Summary of the Los Alamos Spallation Radiation Effects Facility at LAMPF (LASREF)

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Facility

The following components and procedures are in place and have been demonstrated to be operationally reliable. We have also made progress in characterizing the neutron environment, through both calculation and activation foil measurements.

- Three proton irradiation ports, each with a usable volume of 150 cm^3. Total permissible mass density in the beam is 10-20 gm/cm^2, subject to occasional scheduling constraints.
- Proton flux in the beam center of 2 to 4 x 114 protons/cm^2s.
- Proton irradiation capsules capable of controlled operation at elevated temperature.
- Twelve neutron irradiation ports, each with an irradiation volume bounded by dimensions of 10 x 20 x 40 cm.
- Neutron flux of 2-6 x 10^{13} neutrons/cm^2s (at 3 of the 12 ports) determined both by measurement and Monte Carlo calculations. The energy distribution resembles a fission spectrum with the addition of substantial numbers of neutron in the 10-100 MeV range, i. e., a high-energy tail.
- Neutron irradiation capsules/furnaces that have operated up to temperatures of 650°C. Samples experience an inert gas atmosphere.
- Closed-loop water and helium heating/cooling systems.
- On-line continuous data acquisition and experiment control.
- Remote handling of radioactive samples. Experiment changes have been made in 6 h during a scheduled LAMPF maintenance day.
- Field-Ion-Microscopy laboratory has been used successfully to explore atomic-resolution details of depleted zones.

Irradiation experiments performed

- Five independent proton irradiations containing about 30 different materials/alloys.
- Four independent neutron irradiations containing about 50 different materials/devices.
- Seven approved LAMPF experiments over the last three years. Includes ceramics and graphites sponsored by KFA Julich for the European fusion community.

Active experiments/spokespersons/sponsors

Experiment #769 "Proton Irradiation Effects on Candidate Materials for the German Spallation Neutron Source"
- W. Lohmann, KFA Julich, FRG
- W. Sommer, Los Alamos

Experiment #936 "Additional Measurements of the Radiation Environment at the Los Alamos Spallation Radiation Effects Facility at LAMPF"
- D. Davidson, Iowa State University
- M. Wechsler, Iowa State University

Experiment #943 "Microstructural Evolution and Mechanical Property Changes in 316 Stainless Steel, Al, and Mo under Irradiation with Different Displacement/Helium Production Rates and Ratios"
- J. Yu, Institute of Atomic Energy, Peoples Republic of China
- M. Borden, New Mexico Institute of Mining and Technology
- W. Sommer, Los Alamos

Experiment #929 "Crack Growth in 800-MeV Proton and Neutron Irradiated Alloy 718"
- R. Brown, Los Alamos

Experiment #932 "Radiation Damage in Magnetically Soft Crystalline and Amorphous Alloys"
- J. Cost, Los Alamos
- R. Brown, Los Alamos

Experiment #986 "Spallation Neutron Irradiation of Non-Oxide Ceramics for First-Wall Fusion Reactor Application"
- B. Thiele, KFA Julich
- J. Linke, KFA, Julich

Experiment #987 "Fast Neutron Irradiation Screening Test of Polycrystalline Graphites under Fits-Wall Fusion Conditions"
- W. Delle, KFA Julich
- B. Thiele, KFA Julich

Experiment #1014 "Proton, Spallation Neutron, and Fission Neutron Irradiation of Copper"
- A. Horsewell, RISO National Laboratory, Denmark
- W. Sommer, Los Alamos

Letter of Intent—"Measurement of Point Defect Concentrations in Metals During 800-MeV Proton Bombardment"
- M. Eltrup, A. Horsewell, and B. Singh, RISO National Laboratory, Denmark
- W. Sommer, Los Alamos
- S. Lin, Peoples' Republic of China

Letter of Intent—"Resistivity Measurements on Alumina"
- F. Clinard, Los Alamos

Letter of Intent—"Effects of Temperature, Neutron Spectrum, Size, and Composition on the Neutron-Induced Embrittlement of Nuclear Pressure Vessel Steels"
- A. Kumar, University of Missouri-Rolla
- F. Garner, Battelle Pacific Northwest Laboratories
- M. Hamilton, Battelle Pacific Northwest Laboratories
- G. Lucas, University of California-Santa Barbara

Major results

- Measured neutron flux and spectra are in good agreement with previous Monte Carlo calculations.

- Field-Ion-Microscopy of irradiated W shows detail of a depleted zone and suggests dynamic transport of atoms.

