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Conceptual Design Report for the NGNP Tensile Test Vehicle

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Conceptual Design Report for the NGNP Tensile Test Vehicle

1. Introduction

A conceptual design was preformed to determine the feasibility of irradiating silicon carbide fiber reinforced /silicon carbide (SiC_f/SiC) and carbon fiber reinforced /carbon (C_f/C) tensile test specimens for the Next Generation Nuclear Production (NGNP) program. The design was based on the Flux Trap, Large and Small B irradiation positions in the Advanced Test Reactor. The Test Specimens investigated were 50% SiC_f/SiC composites and 50% C_f/C composites. The specimens geometry were either tapered or fillet type dog bone shape, 25 to 35 mm long with a gauge length of 20 mm, width 6 mm, and 3 mm thick. The width of the support end of the specimens was 10-12 mm.

The test specimens require finite temperature control from 600 to 1,000 ºC. Due to the high temperatures required for the test specimens, the adjacent components will need to be fabricated from composite or graphitic materials. One-third to one-half of the specimens will be unloaded but will have the same geometry and irradiation conditions as the tensile specimens. The desired specimen irradiations damage was 9 dpa and the desired tensile stress limits were from 10 to 30 MPa.

One of the design objectives was to load the test train so that single or multiple specimen failures would not compromise the entire test train. This need was realized from previous irradiations where the specimens were all loaded through a single load path. Any specimen failure along the load path resulted in the entire test train to become unloaded. Another design objective was to determine the best irradiation position that would maximize the target space but still provide the neutron flux needed to complete the irradiations in a reasonable amount of time.

A rough order of magnitude cost estimate and schedule was completed based on previous experiments. The corresponding risk assessment was performed to identify possible items that may affect the overall project success. Depending upon how the risks are mitigated, the cost and schedules may be impacted.

2. Project Work Scope

The work scope for experiment will be accomplished in the following manner. The project will begin by establishing a design requirements document in concert with the Material Sciences group. This document will include all of the requirements from Material Science personnel to ensure the irradiations will provide their essential data. This document will also include all of the INL requirements necessary to safely irradiate the specimens in the ATR. The next step will be to perform the preliminary design, which will develop the overall concepts and enveloping analyses to ensure that the initial concepts will meet the customer's as well as ATR's requirements. There will be a design review held at the end of the preliminary design. All action items and comments from the review will be resolved and incorporated in the final design. Following resolution of any action items identified in the final design review, the experiment and support system drawings and analyses will be approved. Next, the fabrication of the first experiment components and support systems will be accomplished. After these tasks are completed, the experiment test train will be assembled, and the support and control systems will also be installed in the ATR facility. The experiment will then be inserted in the ATR and irradiated. After the experiment has been irradiated in the ATR for the specified amount of time, it will be removed from the reactor to allow the specimens to undergo disassembly and post irradiation examination.

3. Irradiations

3.1 Irradiation Concepts

The purpose of the experiment is to irradiate specimens that are both under a tensile load and in a relaxed or unloaded state. This allows the sponsor to study the tensile effects of the specimens from an irradiation environment. The irradiation, temperature and atmosphere conditions of both the tensile and unloaded specimens will be controlled so that both specimen types are in the same environment.

It was determined that the flux trap positions provide the best environment for this type of testing. This decision was driven primarily by the amount of time that the experiment will need to be in the reactor to reach the desired radiation damage limits. Fortunately the flux trap positions also offer the greatest amount of irradiation space. Unfortunately, these positions are the most expensive to rent. The proposed design could be resized to fit within a Large B position, but this position is not practical unless the dpa requirements are lowered.

After the irradiations have been completed, the test train assembly will be removed from the reactor and placed in the canal for cool down and storage. From the canal area, the capsule section will be removed from the test train and loaded into a commercial cask for shipping. This will require dry loading of the cask where the capsule remains dry through the entire event. A method for performing this operation has been developed for other programs currently underway.

Since the specimens require control of the irradiation temperature within limited specified ranges the irradiation will be performed as instrumented “lead-type” experiments. More detailed descriptions and irradiation conditions of the specimens are included in sections 3.1 and 3.1.1

3.1.1 Temperature Control System

An instrumented lead-type experiment offers active temperature monitoring and control of the specimen temperature. The lead-type experiments are attached to piping that exits out through the reactor vessel. Temperature control gas lines and thermocouples are routed from the experiment to control panels through the lead-out piping. This provides precise control of the irradiation temperature (±5°C) and a temperature history of the specimens at all times during irradiation. This information can remove significant uncertainties and greatly improve the data quality achieved from the experiments.

