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# Environment-Induced Degradation and Crack-Growth Studies of Candidate Target Materials

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**Environment-Induced Degradation and Crack-Growth Studies of Candidate Target Materials (Year III Renewal)**

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**TRP Research Area:** Target / Transmuter

**Budget Request:** $ 145,759

**Abstract:**
During the past two years (2001-2002) of this project, the primary effort was focused on evaluating the effect of hydrogen on the cracking behavior of candidate target materials namely, Alloys EP-823, HT-9 and 422 in aqueous environments of different pH values at ambient and elevated temperatures. More recently, emphasis is being placed to evaluate the cracking behavior of these materials in molten lead-bismuth eutectic (LBE) environment at much higher testing temperatures so as to compare the cracking susceptibility in environments containing molten metals and aqueous solutions, respectively. The most recent tests to evaluate the cracking susceptibility were primarily based on two state-of-the-art techniques known as constant-load and slow-strain-rate (SSR) methods. Simultaneously, efforts were made to determine the localized corrosion (pitting and crevice corrosion) behavior in similar aqueous environments at ambient and elevated temperatures using electrochemical polarization techniques. However, these techniques cannot be applied to LBE environment. Therefore, the work scope described in the original proposal is being modified to include additional testing methods to suit the high-temperature LBE environment. Although, testing still will be continued to complete the original matrix involving all three alloys in aqueous environments using constant-load, SSR, and polarization techniques, future testing will be performed in both aqueous and LBE environments using self-loaded specimens such as C-Ring and U-Bend stress-corrosion-cracking (SCC) test specimens. In addition to this corrosion testing, significant efforts will be made to evaluate the crack-growth behavior of radiation-hardened target materials using sub-size compact tension (CT) specimens. The test materials will undergo appropriate thermal treatments prior to their testing. All tested specimens will be examined metallographically. Further, the scanning electron microscopy (SEM) will be used to determine the extent and nature of cracking in the tested specimens. The thrust of this overall testing program is to evaluate the environmental and radiation effects on the cracking behavior of candidate target materials for applications in spallation-neutron-target (SNT) systems.

**Work Proposed for Year 3 (Summer 2003-Spring 2004), Goals, and Expected Results:**
A world-class research facility called the "Materials Performance Laboratory (MPL)" has been established in the UNLV Engineering Building (Room TBE B-129). The MPL has capabilities to perform numerous corrosion and metallurgical testing using state-of-the-art equipment. During the year 2002, experimental heats (three each) of Alloys HT-9, EP-823 and 422 were melted and processed into round bars at the Timken Research Laboratory (TRL), Canton, OH. Thermal treatments were also performed on a batch of these materials at this vendor's facility. The remaining heats of these alloys are currently being heat treated in the MPL. Thermal treatments will be continued during the third year. SCC testing using constant-load and SSR techniques is ongoing, and will be continued during the year 2003 to complete the planned test matrices and present the resultant data at numerous technical and scientific symposia. Cyclic potentiodynamic polarization (CPP) experiments will be continued during the third year to evaluate the susceptibility of all three test materials to pitting and crevice corrosion as functions of pH and temperature. Significant progress has been made on the fractographic evaluations of broken tensile specimens using SEM that will be continued in year 2003. Metallographic evaluations using optical microscopy are ongoing, and will be continued.

Two additional heats (one each) of Alloys EP-823 and HT-9 were recently melted and processed at the TRL. Subsequently, they will be heat-treated. C-Ring and U-Bend specimens will then be machined at the TRL from these heat-treated materials. These self-loaded specimens will then be subjected to SCC testing in both aqueous solutions (at MPL) and molten LBE (at LANL). Initially, small-scale bench-top experiments will be performed in molten LBE environment, followed by large-scale experiments in the delta-loop at LANL. The crack-growth studies using CT specimens (control and radiated) will be conducted on mechanical testing machine (MTS/INSTRON) at UNLV and/or LANL. Irradiation of the CT specimens will be done either at LANL or IAC. All specimens, upon completion of testing, will be examined by optical microscopy and SEM to determine the extent and morphology of cracking.