- Precipitation hardened alloys of Al-Mg-Si and cold-worked alloys of Al-Mg lose their strength to the annealed level at a low dose of 3×10^{20} protons/cm^2 and at a temperature <100 °C. In the Al-Mg-Si alloy, the Mg_2Si precipitates dissolved and in the Al-Mg alloy, the dislocation structure was greatly altered. This material is a candidate for beamline windows and high conductivity/low activation applications for pulsed neutron sources in Germany, England, and the US.

- Irradiation of electrical components essential for *in-situ* stress-strain, fatigue, and creep measurements showed them to be sufficiently reliable when properly shielded.

- Measurement of gas production (He) in several materials irradiated with protons allows refinement of codes currently used to predict radiation damage parameters.

Future plans/possibilities

- *In-situ* measurement of mechanical properties of irradiated materials. Testing machines developed and built by KFA Julich are now available at LAMPF.

Since the KFA spallation neutron facility project has been canceled, we will need a dedicated team to bring this equipment into use.

- Measurement of microstructural evolution in Cu, Mo, and Al under varying ratios of gas production/atomic displacement. Irradiations are now underway using the LAMPF proton beam, the LAMPF neutron flux, and the Danish DR-3 fission reactor. This experiment tests a recent theory based on non-equilibrium thermodynamics and kinetics developed by Jinnan Yu (visiting scientist from the PRC) during his stay at Los Alamos.

- Measurement of point defect generation and transport using resistivity measurements, positron annihilation technique, field-ion-microscopy, and internal friction measurements. Resistivity measurements will begin at liquid He temperature; we expect to have a cryogenic facility.

- Development of a high-Z target for eventual use at LANSCE. Samples of U and U alloys have been irradiated and await analysis.

- Rutherford/ISIS advanced target development.

- LAMPF Advanced Hadron Facility target cell development.

- Investigations of properties of superconducting materials under radiation for the Superconducting Super Collider project.

- Increased involvement with universities/graduate students.

Active collaborators

- RISO National Laboratory, Denmark
  - A. Horsewell
  - M. Eltrup
  - B. Singh
- KFA—Julich, West Germany
  - W. Lohmann
  - B. Thiele
- SIN/EIR, Switzerland
  - W. Green
  - M. Victoria
- Atomic Energy Commission, Peoples Republic of China
  - J. Yu
  - S. Lin
- Iowa State University
  - M. Wechsler
- New Mexico Institute of Mining and Technology
  - O. Inal
  - M. Borden
- Battelle Pacific Northwest Laboratories
  - F. Garner

- Los Alamos National Laboratory
  - R. Brown
  - J. Cost
  - G. Russell
  - G. Legate
  - F. Clinard
- University of Missouri-Rolla
  - A. Kumar

Program Advisory Committee (PAC)

LAMPF utilizes peer review of research proposals to determine the scientific merit and feasibility for each proposed experiment. A Materials Science Subcommittee of the PAC is in place. Present members of the PAC are:

Frank Garner, Battelle Pacific Northwest Laboratories, Chairman
Ken Russell, Massachusetts Institute of Technology
James Stubbins, University of Illinois
Arvind Kumar, University of Missouri

Theoretical/computational

L.N. Kmetyk, W.F. Sommer, J. Weertman, and W.F. Green, "An Analytic Comparison of the Effect of Steady State and Cyclic Pulsed Radiation on Void Growth and Swelling," J. Nucl. Mater. 85 and 86, pp. 553-557 (1979).

L.N. Kmetyk, W.F. Sommer, and J. Weertman, "The Effect of Cyclic Pulsed Temperature on Void Growth in Metals During Irradiation," J. Nucl. Mater. 103 and 104, pp. 1409-1414 (1981).

L.N. Kmetyk, J. Weertman, W.V. Green, D.M. Parkin, and W.F. Sommer, "Void Growth and Swelling for Cyclic Pulsed Radiation," J. Nucl. Mater. 98, pp. 190-205 (1981).

Wechsler, M.S., Davidson, D.R., Greenwood, L.R., and Sommer, W.F., "Calculation of Displacement and Helium Production at the Clinton P. Anderson Meson Physics Facility (LAMPF) Irradiation Facility," Effects of Radiation on Materials: Twelfth International Symposium, ASTM STP 870, F.A. Garner and J.S. Perrin, Eds., American Society for Testing and Materials, Philadelphia, PA (1985), pp. 1189-1198.

J. Yu, W.F. Sommer, and J.N. Bradbury, "Microstructural Evolution under Particle (Neutron and Proton) Irradiation: Nonequilibrium Statistics Theory for Bubble Nucleation and Growth," LA-UR 85-2851 Rev., presented at the Second International Conference on Fusion Reactor Materials, Chicago, IL, April 13-17, 1986. To be published in J. Nucl. Mater.

