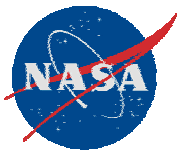


Development of Cryogenic Actuator Materials for Switches, Seals and Valves

**Raj Vaidyanathan
University of Central Florida**

Start Date = July 2002

Planned Completion = December 2006



Research Goals and Objectives

- **Develop shape memory alloy based cryogenic actuator materials for hydrogen related technologies**
- **Lower the operating temperature range of shape memory alloys**

- **Approach**

- **Alloy development**

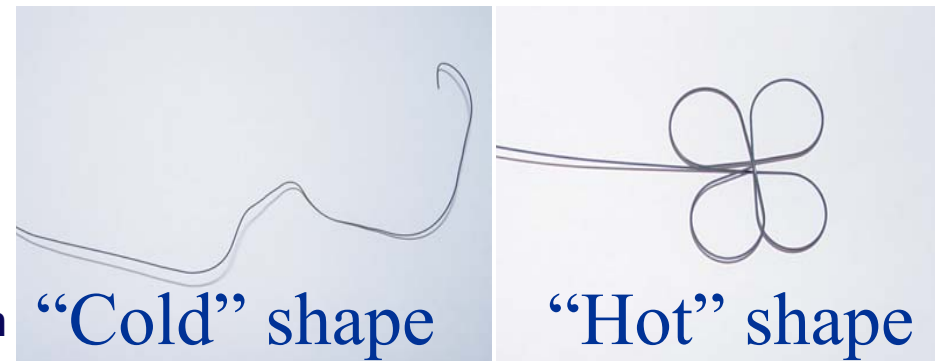
- **NiTiFe alloys**
 - **Composition control**
 - **Thermomechanical processing**

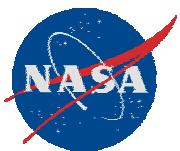
- **Materials testing and evaluation**

- **Dilatometry**
 - **Differential scanning calorimetry**
 - **Indentation**
 - **Neutron diffraction at stress and temperature (at Los Alamos National Laboratory)**
 - **Mechanical testing (dynamic mechanical analyzer)**

- **Cryogenic actuator design and prototype construction**

- **Switches, seals and valves**



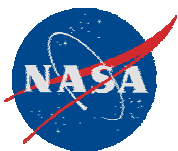


Relevance to Current State-of-the-Art

- Shape memory materials integrate sensory and actuation functions - hence incorporation of shape memory elements in existing devices eliminates sensors and active controls, e.g., gas gap and liquid gap switches for thermal conduction
- Existing commercially available shape memory alloys are not optimized for operation at cryogenic temperature - the alloy development aspect of this project enables their use as cryogenic actuator materials

Relevance to NASA

- The immediate benefit to NASA KSC is the development of a shape memory thermal conduction switch for application in cryogenic liquefaction, densification and zero boil-off systems
- Cryogenic actuators for spacecraft, spaceport and hydrogen technologies
- Broader impacts
 - An active and diverse partnership between a state-university (UCF), a major US national laboratory (Los Alamos National Laboratory) and NASA
 - Realization of the commercialization potential of cryogenic shape memory alloys

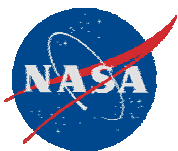


Florida Universities Hydrogen Review 2005

Florida Solar Energy Center • November 1-4, 2005

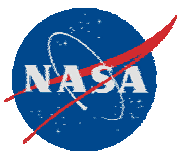
Budget, Schedule and Deliverables

TASK	YEAR/COST					
	0.5	1	1.5	2	2.5	3
		\$130K		\$155K		\$167K
Arc melting of alloys						
Thermomechanical processing						
LN2 testing and demonstration of effect						
Prototype design, fabrication, testing and modification						
Calorimetry and dilatometry (LHe)						
Cryogenic testing at Los Alamos National Lab						
Indentation						
Hot isostatic processing + alloy optimization						
Patent application + extension to other prototype configurations						

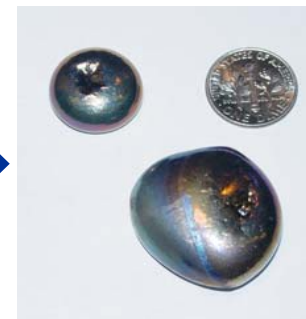
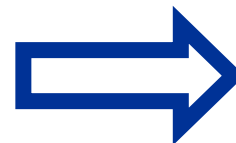
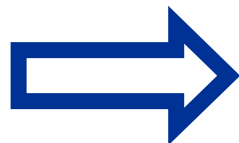
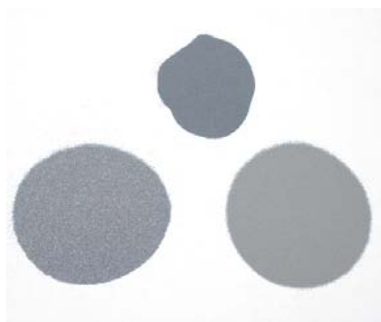