**Background and Rationale:**

Transmutation Research Program (TRP) Task 4 entitled "Hydrogen-Induced Embrittlement of Candidate Target Materials for Applications in Spallation-Neutron-Target Systems," approved for funding during the summer of 2001, was primarily aimed at evaluating the effect of hydrogen on cracking of candidate target materials such as Alloys EP-823, HT-9 and 422. Numerous testing to evaluate the susceptibility to cracking and localized corrosion of these materials in simulated aqueous environments has been ongoing in the MPL since its inception in June 2002. State-of-the-art SCC testing using constant-load and SSR techniques are well in progress in this laboratory. In addition, electrochemical polarization studies are ongoing to evaluate the pitting and crevice corrosion behavior of all three alloys in similar aqueous environments. A major portion of these resultant data will be presented this year at three international/national conferences. However, more recently, an added emphasis is being placed to evaluate the susceptibility of these alloys to SCC and localized corrosion in molten LBE environment so that a comparison can be made between the corrosion data obtained in aqueous solutions and molten LBE, respectively. Since the experimental techniques used so far in these corrosion studies cannot be applied in the presence of molten metals such as LBE, the work scope is being revised to reflect these additional types of testing.

During the third year (summer 2003-spring 2004) SCC and localized corrosion testing involving all three alloys will be continued in the MPL using techniques and environments cited in the original proposal. In addition, self-loaded C-Ring and U-Bend SCC specimens of Alloys EP-823 and HT-9 will be tested in molten LBE environment contained in both bench-top vessel and delta-loop at LANL. Further, in order to compare the SCC data obtained in the molten LBE environment, SCC testing using C-Ring and U-Bend specimens will be performed in the MPL in aqueous environments of different pH values at ambient and elevated temperatures (up to 300$^{o}$C).

Crack-growth behavior of target materials during the transmutation process is of significant importance, particularly under irradiated conditions. In view of this rationale, sub-size CT specimens, irradiated and unirradiated, will be tested using fracture mechanics-based techniques. This type of testing will enable the evaluation of the radiation effect on the metallurgical properties including the hardness, yield strength and microstructures. These metallurgical properties will obviously influence the crack-growth behavior of the tested materials under irradiated conditions.

**Test Materials:**

Three martensitic stainless steels, namely Alloys HT-9, EP 823 and Type 422, having fully tempered martensitic microstructures will primarily be tested in this program. Ni-base austenitic Alloy 718 may also be incorporated later during this testing period if warranted by the TRP needs.

**Types of Testing:**

The susceptibility to SCC/Hydrogen Embrittlement (HE) will be evaluated by using both smooth and notched uniaxial tensile specimens (4-inch long, 1-inch gage length, and 0.25-inch gage diameter). The notched tensile specimen will have a notch diameter of 0.156-inch at the center of the gage section. The tensile specimens will be pulled in an aqueous environment under either a constant load or a slow-strain-rate (SSR) condition. For constant load testing, a loading device such as a calibrated Proof Ring will be used. For each Proof Ring, a calibration curve generated by the manufacturer will be used to determine the amount of deflection needed to apply the desired load to the test specimen. The determination of cracking tendency using this technique will be based on time-to-failure (TTF). An automatic timer attached to the test specimen will record the TTF. Tensile specimens loaded to desired stress level would provide a fail versus no fail result.

The tensile specimens will be fabricated from heat-treated plate/bar materials in such a way that the gage section is parallel to the longitudinal rolling direction. For constant-load testing, the magnitude of the applied stress will be based on the tensile yield strength (YS) of the test material. The test specimens will be loaded at different percents of YS and the corresponding TTF will be recorded.

