

4-27-2004

## Use of Positron Annihilation Spectroscopy for Stress-Strain Measurements

Ajit K. Roy

*University of Nevada, Las Vegas, aroy@unlv.nevada.edu*

Follow this and additional works at: [https://digitalscholarship.unlv.edu/hrc\\_trp\\_sciences\\_materials](https://digitalscholarship.unlv.edu/hrc_trp_sciences_materials)

 Part of the [Mechanical Engineering Commons](#), [Metallurgy Commons](#), [Nuclear Engineering Commons](#), and the [Oil, Gas, and Energy Commons](#)

---

### Repository Citation

Roy, A. K. (2004). Use of Positron Annihilation Spectroscopy for Stress-Strain Measurements. 1-19.

Available at: [https://digitalscholarship.unlv.edu/hrc\\_trp\\_sciences\\_materials/106](https://digitalscholarship.unlv.edu/hrc_trp_sciences_materials/106)

This Grant is protected by copyright and/or related rights. It has been brought to you by Digital Scholarship@UNLV with permission from the rights-holder(s). You are free to use this Grant in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/or on the work itself.

This Grant has been accepted for inclusion in Transmutation Sciences Materials (TRP) by an authorized administrator of Digital Scholarship@UNLV. For more information, please contact [digitalscholarship@unlv.edu](mailto:digitalscholarship@unlv.edu).

## **Project Title:**

### **Use of Positron Annihilation Spectroscopy for Stress-Strain Measurements (For Renewal)**

**April 27, 2004 (revision)**

**Principal Investigator:** Dr. Ajit K. Roy  
Associate Professor  
Department of Mechanical Engineering, UNLV  
Mail Code 4027, 4505 Maryland Parkway  
Las Vegas, NV 89154-4027  
Phone: (702) 895-1463 email: aroy@unlv.nevada.edu

**UNLV Investigator:** Mr. Vikram Marthandam (M.S. Student)  
Mr. Anand Venkatesh (M.S. Student)  
Mr. Satish B. Dronavalli (M.S. Student)  
Department of Mechanical Engineering

**Collaborators (DOE):** Dr. Stuart A. Maloy  
AFCI Materials Team Leader  
MST-8, MS-H809. LANL  
Los Alamos, NM 87545  
Phone: (505) 667-9784 email: Maloy@lanl.gov

Dr. Doug Wells, Associate Professor  
Department of Physics  
Idaho State University (ISU)  
Phone: (208) 282-3986 email: Wells@athena.physics.isu.edu

Dr. Farida Selim, Post Doctoral Researcher  
Idaho Accelerator Center (IAC)  
Idaho State University  
Phone: (208) 282-5877 email: Selim@athena.physics.isu.edu

**AFCI Research Area: Transmuter**

**Funding Profile:** 2002-2003: \$120,438 2003-2004: \$123,963 2004-2005: \$126,174

**Note:** LANL employees do not require funding from UNLV to participate in this project.  
ISU employees do not require funding from UNLV to participate in this project.  
AECL do not require funding from UNLV to participate in this project.

## **Abstract**

The purpose of this collaborative research project involving the University of Nevada Las Vegas (UNLV) and Idaho State University (ISU) is to evaluate the feasibility of determining residual stresses of welded, bent (three-point-bend), and cold-worked engineering materials using a new nondestructive technique based on positron annihilation spectroscopy (PAS). The proposed technique is to use  $\gamma$ -rays from a small MeV electron linear accelerator (Linac) to generate positrons inside the test sample via

pair production. This method can be used for materials characterization and investigation of defects in thick samples that usually cannot be accomplished by conventional positron technique or other nondestructive methods. The data generated will be compared to those obtained by other nondestructive methods such as neutron diffraction (ND) and X-ray diffraction (XRD), and a destructive method known as ring-core technique. Materials tested so far include unirradiated austenitic (Type 304L) and martensitic (EP-823) stainless steels that were cold-reduced, bent (three-point-bending) and welded prior to the evaluation of the resultant residual stresses.

While substantial progress has been made to evaluate residual stresses in all three specimen configurations of Alloy EP-823 and Type 304L stainless steel by the PAS and XRD methods, a large number of testing still needs to be performed by all four measurement techniques. Although, the Linac at ISU has been performing satisfactorily, some unforeseen problems related to the signal resolution are currently being experienced, which has delayed the desired measurements. Further, substantial measurements by ND and ring-core methods are yet to be performed. Collaboration has recently been established with the Atomic Energy of Canada Limited (AECL) to conduct residual stress measurements by the ND technique. Preliminary results obtained at AECL indicate a significant potential for the ND method to analyze residual stresses in thick specimens of different configurations. Microstructural evaluations by optical microscopy have just been initiated. However, a lot more metallographic studies will be performed involving cold-worked and welded specimens following future residual stress measurements. In addition, deformation characteristics in terms of dislocations and their movements resulting from welding and plastic deformation will be analyzed by transmission electron microscope (TEM), once this equipment is available at UNLV. Further, Alloys EP-823, HT-9, and austenitic materials (Type 316L stainless steel and Alloy 718) irradiated by low energy photon beam at ISU will be included in this program during the third year.