Anticipated Technology End Use

- **Thermal switches for**
 - cryogenic liquefaction, densification and zero boil-off systems
 - minimizing parasitic heat loads for redundant cryocoolers not in active use
 - controlling heat flow to a radiator that has periodic day/night cycles (e.g., moon)
 - controlling heat transfer between two cryogenic storage tanks that have varying heat loads (e.g., oxygen and methane on Mars)
- **Extension of shape memory alloy actuator elements developed to cryogenic seals, valves, fluid-line repair and self-healing gaskets for hydrogen related technologies**
- **Development of ambient technologies relevant to NASA such as debris-less separation and latch/release mechanisms are also expected to be favorably impacted**

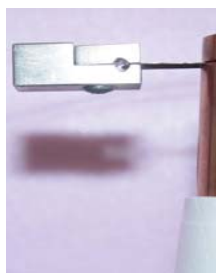


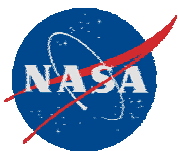
Accomplishments and Results - Overview



77 K

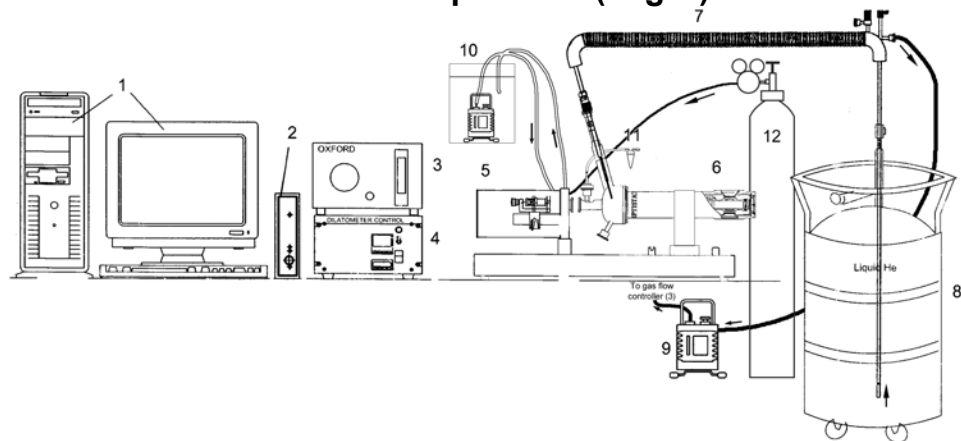
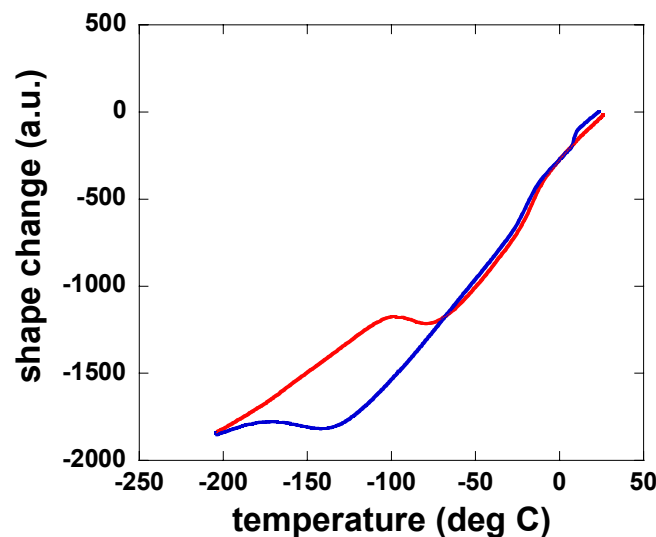
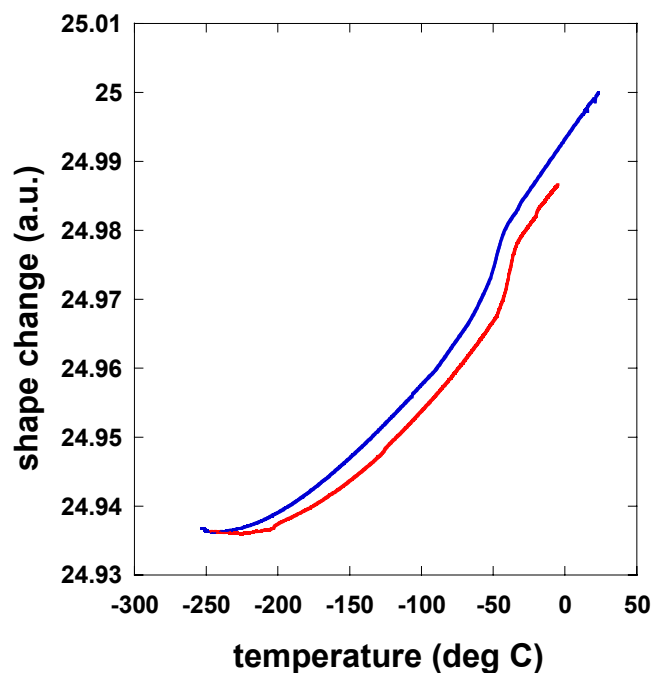
298 K

