4-point Faraday cup system that allows for precise beam monitoring and dose measurement with an operating pressure in the 10^{-8} torr range.

The Michigan Ion Beam Laboratory for Surface Modification and Analysis.

The ion beam assisted deposition system combines film formation with simultaneous ion bombardment in order to control the properties of the deposited layer. The system consists of a low energy, high current ion gun (<1.2 keV, several mA), two 6 kw electron beam guns for vapor deposition, and a versatile stage for controlling the temperature of the substrate between –100°C and 1000°C. Ion type (generally noble gas), ion energy, angle and ion-to-atom arrival rate ratio can be precisely controlled in order to control the physical properties of the film, including density, stress, texture, grain size and the structure of the interface. Beams of nitrogen or oxygen can be used for reactive ion beam deposition in which the ion reacts with the evaporated element to form a nitride or oxide.

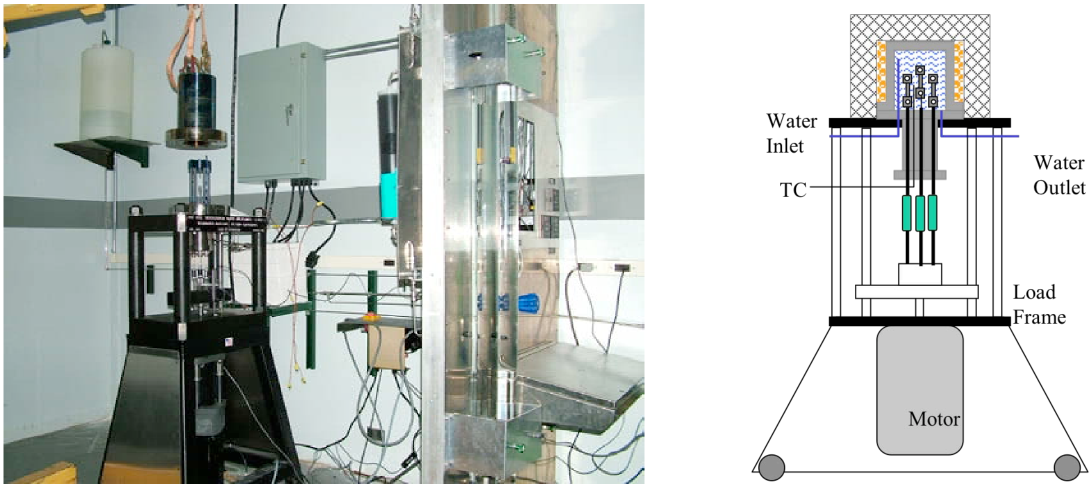
Irradiated Materials Complex (IMC)

The Irradiated Materials Laboratory provides the capability to conduct high temperature mechanical properties, and corrosion and stress corrosion cracking experiments on neutron irradiated materials in an aqueous environment, including supercritical water, and to characterize the fracture surfaces after failure. The facility utilizes two laboratories in the Phoenix Memorial Laboratory at the University of Michigan. They are the Irradiated Materials Laboratory (IML) and the hot cells, which together comprise the Irradiated Materials Complex (IMC).



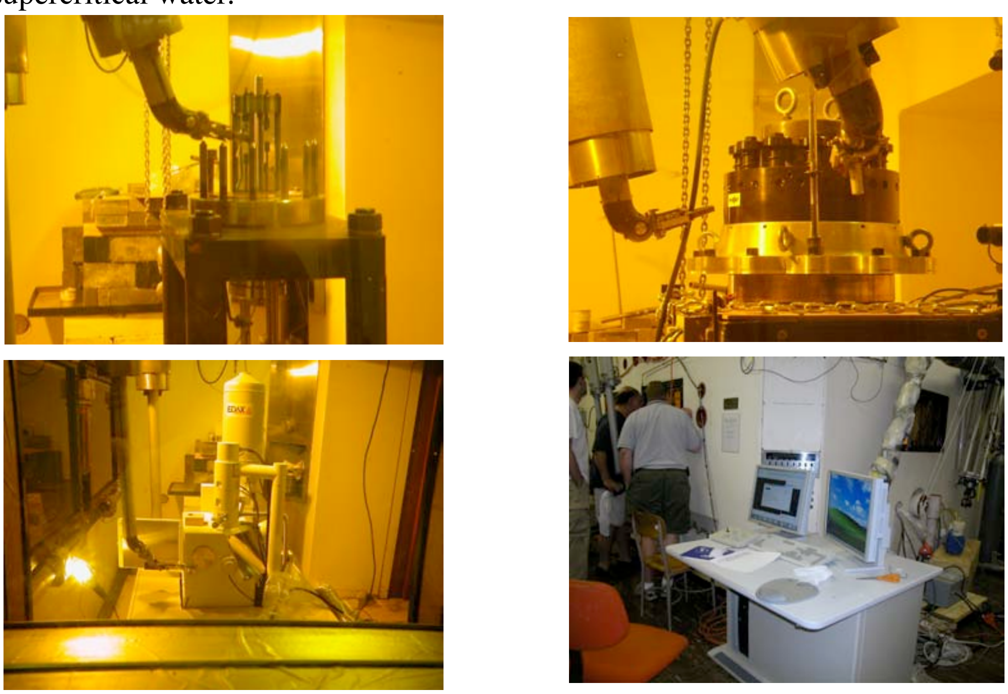
Schematic diagram of the Irradiated Materials Laboratory and Hot Cell #1 in the Irradiated Materials Complex at the University of Michigan.

