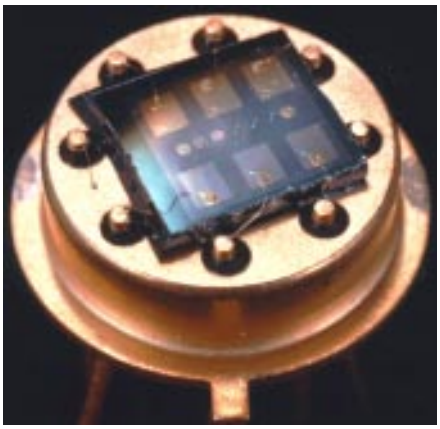
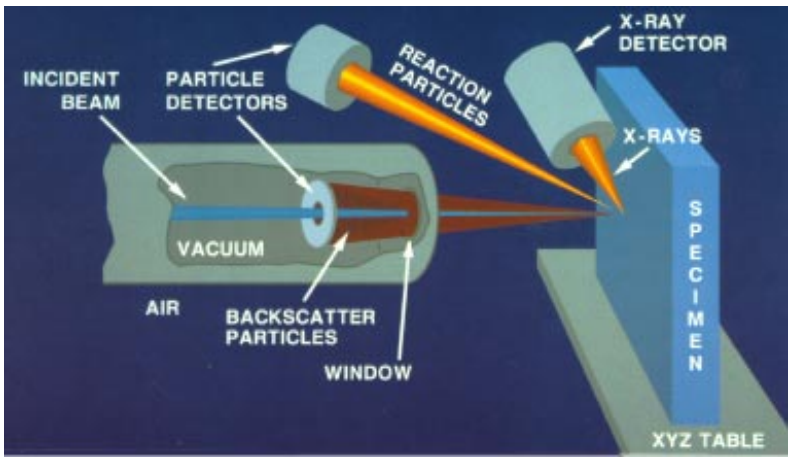
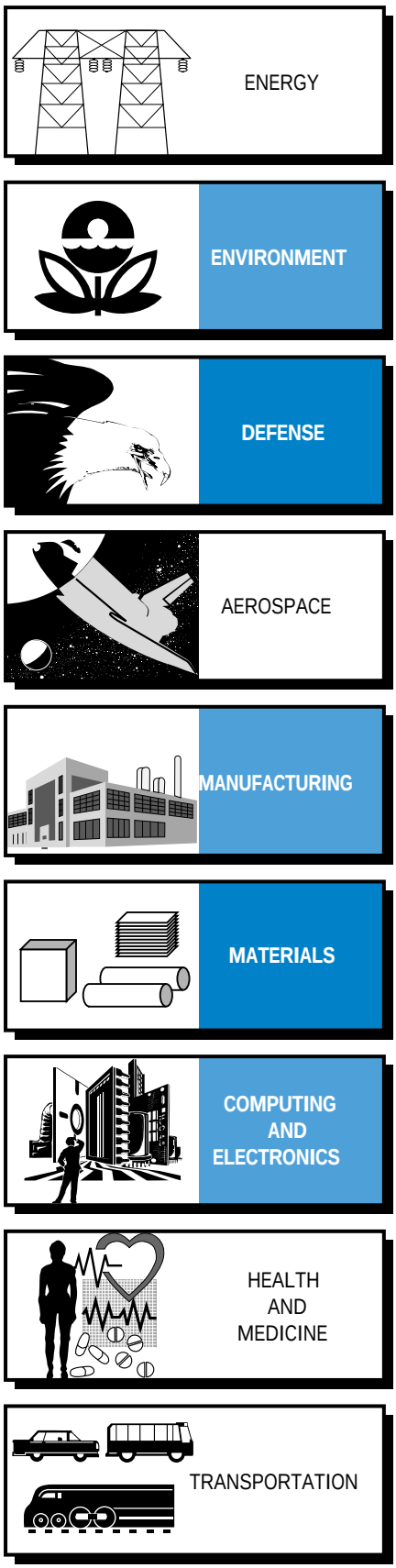
high-efficiency water cooling structures (hypervapotrons and twisted tape inserts). These programs have also extended the database on thermal fatigue limits and critical heat flux limits to ultrahigh heat fluxes (in the range from 10 to 30 MW/m^2).

Diagnostics for characterizing the plasma edge and plasma-materials interactions are also being applied outside the fusion program. External ion beam analysis (X-IBA), also developed at SNL, allows for the nondestructive analysis of large components. This technique was used in a forensic study of the gun turret explosion on board the USS *Iowa* and has been transferred to universities, industry, and the international art community. X-IBA techniques, illustrated below, are being applied to analyze hydrogen content in plastic, to study the incorporation of hydrogen isotopes in electrochemical electrodes, and to study the metal content of pigments in paintings at the Louvre.

Plasma edge diagnostics such as carbon resistance probes are being applied in semiconductor research, and new hydrogen microsensors are being developed as detectors for flammable gas. These tiny sensors (less than 1 mm^2 in area) are very



sensitive to hydrogen, so they can detect a wide range of gases that contain hydrogen, such as methane, ammonia, and hydrogen sulfide. Work is in progress at SNL to optimize sensor design and electronic circuitry so that these miniaturized sensors, shown above, can be used for environmental monitoring.

Computer codes and modeling techniques developed at fusion institutions for studying plasma-materials interactions are being used in other areas. A code that calculates energetic ion ranges in solids is being used to predict dopant profiles in semiconductor processing. Impurity diffusion codes have found applications in defense and environmental areas. Other codes now under development hold promise for modeling the plasma processing of materials.