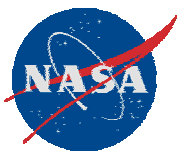




Accomplishments and Results – Year 3

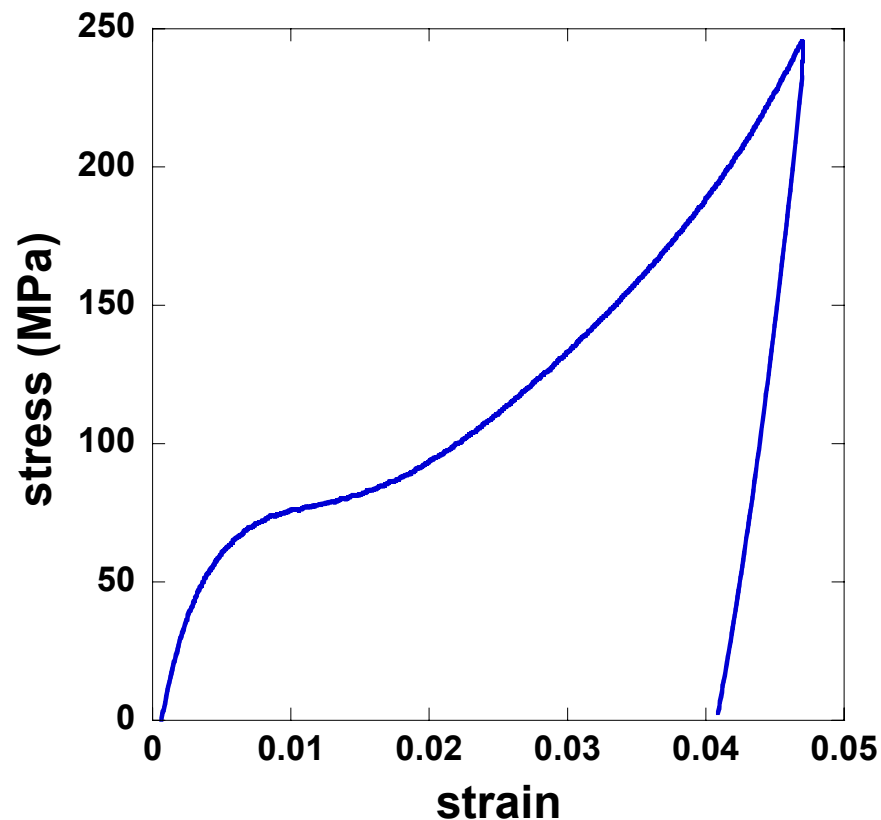
- Successful commissioning of a liquid helium dilatometer to detect shape changes to 20 K

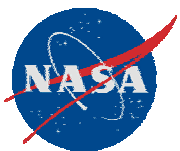




Accomplishments and Results – Year 3

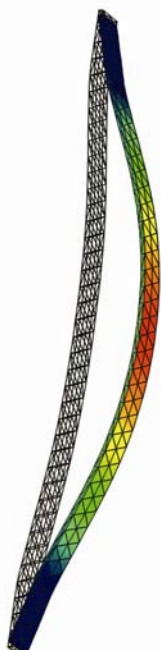
- **Successful commissioning of a dynamic mechanical analyzer; mechanical testing at temperatures as low as 120 K**