There is a vast amount of experience in conducting similar type temperature-controlled experiments at ATR. A very good example is the British Magnox graphite irradiation experiment that was conducted in 2002 with a cover gas environment for the specimens that was separate from the temperature control system. In addition, other active temperature-controlled experiments have been performed in ATR for a number of different programs. Active temperature-controlled experiments were routinely conducted in the Materials Test Reactor and the Engineering Test Reactor at the Reactor Technology Complex from the 1950’s through the 1970’s.

Active temperature control of ATR lead-type experiments is achieved by controlling the heat transfer across a narrow precision-machined insulating gas gap between the specimen holder, heat shields and the outer capsule boundary, which separates the test vehicle internals from the relatively cool (approximately 60ºC) ATR primary coolant. Mass flow controllers are used to blend a mixture of two inert gases with differing thermal conductivities based upon feedback from thermocouples located within the experiment capsules. The gases used in the experiment may be either helium and neon or possibly helium and argon (if the temperatures are difficult to achieve). Typically neon is used due to its low neutron activation; however, argon may be used if additional temperature control band is needed. Figure 1 shows the typical components.

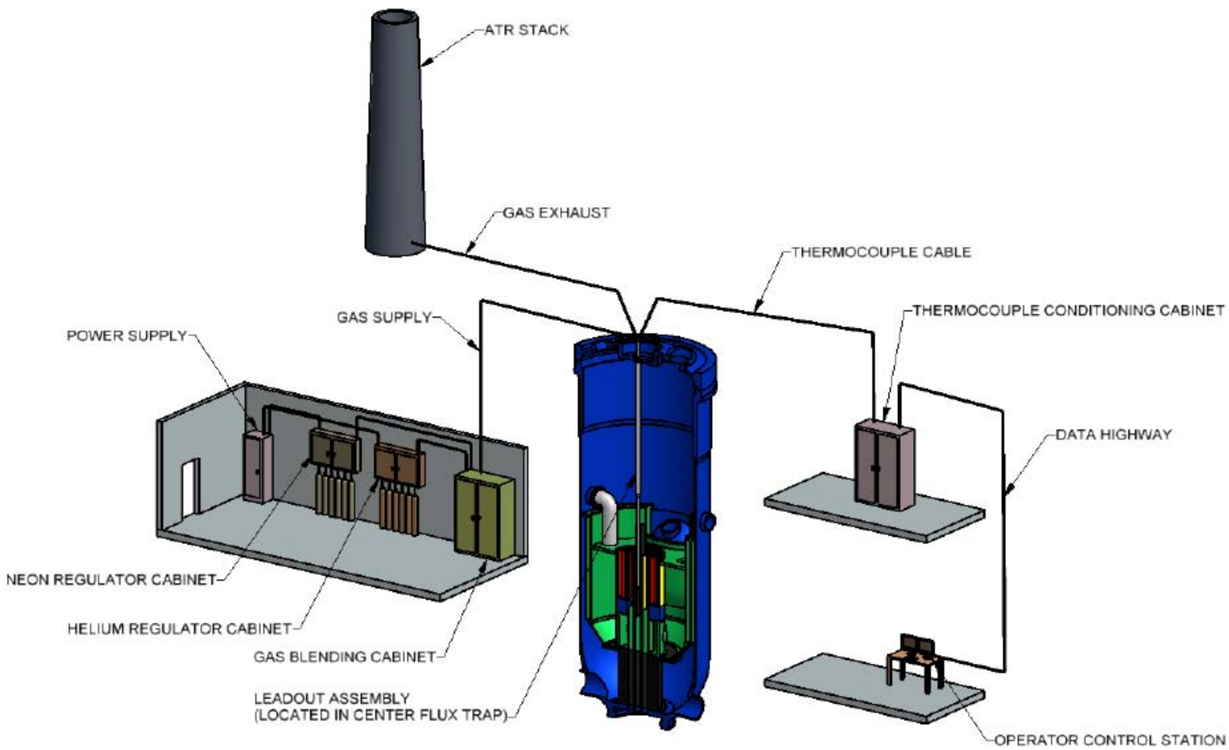

Figure 1. Typical Gas Control System Equipment

ATR temperature controlled experiments are designed by closely integrating the mechanical test train design with both the reactor physics analysis (using the Monte Carlo Neutral Particle [MCNP] analysis code) and the thermal analysis (using ABAQUS) of the experiment. Once an experiment concept has been developed with nominal dimensions and material types, then a reactor physics model is constructed and the calculations are performed