### **Work Proposed for Year 3 (Summer 2004 –Spring 2005), Goals, and Expected Results:**

A new experimental heat of another martensitic stainless steel (Alloy HT-9) has recently been melted by the vacuum-induction melting (VIM) practice at the Timken Research Laboratory (TRL). This heat was subsequently processed by forging, hot-rolling and cold-rolling, respectively followed by thermal treatments to achieve fully-tempered and fine-grained martensitic microstructures. The thermal treatments performed on this alloy at TRL consisted of austenitizing, quenching and tempering followed by air-cooling. Three types of specimen configurations namely, cold-worked, bent and welded specimens were prepared using the heat-treated alloy. The cold-worked specimens were prepared at TRL by reduction of plate thickness at three levels (3, 7 and 12 percent) by cold-rolling. The bent specimens were fabricated by three-point-bending at the Apeks LLC. of Ohio. The welded specimens were prepared by Apeks LLC. by welding plates of similar materials (Alloy HT-9/Alloy HT-9). Additional heats of austenitic Type 316L Stainless Steel and nickel-based Alloy 718 will also be melted by VIM practice, followed by specimen preparations from these materials.

All three types of specimens prepared from candidate test materials will be evaluated at the Idaho Accelerator Center (IAC) of ISU, AECL and other research facilities for determination of residual stresses using four different measurement techniques. The selection of a research laboratory to conduct ring-core measurements is in progress. Previously, Lambda Research Laboratory (LRL) has been used to perform stress measurements in specimens made of Alloy EP-823 and Type 304L stainless steel. Measurements by the PAS technique has been ongoing at IAC, and will be continued during this coming year. Significant efforts will be made during the third year to develop calibration curves using tensile specimens stressed to different levels beyond the yield point. Establishment of calibration curves by this method will enable the estimation of residual stresses based on line-shape parameters such as T, S, and W obtained from the analyses of spectrum during the PAS study.

Neutron diffraction technique is being used through collaborative research with AECL, which will be continued during the third year. Substantial efforts will be made to compare the residual stress measurements by both the PAS and the ND technique. Both X-ray diffraction and ring-core methods are being planned to be used at a new location yet to be selected.

Thus, in essence, measurements of residual stresses using all four techniques will be carried out throughout the third year of this task, followed by the analyses of the resultant data. In addition, the welded specimens will be subjected to post-weld thermal treatment to eliminate or minimize the residual stresses generated during welding, followed by stress measurements by different techniques. This effort will enable comparison of residual stresses in welded specimens, with and without stress relief. Microstructural analyses of the welded specimens before and after thermal treatments will be continued by using optical microscopy. Dislocation characteristics will be evaluated by TEM upon availability of this equipment at UNLV. Further, efforts will be made to irradiate some selected test specimens by low-energy electron beam at IAC/ISU, and subsequently measure the enhanced residual stresses due to radiation-hardening using the PAS method. These specimens will have very low half-lives but hardening due to the low-level radiation will still be retained inside the metal matrix.

### **Background and Rationale**

Plastic deformation of metals and alloys produces an increase in the number of lattice imperfection known as dislocations, which by virtue of their interaction results in higher state of internal stress and reduces ductility. This type of deformation which is carried out in a temperature region and over a time interval such that the strain hardening is not relieved is called cold-work. When cold-working is excessive (greater than the uniform elongation), the metal will fracture before reaching the desired size and shape. Thus, in order to avoid this drawback, cold-working operations are usually carried out in several steps, with intermediate annealing operations to soften the cold-worked metal and restore the ductility. This sequence of repeated cold-working and annealing is frequently called the cold-work-anneal cycle. By suitably adjusting this anneal cycle, the part can be produced with any desired degree of strain hardening. However, in order to remove the undesirable internal stresses, a stress relief thermal treatment needs to be done.

During welding of engineering components, thermal cycles cause changes in physical state, metallurgical phase transformation, and transient thermal stress. The welded part may contain physical discontinuities that arise due to excessively rapid solidification, or adverse microstructure that are due to inappropriate cooling, or tensile residual stresses and distortion resulting from the existence of incompatible plastic strains. Presence of high tensile residual stresses in and around (such as the heat-affected-zone) the welded region can cause premature failure under certain conditions.