During SSR testing, the specimen will be continuously strained in tension until fracture, in contrast to more conventional SCC testing conducted under a sustained load condition. The application of slow dynamic straining ($10^{-6}$ to $10^{-7}$ $sec^{-1}$) to the smooth tensile specimen will facilitate cracking in the test materials that may not exhibit cracking under constant load or may take prohibitively long duration for crack initiation. However, the use of a notched tensile specimen may result in fast crack initiation under both constant load and SSR conditions. The smooth tensile specimen in SSR testing may undergo fast failure in a ductile manner if SCC does not occur, or prematurely in a brittle manner if SCC occurs. Prior to being tested in the aqueous environment, a few SSR specimens (both smooth and notched) will be pulled in air to establish baseline data.

It is well known that electrochemistry can play an important role in characterizing the (SCC)/(HE) behavior of susceptible alloys. Accordingly, at the onset, the corrosion or the open circuit potential ($E_{corr}$) of the test specimen will be measured in the aqueous environment of interest with respect to a standard Ag/AgCl reference electrode. The specimen will then be strained in the test solution either in a constant load or in a SSR condition using either a Proof Ring or a mechanical testing machine (Instron or MTS) with or without a controlled electrochemical potential ($E_{cont}$). The magnitude of $E_{cont}$ will be selected based on the measured $E_{corr}$ value (cathodic versus $E_{corr}$). This cathodic (negative) potential ($E_{cont}$) will be applied potentiostatically during the entire straining period. Two graphite rods will be used as cathodes during the potentiostatic polarization of the tensile specimen (anode). A three-electrode polarization technique will be used.

For conventional SCC tests under static loading condition, the cracking susceptibility will be expressed in terms of a threshold stress ($\sigma_{th}$) below which cracking does not occur during arbitrary test duration, or the TTF at a given applied stress. With SSR tests, however, similar approaches cannot be used since the test specimen is subjected to a continuously changing stress during straining. Therefore, the cracking tendency will be characterized by a number of readily measurable and quantifiable parameters obtained from the load-deflection curve and the examination of the broken test specimen.

Since environment-assisted cracking is usually associated with relatively little macroscopic plastic deformation during crack growth, the ductility parameters such as the percent elongation (%El) and the percent reduction in area (%RA) are very useful in characterizing the cracking susceptibility. In addition, the true fracture stress ($\sigma_f$) obtained from the load-deflection curve and the final specimen dimension is useful in expressing the extent of cracking tendency.

In the modified work scope, the susceptibility to SCC will be evaluated by using self-loaded C-ring and U-bend test specimens in both molten LBE and aqueous environments. The C-ring is a versatile and economic specimen for quantitatively determining the cracking tendency of many engineering alloys in a wide variety of product forms. The stress of principal interest in the C-ring specimen is the circumferential stress. The stress varies around the circumference of the C-ring from zero at each bolt hole to a maximum at the middle of the arc opposite to the stressing bolt (tension on the top surface, and compression on the opposite surface). The C-ring is a constant-strain specimen with tensile stress produced on the exterior of the ring by tightening a bolt centered on the diameter of the ring. The stressing methods are described in the ASTM Designation G 38-01 entitled, “Standard Practice for Making and Using C-Ring Stress-Corrosion Test Specimens.” The C-ring specimens will have outside diameter of 1-inch with a wall thickness of 1/8-inch. The U-bend specimen involves the stressing of a specimen bent to a U-shape, and usually contains both elastic and plastic strain. The applied strain is estimated from the bend conditions. The cracking time is used as an estimate of the SCC resistance of the alloy immersed in environments of interest. The detailed stressing procedure is given in the ASTM Designation G 30-97 entitled, “Standard Practice for Making and Using U-Bend Stress Corrosion Test Specimens.” For crack-growth studies, the CT specimens will be precracked by cyclic loading, followed by uniaxial tensile loading using fracture mechanics-based standard testing techniques.

Secondary ion mass spectrometry (SIMS) will be used to analyze the hydrogen content resulting from the cathodic potentiostatic polarization. Optical microscopy and SEM will be used to characterize the extent and morphology of cracking in all materials tested. Energy dispersive spectroscopy (EDS) will be used to detect and identify chemical species present in the vicinity of cracks.