IML currently has three systems. Each of them consists of a high temperature autoclave, circulating water loop, load frame and servomotor for conducting constant extension rate tensile (CERT) and crack growth rate (CRG) tests in high temperature water. One system has the capability to provide supercritical water at a temperature of 600°C and a pressure of 30 MPa. The other two facilities are rated at 365°C and 20 MPa. Each of the facilities is equipped with two autoclave heads. One is used to test up to 4 samples simultaneously in CERT mode and one is for CGR testing using the DC potential drop (DCPD) technique. All of the test frames are on wheels to permit loading and unloading in the hot cell and testing in IML.



The SCW facility in IML and a schematic of its mobile construction.

Hot cell #1 is used for specimen loading, autoclave closure and pressure testing and sample unloading after test completion. It is also used for post-test SEM analysis of fracture and gage sections. IML consists of a high temperature autoclave, circulating water loop, load frame and servo motor for conducting constant extension rate tensile (CERT) and crack growth rate (CRG) tests in subcritical or supercritical water up to 600°C and 30 MPa. A scanning electron microscope (SEM) is also available for the analysis of fracture surfaces for sample fractured in either CERT or CGR modes in the autoclave system. Both the autoclave system and the SEM are mobile and may be used in either the hot cell or the accompanying laboratory. This facility is the only one in the world with the capability to conduct SCC tests on neutron-irradiated samples in supercritical water.



Specimen loading and autoclave sealing in the hot cell (top row), and placement of the SEM in the hot cell with the control panel outside the cell (bottom row).

Michigan Center for Microstructure Characterization (MC)^2 mc2.engin.umich.edu

(MC)^2 houses state-of-the-art equipment, including aberration corrected transmission electron microscopes, dual beam focused ion beam / scanning electron microscopes, an x-ray photo-electron spectrometer, a tribo-indenter, an atomic force microscope, and an atom probe tomography instrument. In particular, the laboratory contains the following instruments: Tescan MIRA3 FEG SEM, Tescan RISE SEM, FEI Quanta 3D e-SEM/FIB, FEI Nova 200 Nanolab SEM/FIB, FEI Helios 650 Nanolab SEM/FIB, FEI Helios G4 PFIB UXe, FEI Tecnai G2 F30 TWIN Electron Microscope, JEOL 2010F Analytical Electron Microscope, JEOL 2100F Probe-corrected Electron Microscope, JEOL 3100R05 Double Cs Corrected TEM/STEM., FEI Talos Analytical TEM, TEM holders, Cameca LEAP 5000HR atom probe, Zeiss Xradia Versa 520 3D X-ray Microscope with DCT module, Veeco Dimension Icon AFM, Kratos Axis Ultra XPS, Hysitron tribo-indenter, Hysitron pico-indenter, that support the following techniques: Scanning electron microscopy (SEM), focused ion beam (FIB) milling and imaging, X-ray energy dispersive spectrometry (XEDS), Electron backscattered diffraction (EBSD), cryo-electron microscopy, transmission electron microscopy (TEM), including diffraction imaging, high resolution (HREM), scanning (STEM), and aberration-corrected microscopy, in-situ electron microscopy (straining, heating, indentation), 3-D X-ray microscopy, electron energy loss spectrometry (EELS), atom probe microscopy (APM), atomic force microscopy (AFM), x-ray photoelectron spectroscopy (XPS), tribo/pico-indentation.