Materials used in nuclear systems, such as sub-system structural parts surrounding the target material, are likely to be influenced by adverse residual stresses resulting from cold work and welding. In view of this rationale, this research project will be aimed at evaluating the residual stresses of cold worked and welded austenitic Types 304L and 316L stainless steels, martensitic Alloys EP-823 and HT-9, and nickel-base Alloy 718 by four different techniques, as indicated earlier. Alloy EP-823 is a leading structural material to contain lead-bismuth-eutectic (LBE) nuclear coolant needed for fast spectrum operations of the nuclear systems. Types 304L and 316L stainless steels, two universally known corrosion-resistant iron-nickel-chrome alloys having optimum formability and weldability, have long been used in many nuclear systems.

## Experimental Procedure

All test materials will be received from the vendor in the form of plates and round bars of desired dimensions. The dimensions of these plate/bar materials will be decided based on the type of specimens to be machined and tested. They will be procured in properly heat-treated conditions. Austenitic Types 304L and 316L stainless steels are commonly used in a solution-annealed condition. On the other hand, martensitic stainless steels are austenitized and quenched, followed by tempering to achieve a fully-tempered martensitic metallurgical microstructure. Subsequently, these materials will be subjected to three levels (3, 7 and 11%) of cold reduction, bending, and welding, respectively. Welding of similar and dissimilar plate materials will be performed using the gas-tungsten arc welding (GTAW) technique at Apeks LLC. Metallurgical microstructures of all five materials will be evaluated in the as received, cold-worked and welded conditions using optical microscopy at UNLV and LANL.

Four different techniques, namely  $\gamma$ -ray induced positron annihilation spectroscopy (PAS); neutron diffraction (ND), X-ray diffraction (XRD) and ring-core methods will be used to determine the residual stresses present in the test materials. The PAS method is a well-established non-destructive tool to characterize materials and defects. However the conventional positron annihilation spectroscopy use slow positron beams or wide energy spectrum beams from radioactive sources. The thickness of the samples under investigation is severely limited by the range of the impinging positrons inside the sample, which is less than 1 mg/cm<sup>2</sup>. The technique proposed here exploits the high penetrability  $\gamma$ -rays to extend positron annihilation spectroscopy into thick samples and enable measurement of stress, strain and defects in engineering materials. The collimated bremsstrahlung beam from a small electron accelerator (6 MeV pulsed Linac) is used to generate positrons inside the test specimen via pair production. No photon-induced activation is involved in this process. Each generated positron thermalizes and annihilates with one of the sample electrons emitting two annihilation photons (511 keV) back to back. The annihilation photons are recorded by a high-energy resolution HPGe detector, and the data will be analyzed in terms of line shape parameters (S, T and W) of 511 keV annihilation peak. The character and concentration of defects can be investigated from these measurements. The portability, reliability and relatively low cost of small-pulsed electron accelerator can create significant interest in commercial or industrial applications. Stress measurements using the PAS technique will be performed at IAC/ISU.

Neutron diffraction is also a non-destructive method, which is based on measuring the spacing,  $d$ , between the atomic planes of a crystal lattice. When a neutron beam of known wavelength is impinged upon a crystalline specimen, neutrons are diffracted at an angle that depends on  $d$ . With accurate measurement of the diffraction angle, the  $d$ -spacing between the lattice planes can be calculated, to determine if the planes are being pushed together (compression), or pulled apart (tension). The measured patterns of residual stress, as determined by this technique, provide knowledge of the possible location of fracture, and the effectiveness of thermal treatments to relieve the internal stresses arising from welding and cold deformation. Recent study performed at AECL indicates that ND is capable of measuring residual stresses and other metallurgical imperfections in thick specimens of different configurations. In view of these encouraging results, a large number of measurements will be performed on all types of samples at AECL and LANL.

The ring-core method is a mechanical/strain gage technique employed to determine the principal residual stress field as a function of depth in polycrystalline or amorphous materials. The method involves placing a strain gage rosette at the surface at the location of interest on a given component. An annular groove is machined around the strain gage rosette at predetermined depth increments. The

strain relaxation that occurs as a function of machined depth is recorded. The final residual stress values are calculated using the measured change in strain with depth. The ring-core method works well on materials that are coarse grained, such as cast metals and weldments. XRD method, based on the Bragg's Law, will also be used to measure residual stresses. Selection of research facilities to perform ring-core and XRD measurements are currently in progress.