**Test Conditions:**

All three martensitic stainless steels will be received in the form of both bar and plate. This group of materials is called martensitic because they are capable of changing their crystal structure upon heating and cooling. They can be quench (oil/water) hardened to fully martensitic structures without any retained austenite. These plates and bars will be austenitized in the temperature range of 1850 to 2000$^{o}$F for 1 hour followed by a water/oil quench. These martensitic structures are very hard and brittle. Therefore, these quenched materials will further be tempered at 1150$^{o}$F for 1, 1.5 and 2 hour(s) followed by air-cooling. All test specimens will be fabricated from these quenched and tempered stainless steels.

The susceptibility to HE will be evaluated by subjecting the thermally treated tensile specimens to cathodic charging in a deaerated (by helium/nitrogen) acidic brine (NaCl solution) at temperatures ranging from ambient (25$^{o}$C) to elevated temperatures (up to 120$^{o}$C). The strain rate used during the SSR tests will range from $10^{-6}$ to $10^{-7}$ sec$^{-1}$. The pH of the test solution will range between 2 and 3. Duplicate specimens of each material will be tested under each heat-treat and electro-chemical conditions. For testing in the LBE environment, a small bench-top vessel and the delta loop at LANL will be used to accommodate temperature up to 600 $^{o}$C.

**Expected Data:**

The proposed experimental program will generate the following data:

- Corrosion potential ($E_{corr}$)
- Failure load ($P_f$)**
- True fracture stress ($\sigma_f$)**
- Threshold stress for cracking ($\sigma_{th}$)**
- Percent elongation (%El)**
- Percent reduction in area (%RA)**
- Time-to-failure (TTF)**
- Fracture toughness (K)

- Crack growth rate (da/dt vs K or $\Delta K$)
- Hydrogen content evaluated by SIMS
- Metallurgical microstructures evaluated by optical microscopy
- Fracture Characteristics evaluated by scanning electron microscopy

**Versus $E_{cont}$

The resultant data will enable a mechanistic understanding of the SCC/HE processes in candidate target materials under the synergistic influence of applied tensile stress and the corrosive media with or without the presence of hydrogen. Others may eventually utilize these data in developing and validating the hydrogen-induced degradation models for target materials used in transmutation systems.

**Research Capabilities at UNLV**

The following equipment are currently available in the MPL, and the Materials Testing Laboratory (Room No. TBE B-150).

- Twelve Cortest Constant Load Testing Fixtures (Proof Rings – 7,500 lb Load Capacity)
- Four Cortest SSR Test Frames (Constant Extension Rate Test Fixture - 7,500 lb Load Capacity)
- Twelve High-Temperature (120$^{o}$C) Corrosion-Resistant Test Vessels (Hasteloy C-276)
- One High-Temperature (500$^{o}$C) Corrosion-Resistant Autoclave (Hasteloy C-276) with Lid having Electrochemical Connections
- Two EG&G Model 273A Potentiostats, and one EG&G eight-channel multiple potentiostat
- One Blue-M 1200$^{o}$C Heat Treatment Furnace
- High – Temperature Water Bath and Mettler Electronic Balance, one each
- Twelve Custom Luggin Probes for Polarization under Controlled Electrochemical Potential
- One 1000X Resolution Leica Optical Microscope with Digital Image Capture
- Buehler Sample Preparation Accessories – Isomet 4000 Linear Precision Saw, Abrasimet 2 Abrasive Cutter, Ecomet 6 Variable Speed Grinder/Polisher with Automet 2 Power Head
- One High-Temperature (1000$^{o}$C) Furnace with Inert Gas Purge for Tensile Properties Evaluation in Association with an MTS Axial/Torsional Test System (50,000 lb Load Capacity)

<u>Additional Heat Treatment Facilities</u>
Two high temperature furnaces are available:

1) Lindberg Furnace
The maximum temperature is 1200 $^{o}$C (2200 $^{o}$F). The working dimensions are 15” x 7.5” x 5.5”.