J. Yu, W.F. Sommer, and J.N. Bradbury, "Interstitial Dislocation Loop Nucleation and Growth and Swelling Produced by High Energy Cascades," LA-UR 85-3011, presented at the Thirteenth International Symposium on Effects of Radiation on Materials, Seattle, WA, June 23-25, 1986. To be published in the Proceedings.

Facility characterization/description

W.F. Sommer, L.N. Kmetyk, W.V. Green, and R. Damjanovich, "Use of the LAMPF Accelerator as a Fusion Materials-Radiation Effects Facility," J. Nucl. Mater. 103 and 104, pp. 1583-1588 (1981).

K.E. Christensen, G.A. Bennett, and W.F. Sommer, "An In-Situ Mechanical-Radiation Effects Test Capsule for Simulating Fusion Materials Environments," J. Nucl. Mater. 103 and 104, pp. 1517-1521 (1981).

R.D. Brown and D.L. Grisham, "Design and Operation Water-Cooled Pyrolytic Graphite Targets at LAMPF," 1981 Particle Accelerator Conference, Accelerator Engineering and Technology, Washington, DC., March 11-13, 1981, IEEE Transactions on Nuclear Science, Vol. NS-28, 2940 (1981), Los Alamos National Laboratory Report LA-UR 81-685 (1981).

R.D. Brown and D.L. Grisham, "Graphite Targets at LAMPF," Particle Accelerator Conference, March 21-23, 1983, IEEE Transactions on Nuclear Science, Vol. NS-30, 2801 (1983), Los Alamos National Laboratory Report LA-UR 83-956 (1983).

L. Agnew, D. Grisham, R.J. Macek, W.F. Sommer, and R.D. Werbeck, "Design Features and Performance of the LAMPF High Intensity Beam Area," presented at

the ICANS VII meeting, Chalk River, Ontario, CANADA, Sept. 12-16, 1983. To be published in the Proceedings.

D.R. Davidson, R.C. Little, W.F. Sommer, J.N. Bradbury, and R.E. Prael, "Characterization of the Radiation Environment at a New Proposed Irradiation Facility at LAMPF," J. Nucl. Mater. 122 123, pp. 989-994 (1984).

M.S. Wechsler and W.F. Sommer, "The Radiation Damage Facility at the LAMPF A-6 Target Station," J. Nucl. Mater. 122 123, pp. 1078-1084 (1984).

Davidson, D.R., Greenwood, L.R., Reedy, R.C., and Sommer, W.F., "Measured Radiation Environment at the Clinton P. Anderson Meson Physics Facility (LAMPF) Irradiation Facility, Effects of Radiation on Materials: Twelfth International Symposium, ASTM STP 870, F.A. Garner and J.S. Perrin, Eds., American Society for Testing and Materials, Philadelphia, PA, 1985, pp. 1199-1208.

D.R. Davidson, W.F. Sommer, I.K. Taylor, R.D. Brown, and L. Martinez, "'Rabbit' System for Activation Foil Irradiations at the Los Alamos Spallation Radiation Effects Facility at LAMPF," LA-UR 85-3630 Rev., presented at the Second International Conference on Fusion Reactor Materials, Chicago, IL, April 13-17, 1986. Not to be published.

W.F. Sommer, W. Lohmann, I.K. Taylor, and R.M. Chavez, "Operating Experience at the Los Alamos Spallation Radiation Effects Facility at LAMPF," LA-UR 85-3917, presented at the Thirteenth International Symposium on Effects of Radiation on Materials, Seattle, WA, June 23-25, 1986. To be published in the Proceedings.

D.L. Grisham, J.E. Lambert, and W.F. Sommer, "Major Facility Overhauls at LAMPF," IEEE Transactions on Nuclear Science, NS-32(5), 3095-3097, (1985). Los Alamos National Laboratory document LA-UR 85-1736 (1985).

W. Lohmann and W.F. Sommer, "Materials Problems Relevant to a Pulsed High Power Spallation Target," Rutherford Report, ISIS/PGT/15, November 1986.

Experiments

H. Jang, J. Moteff, L. Levinson, R.D. Brown, and W.V. Green, "Defect Formation in 800-MeV Proton Irradiated Aluminum," Los Alamos National Laboratory Report LA-8127-MS, November 1979.

R.D. Brown, W.F. Sommer, and W.V. Green, "Irradiation Damage in Metals Produced by 800-MeV Protons," Los Alamos Scientific Laboratory Report LA-7939-MS (July 1979).