### **Expected Data**

The proposed research program will develop the following scientific/technical information, elucidating the applicability of positron annihilation spectroscopy, and its comparison to other techniques.

- Metallurgical microstructures of as-received, cold-worked, welded and stress-relieved material(s)
- Residual strains resulting from cold work, bending, and welding operations
- Estimation of residual stresses corresponding to the measured strain values
- Comparison of residual stresses in materials with and without stress relief

### **Research Capabilities at UNLV**

The following equipment are currently available in the Materials Performance Laboratory (Room No. TBE B129) and the Materials Testing Laboratory (Room No. TBE B150).

- 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<sup>0</sup>C) Corrosion-Resistant Test Vessels (Hasteloy C-276)
- One High-Temperature (500<sup>0</sup>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<sup>0</sup>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<sup>0</sup>C) Furnace with Inert Gas Purge for Tensile Properties Evaluation in Association with an MTS Axial/Torsional Test System (50,000 lb Load Capacity)

### Additional Heat Treatment Facilities

Two high temperature furnaces are available:

#### 1) Lindberg Furnace

The maximum temperature is 1200 <sup>0</sup>C (2200 <sup>0</sup>F). The working dimensions are 15” x 7.5” x 5.5”.

#### 2) Thermodyne Furnace

The maximum temperature is 1200 <sup>0</sup>C (2200 <sup>0</sup>F). The working dimensions are 6.5” x 4.5” x 4.5”.

### Machine Shop

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. None of this equipment is automated so we have developed good working relationships with several 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° 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 ( $\pm 10\%$ ). 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  $\pm 1\%$  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 been 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 spring of 2004.

## **Research Capabilities at ISU**

The Idaho Accelerator Center at Idaho State University (ISU) provides opportunities for nuclear physics research and development to university, industrial, and governmental organizations. The center combines accelerators owned by the U.S. Department of Energy and the state of Idaho with the university's facilities and the technical expertise of university faculty and researchers. The IAC's mission is to conduct and to promote research and development in radiation science and accelerator applications. The laboratory creates partnerships with scientists and engineers in government, university and the private sector designed to lead to new advances and practical applications in nuclear and radiation science. The Center occupies some 16,000 square feet of laboratory space on the Idaho State University campus, including the new Accelerator Center Building completed in October 1998, which houses Center operations and the major electron Linear Accelerator (LINAC). Center management is in the hands of a director and two part-time associate directors. Proposals for accelerator and facilities usage and advice on operations is given by a Users Advisory Group comprised of representatives from the university and national laboratories. Strategic direction and peer review is given by the Advisory Board, a group of nationally prominent scientists, public policy and business leaders.

The Center has available the following accelerators:

1. A 30 MeV electron linac which can produce 10 to 50 ps, 10nC pulses in the short pulse mode. The energy range in this mode is 0.5 to 28 MeV. Long pulses to 4 microseconds are also available. Repetition rates are to 360Hz. Beam energy spread can be as small as 0.5%. Three beam ports are available.
2. Two Van de Graaff type positive ion accelerators one is equipped for materials analysis studies (back-scattering, PIXE, channeling, etc.). The other Van de Graaff is principally for variable energy neutron production, using (p,n) and (d,n) reactions.
3. A mobile, variable energy (2-12 MeV) electron linac for photo-nuclear studies and applications.
4. A 6 MeV electron linac, equipped for radiation effects studies can deliver high radiation dose rates with precision dosimetry.
5. An 18 MeV electron linac for photo-nuclear studies.
6. A field portable 4MeV electron linac for radiography and neutron generation.
7. A large-scale industrial Scientific Measurements Systems x-ray tomography system, which can be equipped with 450keV or 4MeV x-ray source.

The Center has available a wide range of nuclear detector types, including neutron detectors, and supporting electronics. Custom electronics and mechanical design and fabrication are available.

## *Research & Applications*

Current research activities include:

Radiography, tomography and nuclear techniques for NDE/NDA.  
Industrial and agricultural applications of accelerator-produced radiation.  
Ion and photon beam analysis for environmental and mineral extraction needs.  
Radiation science in medicine; radioisotope production, accelerator based neutron sources  
BNCT and other forms of neutron therapy.  
Instrument and radiation detector testing for weapons surety studies and other applications.

## *Education*

The Idaho Accelerator supports educational activities at all levels of ISU's academic areas, including:

Physics  
Health Physics  
Engineering  
Waste Management  
Geology  
Biological Sciences  
Health Sciences

## *Facilities and services*

Two other IAC facilities on campus house positive ion accelerators, scanners, imaging facilities, and support services. This arrangement provides a venue for convenient, inexpensive proof of principle testing, integrated demonstrations, and basic research. The broad range of ongoing scientific and engineering activities facilitates collaboration from a variety of private, university and governmental agencies, while providing an academic research environment with all the amenities of a university.