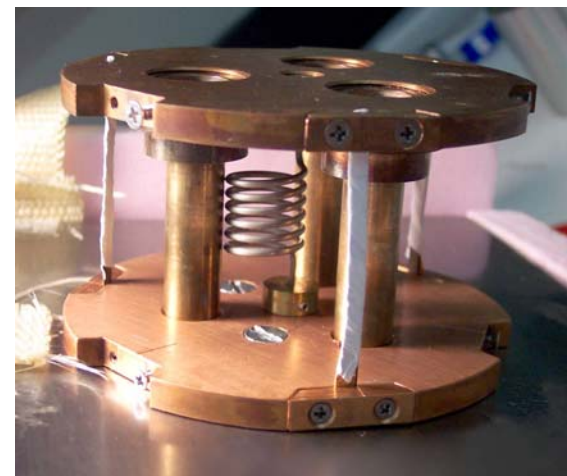
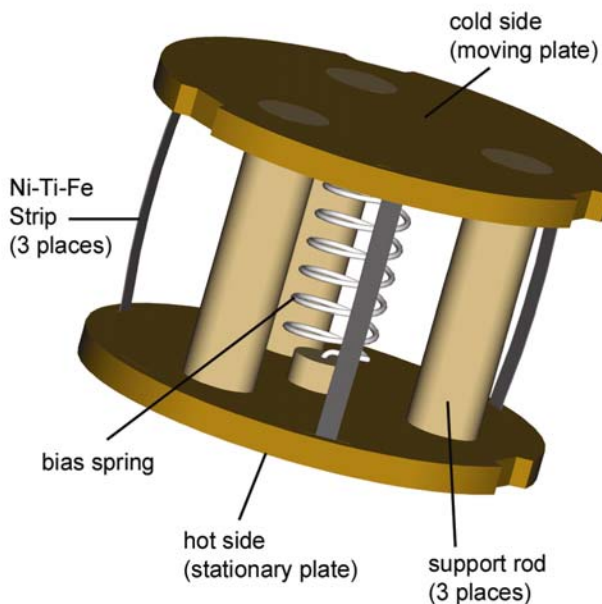


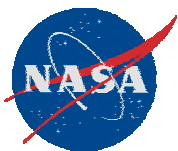
Accomplishments and Results – Year 3

- Successful design, fabrication and testing of a low hysteresis thermal conduction switch; modifications needed to minimize thermal gradient