2) Thermodyne Furnace
The maximum temperature is 1200 $^{o}$C (2200 $^{o}$F). The working dimensions are 6.5” x 4.5” x 4.5”.

<u>Machine Shop</u>
The UNLV College of Engineering has a machine shop with two vertical mills, two lathes, a welding station, and a variety of band saws, shear breaks, and drill presses. Because this equipment is not automated, some machining needs are contracted to local machine shops. There are several good local shops with CNC, EDM, water jet, and laser cutting capabilities that can be contracted at reasonable rates.

Mechanical Testing

The UNLV College of Engineering has a 55 kip Axial/Torsional Servo hydraulic MTS Materials Testing System. The machine has hydraulically controlled actuator with 5.5" of stroke and approximately $55^{O}$ of angular rotation. It also has a hydraulic grip supply and two different hydraulic grips: a set of 55 kip axial/torsional collet grips and a set of 27 kip wedge grips. The axial motion can be controlled by force, displacement, or an external signal such as a strain gage. The torsional motion can be controlled by torque, angular position, or an external signal. The machine is equipped with an 8-channel signal-conditioning box from the Measurements Corporation for monitoring strain gages, extensometers, and other sensors. Signals from this box are processed directly by the MTS control software programs TestStar and TestWare SX. Other accessories for this machine include: digital longitudinal and transverse extensometers and a digital deflectometer. This machine has been used for tensile, torsion, flexure, and compression testing of metals, polymer composites, and polymer foams.

Microstructural Analysis

The UNLV Mechanical Engineering Department has a photomicroscopy lab with two 3-wheel sample polishing stations along with a sample potting machine and sanding wheels. The lab has a Unimet Unitron 8644 Inverted Metallurgical Microscope with 800X magnification equipped with a digital camera and computer for recording micrographs. The lab also has a Leco M-400A microhardness tester, several Wilson and Clark Rockwell hardness testers, and a Beuler sample mounting press.

However, the metallographic laboratory needs to be upgraded with a high-resolution optical microscope and accessories to perform microstructural characterization planned in this project. Analyses of hydrogen content by SIMS can be performed at LANL.

Scanning Electron Microscopy (http://www.unlv.edu/Colleges/Sciences/Geoscience/EMIL.htm)

The UNLV Geosciences Department has a JEOL-5600 Scanning Electron Microscope (SEM). It is optimized for imaging micron to millimeter scale topographic detail of solid materials. Resolution of up to 50 nm at 100,000 times magnification is possible. The SEM is equipped with a BSE detector and an Oxford ISIS EDS system, capable of semi-quantitative analysis (± 10%). The topographic and compositional images can be processed directly on the screen to show pseudo-color and critical point measurement of features. The images can also be combined, allowing for easy comparison of samples or different magnifications. The manual stage can accommodate four 1-cm diameter samples or one sample up to 3.2-cm diameter. The SEM and EDS are controlled by two networked Windows 95 operating systems allowing for intuitive, simple operation.

The UNLV Geosciences Department also has the JEOL-8900 Electron Probe Microanalyzer (EPMA). It is optimized for quantitative, non-destructive chemical analysis of solid materials on a micron scale. Four fully automated wavelength dispersive spectrometers (WDS) are equipped with 2 crystals each and are capable of quantifying elements ranging from boron to uranium. Concentrations of at least 0.10 wt % can be measured to within ±1% of the measured abundance. In addition, elements present in smaller concentrations can be measured with somewhat less precision. The energy dispersive spectrometer (EDS) collects a full spectrum of x-rays at once and is capable of rapidly qualifying up to 8 elements at one time. Both EDS and WDS can also be used to obtain high-precision x-ray maps and line scans of spatial variation in chemical composition. The instrument is also equipped with backscattered electron, secondary electron, and cathodoluminescence detectors capable of producing "real time" images, or automated images in tandem with x-ray mapping to further characterize the area of interest. A fully automated stage, capable of holding up to nine one-inch round samples (or six petrographic sections) has reproducibility of less than one micron. Unmounted samples up to 15 cm in diameter can also be accommodated. The EPMA is controlled by a graphical user interface on a HP-UX UNIX workstation. These two instruments are available as a user facility. A fee structure has currently being developed.