The Center can provide in house expertise in:

Neutron and photon transport calculations using various codes including MCNP, and ACCEPT.  
Neutron spectroscopy using various detector types  
A wide range of nuclear and radiation measurements  
Precision dosimetry for gamma radiation and neutrons

## **Research Capabilities at LANL**

Los Alamos National Laboratory (LANL) has numerous capabilities for manufacturing and characterizing materials. The facilities proposed to be used in this work include qualified gas-tungsten arc (GTA) welding by Felix Olivas of LANSCE-2, and neutron diffraction using the facilities at the Manuel Lujan Neutron Scattering Center by Mark Bourke. After a proposal is submitted and accepted, stress measurements by the neutron diffraction technique can be performed during the July-December 2002 run cycle.

## **Project Timeline**

### Timeline Narrative

Significant progress has been made during the first two years of this research project. As proposed, three test materials (Type 304L stainless steel and Alloys EP-823 and HT-9) were melted and processed into plates within the specified time period. They were thermally treated, followed by cold reduction, bending and welding, as discussed earlier. The bent specimens were analyzed by X-ray diffraction technique at LRL for determination of residual stress due to three point bending. The measurements of residual stresses in the welded specimens were also performed at LRL using the ring-core method. The imperfections generated in the cold-worked (7 and 11%) specimens were characterized by PAS at IAC/ISU. Similar types of measurements are currently being performed on all three types of specimens at IAC/ISU. Efforts are ongoing at IAC to generate calibration curves using tensile specimens loaded to different stresses levels. Neutron diffraction technique has been used at AECL to determine the residual stresses in all three types of test specimens. The welded specimens will eventually be stress relieved at UNLV's Materials Performance Laboratory followed by their stress measurements. Microstructural analyses of welded specimens, before and after stress relief, will be performed by optical microscopy both at UNLV and LANL. The deformation characteristics (dislocations and their interactions) in bent and cold worked specimens will be analyzed by TEM both at LANL and UNLV.

Significant interactions took place during this past year among collaborators (IAC/ISU and LANL) and AECL. The UNLV researchers (faculty and graduate students) have visited both LANL and IAC/ISU to familiarize with the related experimental facilities, develop testing plans, and conduct experiments. A trip was made to LRL to perform residual stress measurements on welded specimens by using ring-core method. These trips have provided the researchers with the special capabilities such as software codes and equations needed to analyze the resultant experimental data. Additional trips are being planned.

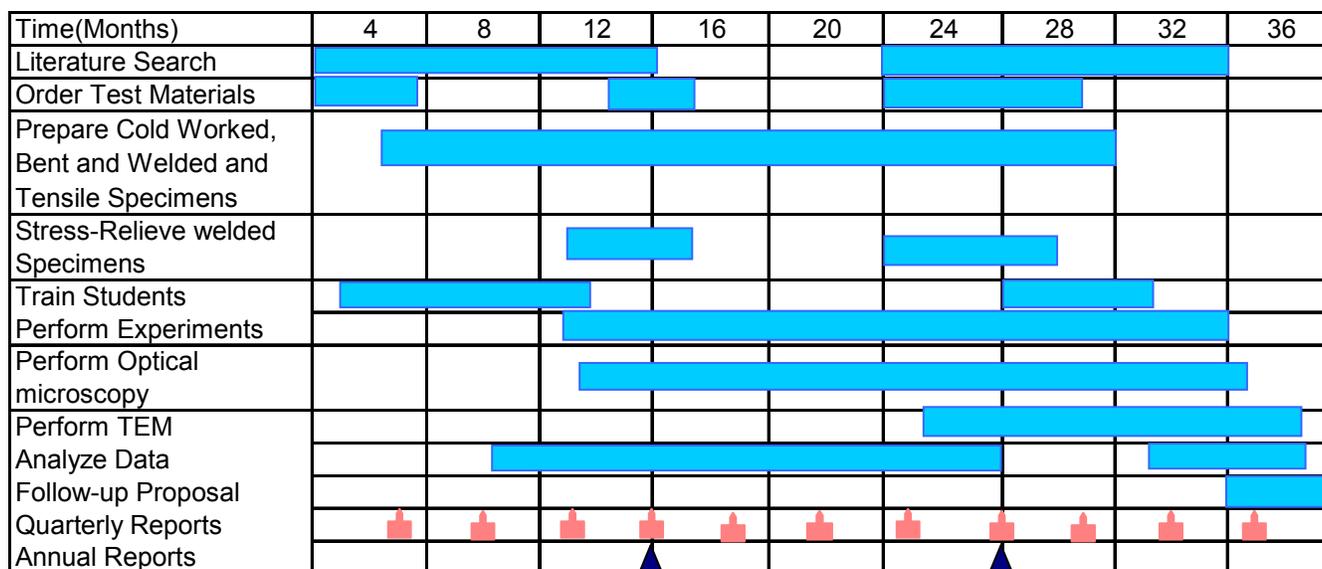
Numerous technical papers based on the recent results have been presented at different conferences (see the list of publications), which will also be published in the symposium proceedings. Three more technical papers are currently being prepared for future conferences (ASTM, SEM and ASNT) to be held during 2004-2005. In addition quarterly and annual reports have been prepared and submitted as usual. A three-year schedule is shown in Table 1.