using MCNP. The calculated neutron reaction and gamma heating values from the reactor physics analysis are then input to the thermal analysis to predict the temperatures in the specimens. Based upon the thermal analysis results, the necessary changes are made to the design and the whole process is repeated until the specified temperatures are attained. The options available for achieving the desired temperatures are the insulating gas gap width, the amount of mass in the experiment for gamma heating, and the types and relative mixtures of the gases in the gas gap. The amount of mass in the experiment may be adjusted by using materials with different densities and/or by changing the location and relative dimensions of the experiment components. Different insulator gases (neon, argon, etc.) may also be used to increase or decrease the gas gap width.

The axial temperature variation across the specimens will be determined by the thermal conductivity of the specimens, the axial flux distribution across the core, and the actual design of the capsules. The axial flux profile is relatively flat for approximately 760 mm of core height centered about the core mid-plane. This area generally provides uniform temperature distribution, and the proposed irradiation concepts for the experiment fit well within this window. See Figure 2 below for a typical flux distribution in an ATR flux trap position.

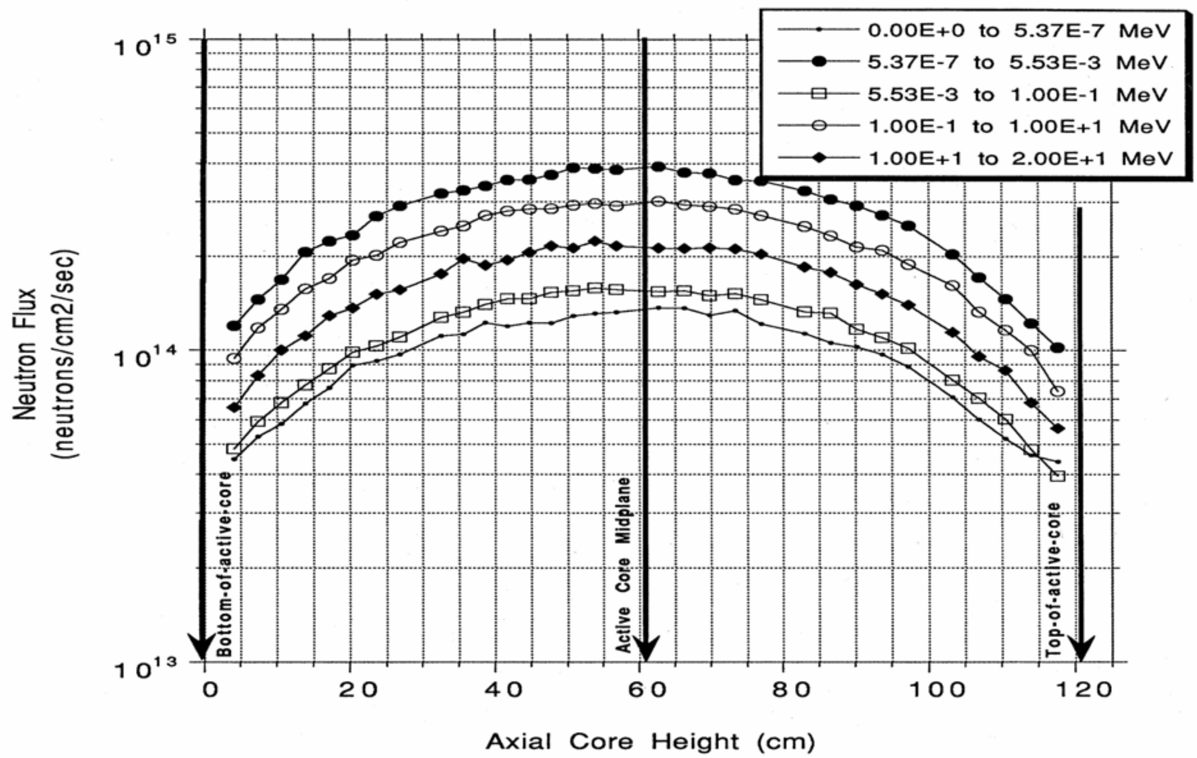

Figure 2. Typical flux distribution in ATR

3.1.2 Reactor Irradiations Positions

Three different reactor positions were considered for this irradiation, the Flux Traps, and the Large and Small B positions. The Small B positions are 22.2 mm in diameter, the Large B positions are 38.1 mm in diameter, and the Flux Traps are 76.2 mm in diameter. All three positions have an active core length of 1.22 meters. Figure 3 shows a cross section of the ATR core, with the various irradiation positions labeled, including the Flux Trap (in-Pile Tube) positions.