O.T. Inal and W.F. Sommer, "800-MeV Proton Damage in Tungsten and Molybdenum, A Field-Ion Microscope Observation," J. Nucl. Mater. 99, pp. 94-99 (1981).

J.R. Cost and W.F. Sommer, "Response of Metallic Glasses, $Fe_{40}Ni_{40}P_{14}B_6$ and $Fe_{80}B_{20}$ to Irradiation with 800-MeV Protons," J. Nucl. Mater. 103 and 104, pp. 773-778 (1982).

W.F. Sommer, D.S. Phillips, W.V. Green, L.W. Hobbs, and C.A. Wert, "Proton Irradiation Damage in Cyclically-Stressed Aluminum," J. Nucl. Mater. 114, pp. 267-276 (1983).

D.J. Farnum, W.F. Sommer, and O.T. Inal, "A Study of Defects Produced in Tungsten by 800-MeV Protons Using Field Ion Microscopy," J. Nucl. Mater. 122 123, 996-1001 (1984).

R.D. Brown, J.R. Cost, and J.T. Stanley, "Effects of Neutron Irradiation on Magnetic Permeability of Amorphous and Crystalline Magnetic Alloys," Conference on Magnetism and Magnetic Materials, Pittsburgh, PA, November 8-11, 1983, published in J. Appl. Phys. 55, 1754 (1984), Los Alamos National Laboratory Report LA-UR 83-2718 (1983).

R.D. Brown and J.R. Cost, "Mechanical Properties of 800-MeV Proton-Irradiated

Metals,"Effects of Radiation on Materials, Eleventh Conference, ASM STP 782 H. R. Brager and J.S. Perrin, Eds., American Society for Testing and Materials, pp. 917-926, 1982, Los Alamos National Laboratory Report LA-UR 82-672 (1982).

R.D. Brown, J.R. Cost, and J.T. Stanley, "Irradiation-Induced Decay of Magnetic Permeability of Metglas 2605S-3 and Mumetal," published in J. Nucl. Mater., 131, 37 (1985), Los Alamos National Laboratory Report LA-UR 84-875 (1984).

D.R. Davidson, W.F. Sommer, and M.S. Wechsler, "Additional Measurements of the Radiation Environment at the Los Alamos Spallation Radiation Effects Facility at LAMPF," LA-UR 85-3502 Rev., presented at the Thirteenth International Symposium on Effects of Radiation on Materials held at Seattle, WA, June 23-25, 1986. To be published in the Proceedings.

D.J. Farnum, W.F. Sommer, O.T. Inal, and J. Yu, "Quantitative Study, by Field Ion Microscopy, of Radiation Damage in Tungsten after Neutron and Proton Irradiation," LA-UR 85-3918, presented at the Thirteenth International Symposium on Effects of Radiation on Materials, Seattle, WA, June 23-25, 1986. To be published in the Proceedings.

W. Lohmann, A. Ribbens, W.F. Sommer, and B. Singh, "Microstructure and Mechanical Properties of 800-MeV Proton Irradiated Commercial Aluminum Alloys," LA-UR 85-2296, presented at the RISO National Laboratory Workshop on The Relation Between Mechanical Properties and Microstructure Under Fusion Irradiation Conditions, June 27-July 2, 1985. To be published in Rad. Effects.

B.N. Singh, W. Lohmann, A. Ribbens, and W.F. Sommer, "Microstructural Changes in Commercial Aluminum Alloys after Proton Irradiation," LA-UR 85-4074, presented at the Thirteenth International Symposium on Effects of Radiation on Materials, Seattle, WA, June 23-25, 1986. To be published in the Proceedings.

B.N. Singh, W.F. Sommer, and W. Lohmann, "Transport and Accumulation of He-

lium Produced During 800-MeV Proton Irradiation of Aluminum and Aluminum Alloys," LA-UR 85-3403, presented at the Second International Conference on Fusion Reactor Materials, Chicago, IL, April 1986. To be published in the J. Nucl. Mater.

D.J. Farnum, W.F. Sommer. O.T. Inal, and J. Yu, "Field Ion Microscopy Study of Depleted Zones in Tungsten after Proton Irradiation," LA-UR 85-3916 Rev., presented at the Second International Conference on Fusion Reactor Materials, Chicago, IL, April 13-17, 1986. Not to be published.

K.O. Jensen, M. Eldrup, B.N. Singh, A. Horsewell, M. Victoria, and W.F. Sommer, "Characterization of Vacancy and Vacancy-Gas Agglomerates in Aluminum Irradiated with Medium-Energy Protons by Positron Annihilation," presented at the International Conference on Vacancies and Interstitials in Metals and Alloys, Berlin, FRG, September 14-19, 1986.