### List of Publications

- Ajit K. Roy, Vikram Marthandam, Anand Venkatesh, Satish B. Dronavalli, "Residual Stress Measurements by Nondestructive and Destructive Methods," American Nuclear Society (ANS) Meeting, Paper No. 79417, June 1-5, 2003, San Diego, California, USA
- Ajit K. Roy, Satish B. Dronavalli, Vikram Marthandam, Anand Venkatesh, "Residual Stress Measurements for Spallation Target Materials," American Society of Metals (ASM) International Surface Engineering Conference, September 15-17, 2003, Indianapolis, Indiana, USA

- Ajit K. Roy, Vikram Marthandam, Anand Venkatesh, Satish B. Dronavalli, “Residual Stress Measurement By Positron Annihilation Spectroscopy,” 46<sup>th</sup> Annual Non-Destructive Testing Forum, September 22-25, 2003, Montreal, Quebec, Canada
- Ajit K. Roy, Anand Venkatesh, Vikram Marthandam, Satish B. Dronavalli, “Residual Stress Measurements in Target Materials,” Society for the Advancement of Material and Process Engineering (SAMPE) International Technical Conference, September 28-October 2, 2003, Dayton, Ohio, USA
- Vikram Marthandam, “Residual Stress Measurement In Type 304 Stainless Steel Using Non-Destructive Techniques,” American Nuclear Society (ANS) Student Conference, April 2-5 2003, Berkeley, California, USA
- Anand Venkatesh, “Residual Stress Measurement In EP 823 Using Non-Destructive Evaluation Techniques,” American Nuclear Society (ANS) Student Conference, April 2-5 2003, Berkeley, California, USA

Table 1: Three-Year Research Plan



Year 3 Milestones (Assuming a start date of May 01, 2004)

- (April 2004): Submit annual report on year 2 progress
- (May 2004): Initiate stress measurements on all new specimens.
- (June 2004): Initiate post-weld thermal treatment of welded specimens and start stress measurements on stress relieved specimens.
- (November 2004): Complete Metallographic evaluation on all specimens
- (February 2005): Evaluate overall data and prepare follow up proposal.
- (April 2005) Prepare Year 3 annual report.

## Deliverables

- **Train New and Existing Graduate Students:** The primary deliverable will be training all graduate students in a field relevant to the national AFCI program needs. An undergraduate student will also be added to train in relevant technical areas.
- **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.
- **Progress Reports:** Brief reports indicating progress will be provided every month, quarter, and annual (to support DOE AFCI reporting requirements).
- **Bi-Annual Reports:** Written reports detailing experiments performed, data collected and results to date (to support DOE AFCI semi-annual reviews).
- **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.

## **Roles and Responsibilities**

### UNLV Researchers

As Principal Investigator (PI), Dr. Roy will take the lead in the overall coordination of this project. He will assume responsibility for many different aspects of this project to ensure that all desired tasks are accomplished in a timely and cost-effective manner. He will train all three graduate students for performing the various research tasks, supervise the preparation of their thesis, and provide them with an interdisciplinary working environment so that they can make steady progress towards their research goals. As their supervisor, Dr. Roy himself will not perform the related research work but will ensure that high quality work is performed by these students through continuous guidance and consultation in areas of metallurgy, mechanics, thermal treatment, fractography and fabrication techniques. He will also be responsible for specifying and ordering test materials from prospective vendors. The graduate students will conduct and monitor the related experimental work, and will record all test data in the scientific notebooks under the supervision of the PI. Dr. Roy will analyze the resultant data, and will subsequently outline the follow-up experimental work to be performed by the graduate students. He will also prepare the interim and final reports.