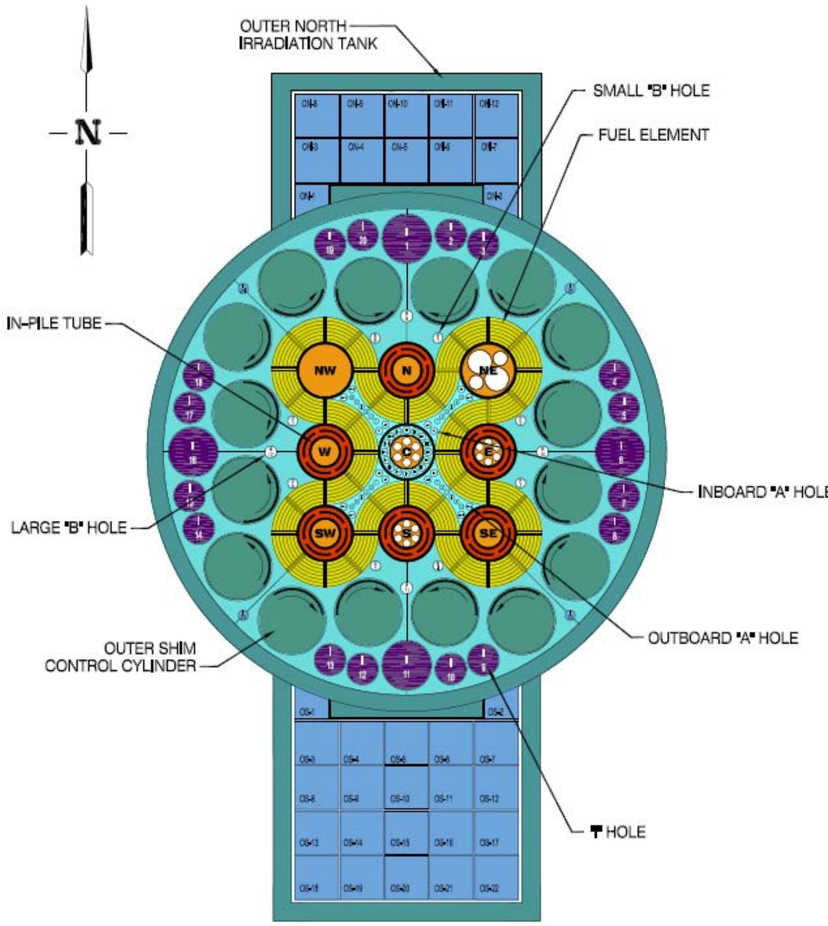

Figure 3. ATR Core Cross-Section

The available space for specimens in each of the reactor positions is determined by the size of the push rods, the heat shield and capsule thickness, the temperature control gas annulus width, and the space needed for thermocouples and gas lines. Table 1 shows the number of specimens that can fit in each of the irradiation positions based on the available space. The sample sizes used in these figures have 12 mm wide by 3 mm thick end pieces. In addition to the space limitations, there is limited space in the leadout piping above the core section for the equipment needed to load the specimens. At higher tensile loads, the available tensile load output of this equipment will limit the number of specimens. This is addressed further in section 3.2.1.

Table 1. Number of Test Specimens per Reactor Position

Reactor Position	Number of Test Specimens
Small B Position	1
Large B Position	3
Small Flux Trap	18

The neutron physics results from the NGNP Advanced Graphite Capsule (AGC) were used to determine the resident time for the tensile test. Dose values for SiC are generally 1 dpa = 1×10^{21} n/cm^2 in a thermal LWR which is about 75% of a graphitic or C_f/C composites material. Since the types of materials and dimensions of the conceptual tensile test experiment are similar to the AGC test capsule materials the neutron physics are assumed to be similar. The AGC capsule is scheduled to go in the south flux trap with an average fast flux (<0.1 MeV) of about 2.7 X 10^{14} neutrons/cm^2-sec yielding an average radiation material damage rate of 0.018 dpa/day. Using this rate for the tensile test, it will take 556 effective full power days (EFPD) to reach a maximum material damage goal of 10 dpa. Because the reactor operates about 60% of the time, it will require 780 days or approximately 2.1 years to complete the total irradiations cycle. Based on the published fast flux ratios for the other positions, it will require approximately 2.6 years to complete the maximum irradiation in a small B position and 13 years in a large B position. Table 2 shows the approximate operating time for the different positions to reach 1, 5, and 10 dpa. However, the actual irradiation times will be determined by using computer codes and the actual reactor operating power history at the specific irradiation position.