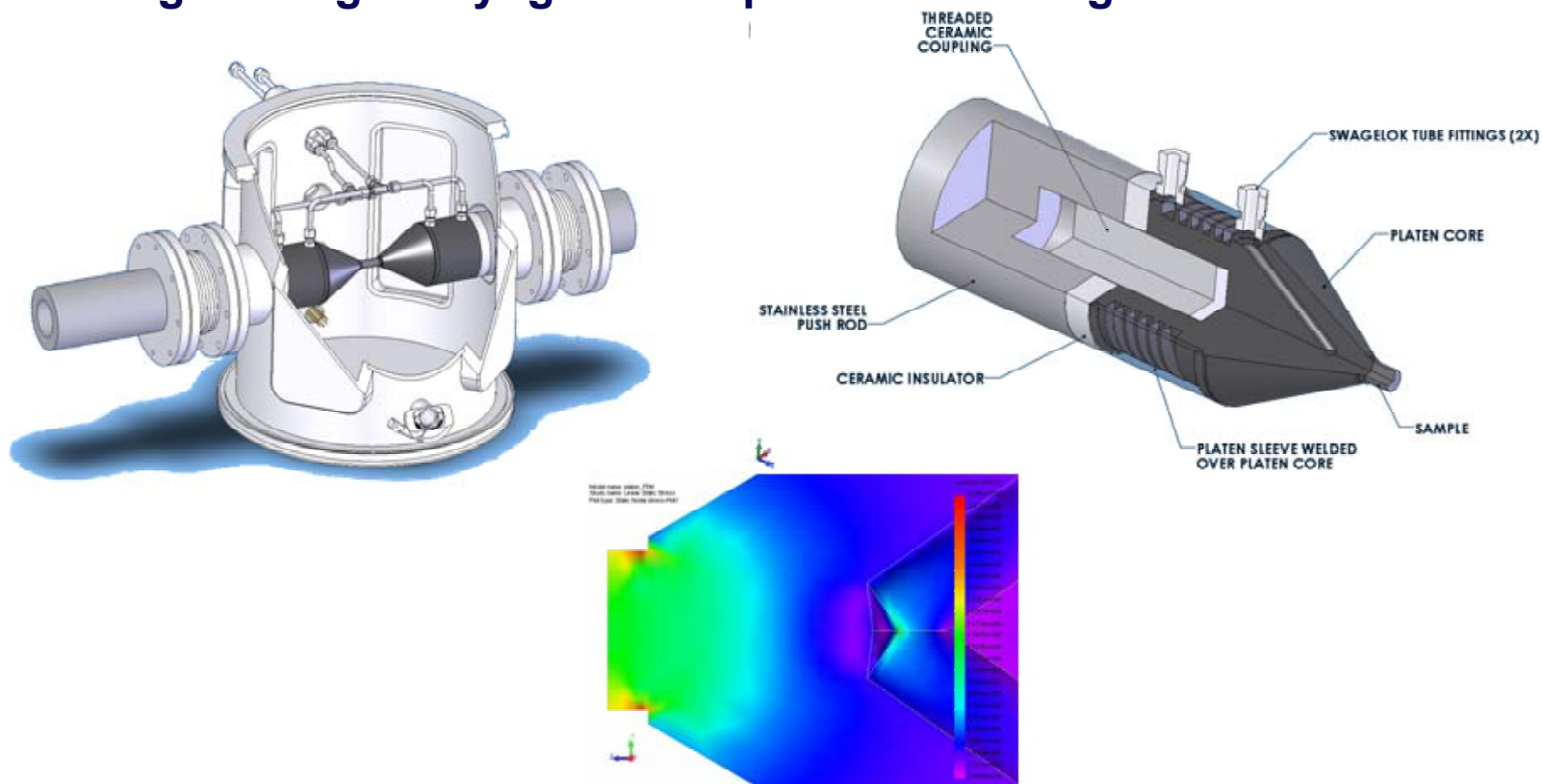
**Max:
95.6
MPa**

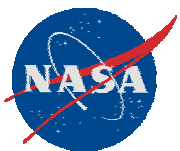




Accomplishments and Results – Year 3

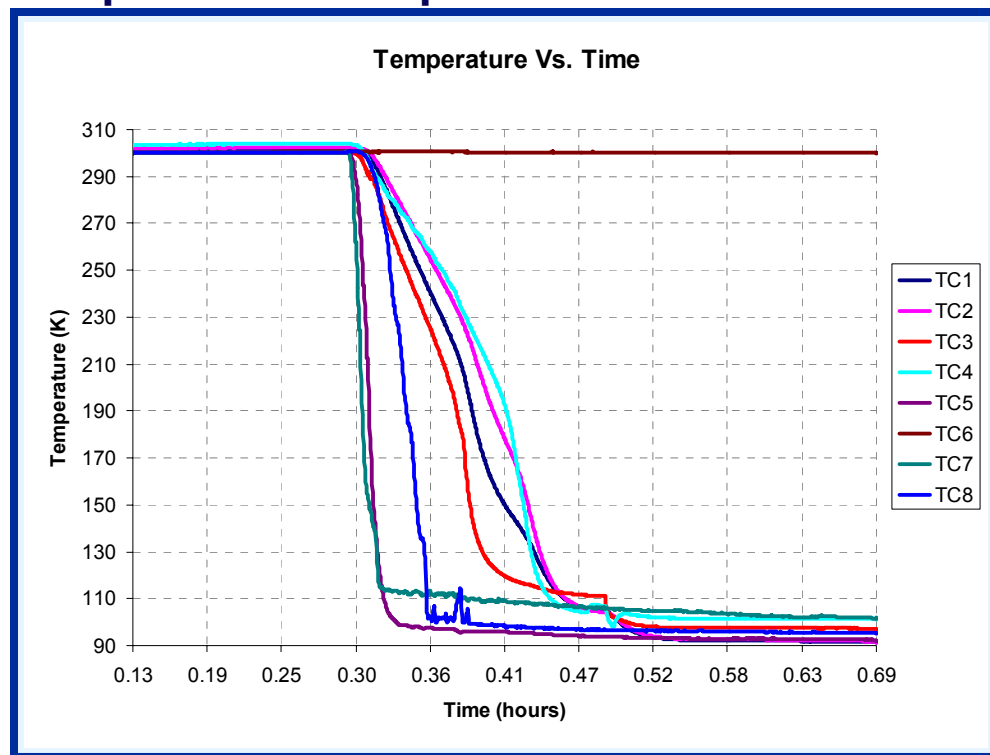
- Successful modification of neutron diffraction set up at Los Alamos National Laboratory for neutron diffraction measurements during loading at cryogenic temperatures - design



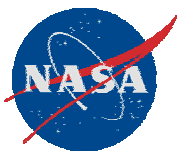


Accomplishments and Results – Year 3

- Successful modification of neutron diffraction set up at Los Alamos National Laboratory for neutron diffraction measurements during loading at cryogenic temperatures - implementation