### ISU Collaborators

Doug Wells, Associate Professor and Farida Selim, Post Doctoral researcher at IAC/ISU will be responsible for the overall design and completion of the experiments of positron annihilation spectroscopy, which will be performed at ISU. They will perform positron measurements on the specimens supplied from UNLV to evaluate the residual stresses and microstructures and provide UNLV with the data. They will also provide guidance and daily hands on scientific expertise to the graduate students involved in the project.

## RESUME OF DOUGLAS P. WELLS

Department of Physics  
Idaho State University

Phone: 208-282-3986  
E-mail: WELLS@PHYSICS.ISU.EDU

### PROFESSIONAL PREPARATION

Rutgers University	Physics	B.A. 1982
University of Virginia	Mathematics	M.S. 1984
University of Illinois	Physics	M.S. 1985
University of Illinois	Physics	Ph.D. 1990

### APPOINTMENTS

- 1997 - Present: Associate Professor of Physics, (tenure-track), Department of Physics and Health Physics, Idaho State University, Pocatello, ID.
- 1996 - 1997: Associate Professor of Health Physics, (non-tenure-track) Department of Physics and Health Physics, Idaho State University, Pocatello, ID.
- 1993 - 1996: Radiation Health Physicist, Radiation Protection Division, Washington State Department of Health, Olympia, WA.
- 1990 - 1992: Post-Doctoral Research Associate, Department of Physics, University of Washington, Seattle, WA.

### SELECTED RECENT PUBLICATIONS

1. D.P. Wells, J.L. Jones, W.Y. Yoon and F. Harmon, "Cabinet-Safe" Study of 1-8 MeV Electron Accelerators, Nuclear Instruments and Methods in Physics Research A 463, 118 (2001).
2. D.P. Wells, J.F. Harmon, W.W. Scates and R. Spaulding, *A Test of the Exponential Decay Law by Photo-Production of Nuclear Isomers*, 16th International Conference on the Application of Accelerators in Research and Industry CAARI 2000, AIP Press, Denton, Texas (2001).
3. J. L. Alvarez, R. Geddes, J. E. Rice, T. F. Gesell, and D. Wells, *Elemental Phosphorous Slag Exposure Study in Southeastern Idaho, USA*, 5<sup>th</sup> International Conference on High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects, Munich, Germany, 2000. (Accepted for publication in International Conference Series No. 1225: 5th International Conference on High Levels of Natural Radiation and Radon", January, 20012)
4. Chouffani, K., Wells, D.P., Harmon, J.F., *Optical Transition Radiation from Copper, Aluminum and Silicon Crystals*, Proceedings of the 21<sup>st</sup> ICFA Beam Dynamics International Conference on Colliding Beams, Brookhaven, NY, (2001).
5. Selim, F.A., D.P. Wells, J. F. Harmon, W. Scates, J. Kwofie, R. Spaulding, S.P. Duttagupta, J.L. Jones, T. White and T. Roney , *Doppler Broadening Measurements of Positron Annihilation using Bremsstrahlung Radiation*, 11<sup>th</sup> International Positron Conference, Sante Fe, NM, July, 2001. (Accepted for Publication in Nucl. Instr. Meth. B, 2002)
6. D.P. Wells, D.P., F. A. Selim, J. F. Harmon, W. Scates, J. Kwofie, R. Spaulding, S.P. Duttagupta, J.L. Jones, T. White and T. Roney, *Development of Accelerator-Based X-ray Fluorescence for Large Sample Assay*, 40<sup>th</sup> International Denver X-ray Conference, Steamboat Springs, CO, July 2001. (Accepted for publication in *Advances in X-Ray Analysis*, Volume 45 (2002).)
7. Selim, F.A., D.P. Wells, F. J. Harmon, J. Kwofie, W. Scates, R. Spaulding, G.Erickson, S.A. Parke, S.P. Duttagupta, J.L. Jones, T. White and T. Roney, *Development of Bremsstrahlung-based Positron Probe for Assay and Defect Analysis*, 1<sup>st</sup> Inland Northwest Research Alliance Conference on Sub-surface Science, (2001).
8. Kwofie, J., D.P. Wells, F. A. Selim, F. J. Harmon, W. Scates, R. Spaulding, G.Erickson, S.A. Parke, S.P. Duttagupta, J.L. Jones, T. White and T. Roney, *Accelerator-Based XRF for Subsurface Science*, 1<sup>st</sup> Inland Northwest Research Alliance Conference on Sub-surface Science, Aug. 2001.
9. Wells, D.P., Kwofie J.E., Selim, F., Harmon, J.F., and Scates, W., *Accelerator-Based X-Ray Fluorescence (AXRF) for Waste Assays and Environmental Applications*, Health Physics 80, S114 (2001).