Table 2. Average Irradiation Time for Three Reactor Position

Average Irradiation Time	1 dpa	5 dpa	10 dpa
Small Flux Trap	0.21 years	1.1 years	2.1 years
Small B Position	0.26 years	1.3 years	2.6 years
Large B Position	1.3 years	6.5 years	13 years

The long irradiations time associated with the large B position dismissed this position as a candidate for the tensile test irradiation as the small number a specimens dismissed the small B position. The Large B position could be utilized for irradiations for lower material damage testing (< 2 dpa). The flux traps offer the most space and the highest fluence but they are more expensive than the other reactor positions and the future availability would need to be determined.

The Center, East and South flux trap positions do not contain in-pile tubes and are therefore the logical choices for this type of testing. A lead-out assembly has not been installed in a flux trap position, but the NGNP AGC testing is scheduled to install one in the South Flux Trap. The design of the AGC experiment was started in 2005, and is scheduled for completion along with initial experiment fabrication by the end of 2006. Irradiation of the first experiment is expected to begin in late 2007. These tests are scheduled to take place through 2009. The Advanced Fuel Cycle Initiative (AFCI) and Light Water Reactor (LWR) fuel concepts began using the East Flux Trap for irradiation test in July 2003, and plans to continue using the ATR throughout the duration of the program. The AFCI has currently planned irradiations for ATR through at least 2010, and is continuing to identify additional testing for ATR into the future. The Materials and Fuels Complex (MFC) is developing new low enriched fuels to replace the high enriched fuel used in research and test reactors. This is the Reduced Enrichment for Research and Test Reactors (RERTR) Fuel Irradiations Program. RERTR full size fuel plate experiments are planned for the Center Flux Trap. The first full size fuel plate experiment will be inserted in ATR in January 2007 and are expected to be completed in Novmber 2007. The planned use of the Center Flux Trap for the RERTR program be completed before a NGNP Tensile Test experiment would be ready for irradiation. The NGNP Tensile Test experiment conceptual design is therefore based on the Center Flux Trap position.

3.2 Tensile Test Experiment

The approach for NGNP Tensile Test experiment conceptual design would be to place a combination of silicon carbide fiber reinforced /silicon carbide (SiC_f/SiC) and carbon fiber reinforced /carbon (C_f/C) composite tensile specimens in the region of the reactor core centerline. The specimens would be either the typical dog bone shape or have tapered ends as shown in Figure 4. One-third to one-half of the specimens would be unloaded. The remaining specimens would be under an axial load. The desired axial load for these specimens is from 10 to 30 MPa.