Transmission Electron Microscopy

A transmission electron microscope (TEM) has recently been procured from FEI, and is in the process of being installed at the Harry Reid Center. The anticipated date for the establishment of the TEM facility is in the fall of 2003.

## Project Timeline

Timeline Narrative

Significant progress has been made during the year 2002 in terms of the establishment of the MPL having numerous research capabilities including metallurgical and corrosion testing, generation of key scientific and technical data on SCC (constant-load and SSR), metallurgical microstructures (optical microscopy), and fractographs (SEM) of broken test specimens. Three technical papers based on the resultant data have been accepted for presentation at the IHLRWM conference, ECS conference, and ANS conference to be held in year 2003, and subsequent publication in the symposium proceedings/technical society journals.

During the past year, three graduate students have joined this task, and have been working diligently since then. Mohammad K. Hossain, a Ph.D. student in mechanical engineering, started working on this project the summer of 2002. Subsequently, Sudheer Sama and Ramprashad Prabhakaran (both M.S. Students) were added to this program in August 2002. More recently, Phani P. Gudipati and Venkataramakrishnan Selvaraj have joined this task. Mr. Selvaraj is currently a teaching assistant (TA) in mechanical engineering, and plans to be fully devoted to this task when his TA assignment is complete.

Mark Jones (M.S. Student) decided to work on TRP Task 10 since last fall. Aaron Tippetts is about to complete his B.S. degree in mechanical engineering during this summer, and has decided to accept a full-time engineering position upon graduation. Mr. Tippetts is still participating in this task. During 2002, some of these graduate students visited LANL materials research facilities to familiarize with numerous related testing techniques.

In view of the revised work scope for the third year (summer 2003-spring 2004), the timeline is being modified to include the additional testing and analyses, as shown in Table 1. While the testing identified in the original proposal will be continued to complete the key test matrices, emphasis will be placed on conducting the new tests as indicated earlier in this renewal package.

Table 1: Three-Year Research Plan

| Dates (starting May 2001) | | | | 4/02 | | | | 4/03 | | | | 4/04 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time (Months) | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 | 36 |
| Literature Search | | | | | | | | | | | | |
| Set-up Laboratory | | | | | | | | | | | | |
| Prepare Materials/Samples | | | | | | | | | | | | |
| Train Students | | | | | | | | | | | | |
| SSR Experiments | | | | | | | | | | | | |
| Constant Load Experiments | | | | | | | | | | | | |
| Perform Microscopy | | | | | | | | | | | | |
| Perform SEM | | | | | | | | | | | | |
| C-Ring, U-Bend Experiments | | | | | | | | | | | | |
| Establish CT Test Facility/Prepare CT Specimen | | | | | | | | | | | | |
| Perform CT Experiments | | | | | | | | | | | | |
| Data Analyses | | | | | | | | | | | | |
| Prepare Final Report | | | | | | | | | | | | |
| Quarterly Reports | | | | | | | | | | | | |
| Semi-Annual Reports | | | | | | | | | | | | |

Year 3 Milestones (Assuming a start date of May 20, 2003)

- (March 2003) Prepare samples for C-Ring and U-Bend experiments.
- (November 2003) Present initial C-Ring and U-Bend test data.
- (December 2003) Complete new test facility for crack growth studies.
- (January 2004) Initiate CT experiments.
- (January 2004) Complete SSR and Constant Load experiments using smooth and notched specimen.
- (February 2004) Complete metallographic evaluation by SEM and optical microscopy.
- (March 2004) Complete data analysis.
- (April 2004) Year 3 report is submitted.