10.Scates, W., Harmon, J.F., Nigg, D., Harker, Y., and Wells, D.P., *Monte-Carlo Investigation of Photo-Neutron Sources for Boron Neutron Capture Therapy*, Health Physics 80, S108 (2001).

### RESUME OF FARIDA SELIM

Department of Physics  
Idaho Accelerator Center  
Idaho State University  
Pocatello, ID 83209-8106

#### EDUCATION:

Ph.D. in Eng. Phys., Alexandria University, 1999  
(Channel program between Harvard and Alexandria University)  
Thesis: Penetration of energetic positrons through amorphous and crystalline media

#### PROFESSIONAL EXPERIENCE:

Jan. 2001- now: Post doctoral researcher, Department of Physics, Idaho State University.  
1999 - 2000: Assistant professor, Department of Physics, Alexandria University.

#### RESEARCH:

Post doctoral researcher, Department of Physics, Idaho State University, Current research spans several areas of applied physics, including Material research, Accelerator-based XRF and Positron Annihilation Analysis, Isomeric Photo-Nuclear Physics.

#### SELECTED PUBLICATIONS:

- \*F.A. Selim, D.P. Wells, et al., *Doppler Broadening Measurements of Positron Annihilation using Bremsstrahlung Radiation*, 11<sup>th</sup> International Positron Conference (Accepted for Publication in Nucl. Instr. Meth. B, 2002)
- \*F.A. Selim, D.P.Wells, et al., *Development of Bremsstrahlung-based Positron Probe for Assay and Defect Analysis*, Subsurface science symposium, Idaho Falls, 2001
- \*F.A. Selim, Positron dechanneling by electronic and nuclear scattering, Mat. Sci. Forum 363-365 ( 2001), p. 487
- \*F.A. Selim, A.W. Hunt, R.H. Howell, K.G.Lynn, J. A. Golovchenko, Developments on positron scattering experiments including beam production and detection, Mat. Sci. Forum. 363-365 (2001), p. 614
- \*F.A. Selim, A.W. Hunt, J. A. Golovchenko, R.H. Howell, R. Haakenaasen, K. G. Lynn, Improved source and transport of monenergetic MeV positrons, Nucl. Inst.& Meth B 171 (2000), p. 182
- \*F.A. Selim, A.W. Hunt, R.H. Howell, K.G.Lynn, J. A. Golovchenko, Multiple scattering measurements of energetic positrons in a thin gold polycrystal, Nucl. Inst. & Meth. B 168 (2000), p. 1
- \*D.P. Wells, F. A. Selim, J. F. Harmon, et al., *Development of Accelerator-Based X-ray Fluorescence for Large Sample Assay*, 40<sup>th</sup> Intl. Denver X-ray Conf., *Advances in X-Ray Analysis*, Volume 50 (2002).
- \*A.W. Hunt, D.B.Cassidy, F.A. Selim, R. Haakenaasen, T.E. Cowan, R.H. Howell, K.G.Lynn, J. A. Golovchenko, Spatial sampling of crystal electrons by in flight annihilation of fast positrons, Nature 402 (1999), p. 157

**Note:** ISU employees do not require funding from UNLV to participate in this project.

LANL Collaborators

Felix Olivas – LANSCE-2 (GTA welding)  
Mark Bourke – MST-8 (Neutron diffraction at LANSCE)

**Note:** LANL employees do not require funding from UNLV to participate in this project.

# Los Alamos National Laboratory

*Advanced Accelerator Applications*

*Technology Project Office*

P.O. Box 1663, Mail Stop H809

Los Alamos, NM 87545

(505) 667-9784/ FAX: (505) 667-2787

Date: February 12, 2002

Ajit Roy  
Associate Research Professor  
Department of Mechanical Engineering, UNLV  
Mail Code 4009, 4505 Maryland Parkway  
Las Vegas, NV 89154-4009  
Phone: (702) 895-1463      email: [aroy@unlv.edu](mailto:aroy@unlv.edu)

**Subject: Support for Proposal entitled: "Use of Positron Annihilation Spectroscopy for Stress-Strain Measurements"**

Dear Dr. Roy:

I enthusiastically support your proposal on the "Use of Positron Annihilation Spectroscopy for Stress-Strain Measurements" after welding of Alloy EP823 and 316L stainless steel. I believe that this proposal will lead to proof for using such a method for analyzing residual stresses. Such results will be extremely important for the design of the targets for the ATW project and such research is not being performed at any other facilities that I am aware of.

Sincerely,  
Stuart A. Maloy  
AAA Materials Team Leader