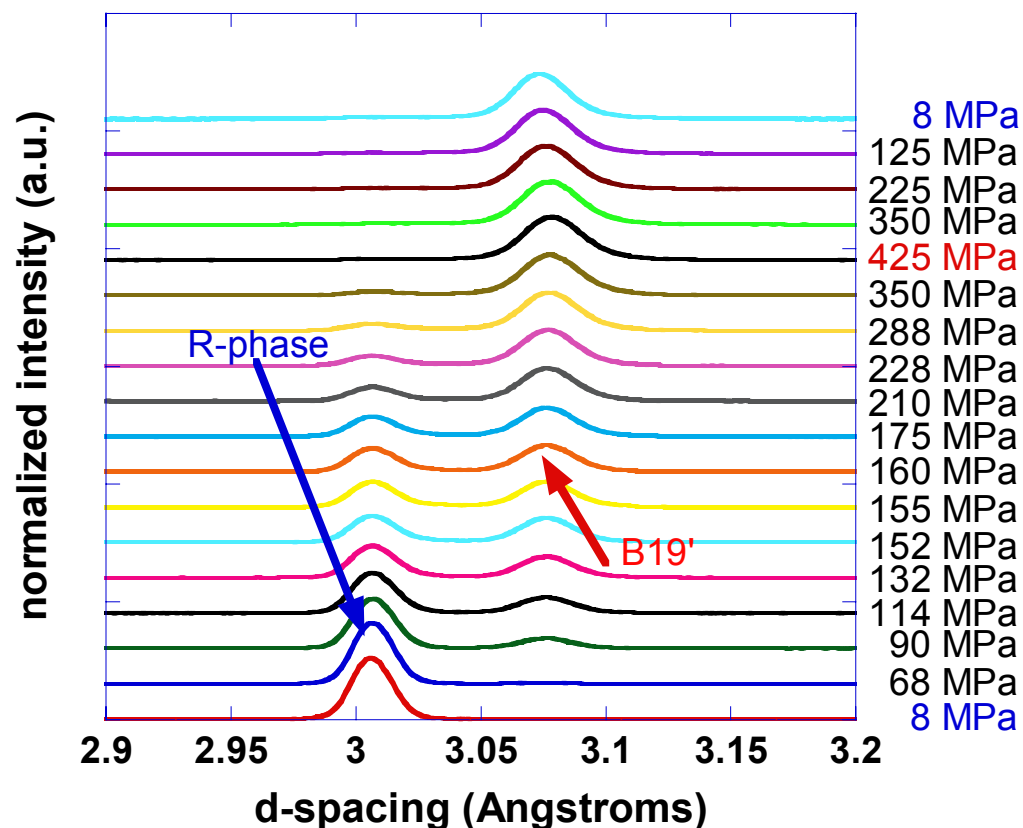


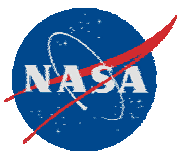
- Steady state in 18 minutes
- 16 L/hr of LN₂



Accomplishments and Results – Year 3

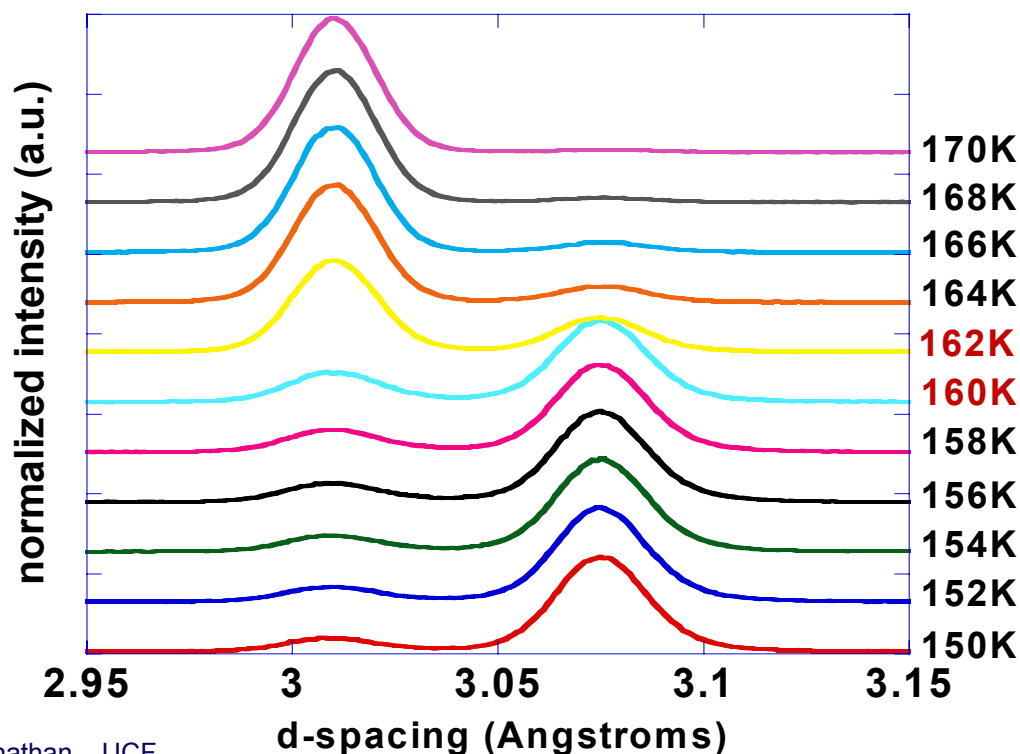
- Phase transformation with application of stress at 92 K
 $R \rightarrow B19'$