Deliverables

- **Collaboration with DOE project:** Monthly communications (by phone or in person) with National Project collaborator and/or technical lead to update on progress, discuss problems, and allow for re-focusing if necessary to address shifts in direction by the National Project.
- **M.S. Degree:** Graduate students will have completed or be very close to completion of their experiments and analyses by the end of the second year.
- **Progress Reports:** Brief reports indicating progress will be provided every quarter (to support DOE AFCI quarterly meetings).
- **Bi-Annual Reports:** Written reports detailing experiments performed, data collected and results to date.
- **Final Report:** Written report detailing experiments performed, data collected, results, and conclusions to be submitted at the end of the project.
- **Project Samples:** For archival purposes, samples generated during the experimental campaigns will be turned over to the National Laboratory partner. For experiments where multiple samples were prepared, only one sample will be turned over. This sample archive will allow the Project researchers (either from the National Laboratories or UNLV or other academic partners) to re-examine samples as necessary, either in support of this work or for use in other research projects.

## Personnel Responsibilities

### Role of the Students:

The graduate students will be given a significant amount of responsibility for this project. All graduate students will undergo training in areas of basic metallurgical and corrosion/electrochemical concepts including heat-treating of metallic materials, electrochemical polarization, preparation of SCC/HE tests, and metallographic evaluation using optical microscopy and SEM. The students will also be trained to perform all of the mechanical testing experiments. The faculty investigators will provide this training. The new graduate students will be advised to take relevant metallurgical, mechanical, and corrosion engineering basic and advanced level courses. New students will prepare and present their research objectives by August 2003 and all current students will prepare and present at least one conference paper/poster per year as appropriate. The students completing projects this year will write up their work as a thesis and a journal publication.

### Role of the Faculty:

The primary responsibility of the faculty members on this project is to train students for performing the various research tasks, supervise the writing of their thesis and/or dissertation, and to provide an interdisciplinary working environment for the students. Dr. Roy joined the Mechanical Engineering Department in July 2001 as an associate research professor, concentrating on both teaching and funded research projects. Fifty percent (50%) of his compensation is funded by the AFCI program. The faculty members will assume responsibility for various aspects of the project to ensure that the students make steady progress towards their research goals. The faculty will not be doing the research for the students but will ensure that high quality work is accomplished in a timely manner.

As the lead principal investigator (PI), Dr. Roy will spend 25% of his time on this project. He will work in close association with Dr. O'Toole in areas of mechanical and metallurgical aspects related to the SSR testing unit. Dr. Roy will be responsible for specifying and ordering test materials from prospective vendors. The students will be included in this process from the onset. Drs. O'Toole and Wang will perform ordering of the new test equipment and setting-up of the related facilities jointly. Dr. Roy will train the new graduate students in areas of electrochemical test techniques, heat-treating practices, microstructural and fractographic analyses. Later, Drs. O'Toole and Roy will train the graduate students on the practical aspects of performing the HE experiments using the SSR method. Dr. Roy will work closely with the graduate students and other supporting staff within the UNLV infrastructure to ensure that the desired data are generated in a timely manner. The graduate students will work under the direct supervision of all faculty participating in this project. Drs. Roy and O'Toole will jointly perform data analyses and prepare the interim and final reports. Dr. Hatchet will be responsible for electrochemical testing and related consultation with graduate students. Dr. Wang will be responsible for the microstructural and fracture mechanics analysis.

Date: February 12, 2002
From: Ning Li, Ph.D., Los Alamos National Laboratory

To Whom It May Concern:

Since the commencement of the project "**Hydrogen-Induced Embrittlement of Candidate Target Materials for Applications in Spallation-Neutron-Target Systems**" in 2001, I have met and discussed the progress and status with Drs. Roy and O'Toole several times during my visits to UNLV and in phone conversations. The focus was mostly on material and equipment procurement, and facility setup in preparation of the test experiments.

The project has received the materials, and equipped a lab with the necessary test instruments, and is ready to perform the main task of testing. The year 2 renewal proposal contains the most important tasks for this project. I strongly recommend the renewal of the project, and look forward to receiving the reports on experimental findings.

Yours truly,

Ning Li