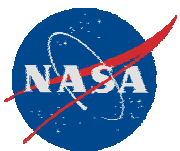




Accomplishments and Results – Year 3

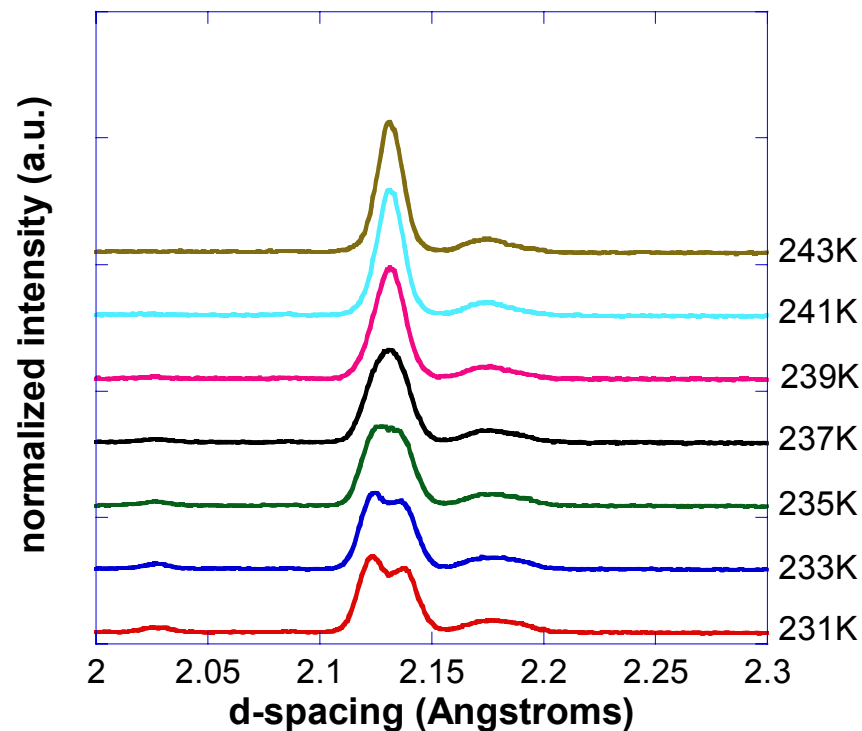
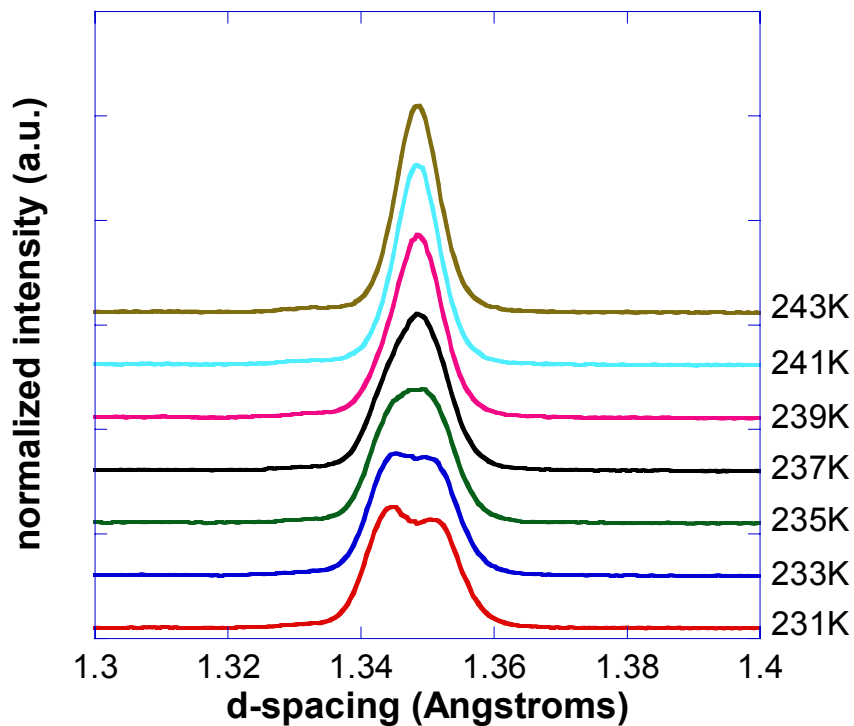
- Controlled heating under a constant stress of 44 MPa
- ~ 2% strain recovery between 160 K and 162 K
- One-time, high-stroke, actuator applications like self-healing gaskets, safety valves and release mechanisms

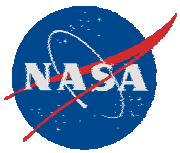




Accomplishments and Results – Year 3

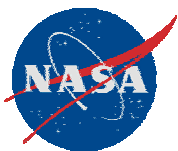
- Controlled heating under a constant stress of 44 MPa
- Cyclic, low-stroke / low-hysteresis, actuator applications like thermal conduction switches





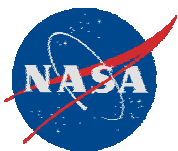
Partnerships and Collaborations

- **NASA Kennedy Space Center (\$120K):** Development of a prototype conduction switch
- **Los Alamos National Laboratory (DOE) (\$100K):** Capability for testing shape memory alloys at low temperatures
- **National Science Foundation CAREER (\$450K):** Deformation studies in shape memory alloys
- **UCF-UF Space Research Initiative (\$485K):** Experimental and Computational mechanics of shape memory materials
- **UCF Presidential Equipment (\$57K):** Support for a low temperature differential scanning calorimeter and a low temperature mechanical analyzer
- **Sierra Lobo at NASA KSC:** Assistance with developing a cryogenic testing capability at Los Alamos
- **NASA's flow liner problem:** Flow liner testing piggy-backed on shape memory alloy testing setup



Publications

- S. Rajagopalan, A.L. Little, M.A.M. Bourke and R. Vaidyanathan, "Elastic Modulus of B19' Shape-Memory NiTi from in situ Neutron Diffraction during Loading, Instrumented Nanoindentation and Extensometry", **Appl. Phys. Lett.** (2005) 86 081901-3.
- C.R. Rathod, V. Livescu, B. Clausen, M.A.M. Bourke, W.U. Notardonato, M. Femminino and R. Vaidyanathan, "Neutron Diffraction Characterization of Residual Strain in Welded INCONEL 718 for NASA Space Shuttle Flow Liners", **Advances in Cryogenic Engineering**, American Institute of Physics, (2004) 50A 167-175.
- V.B. Krishnan, J.D. Singh, T.R. Woodruff, W.U. Notardonato and R. Vaidyanathan, "A Shape Memory Alloy Based Cryogenic Thermal Conduction Switch", **Advances in Cryogenic Engineering**, American Institute of Physics, (2004) 50A 26-33.
- V. Livescu, T.R. Woodruff, B. Clausen, T. Sisneros, M.A.M. Bourke, W.U. Notardonato and R. Vaidyanathan, "Design and Rationale for an in situ Cryogenic Deformation Capability at a Neutron Source", **Advances in Cryogenic Engineering**, American Institute of Physics, (2004) 50A 83-89.
- C.R. Rathod, S. Rajagopalan and R. Vaidyanathan, "Mechanical Characterization of Shape-Memory Alloys using Diffraction and Instrumented Indentation", **Shape-Memory and Superelastic Technologies**, International Organization on Shape-Memory and Superelastic Technology, (2004) 331-339.
- V. Krishnan, W.U. Notardonato and R. Vaidyanathan, "Design, Fabrication and Testing of a Shape Memory Alloy based Cryogenic Thermal Conduction Switch", **Smart Mater. Struct.** (2004) submitted.
- J. L. Lemanski, V. B. Krishnan, R. Mahadevan Manjeri, W. Notardonato and R. Vaidyanathan, "A Low Hysteresis NiTiFe Shape Memory Alloy based Thermal Conduction Switch", **Advances in Cryogenic Engineering**, American Institute of Physics, (2005) submitted.
- C.R. Rathod, B.C. Clausen, M.A.M. Bourke and R. Vaidyanathan, "A Neutron Diffraction Investigation of Hysteresis Reduction and Increase in Linearity in the Stress-Strain Response of Superelastic NiTi", **Appl. Phys. Lett.** (2005) submitted.
- 3 manuscripts under preparation



Future Plans

- **Optimization of thermomechanical processing**
 - for wire drawing
 - based on dynamic mechanical analyzer results
- **Overcome heterogeneity issue**
 - improve mixing
 - pre-alloyed powders
 - vacuum quenching
- **Hot isostatic processing**
- **Extension to other prototype configurations - self-healing gaskets**
- **Patent application for thermal conduction switch with a configuration that minimizes the thermal gradient**
- **Contract with NASA KSC contractor ASRC to supply shape memory actuator elements for use in a low temperature convective heat pipe type thermal conduction switch; start date November 1, 2005; potential patent**
- **Commercial partner or SBIR/STTR funding**