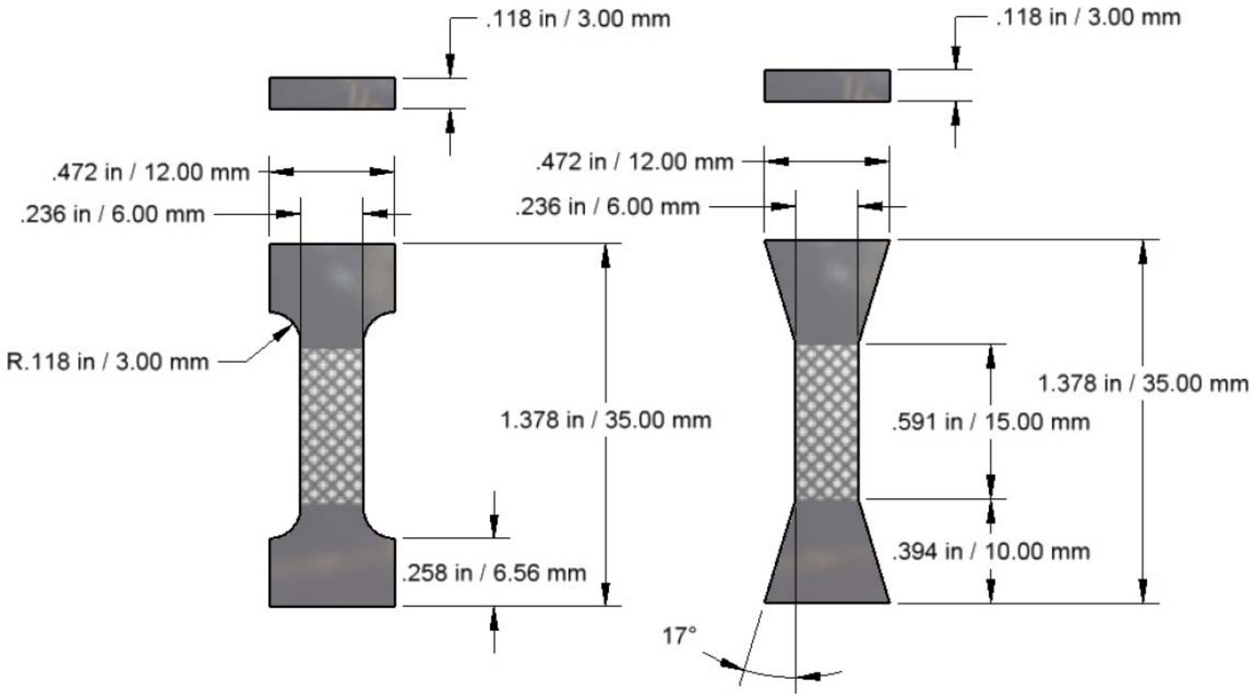

Figure 4. Specimen Geometries

3.2.1 Tensile Loading of Test Train Specimens

The experiment test train will consist of seven separate capsules that will each contain 18 specimens. Four of the capsules will contain tensile loaded specimens (72 total) with the other three containing unloaded (relaxed) specimens (54 total). The specimen capsules will alternate between tensile and relaxed specimens. The tensile loading for each of the tensile capsules will be independent from one another. This will be accomplished by placing the specimens in a holder, fixing the top of the holder in place, and pushing down on the bottom holder with a pneumatic or hydraulic cylinder (ram). The cylinders would be located above the core of the reactor to minimize radiation damage. The load from the cylinder would be transmitted to the bottom specimen holder through push rods. The push rods will need to be fabricated from either graphite or composite material to withstand the high temperatures. A load cell will be placed inline with each of the push rods to measure the tensile load. This will eliminate uncertainties with thermal growth in the push rods and the output of the load cylinders. A horizontal cross-section and a vertical section of the proposed capsule is shown in Figure 5 and Figure 6.

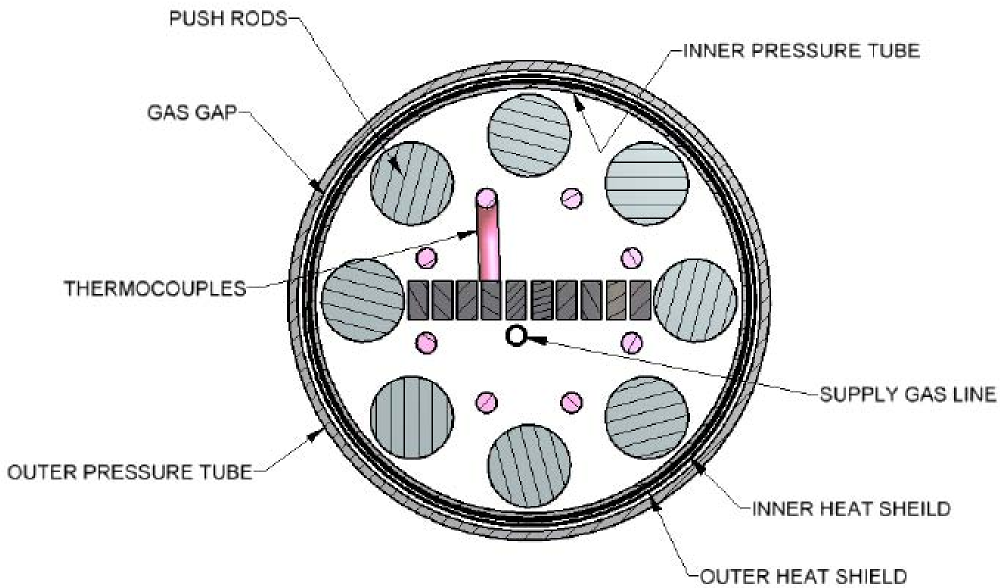

Figure 5. Horizontal Sections of Tensile Test Capsule

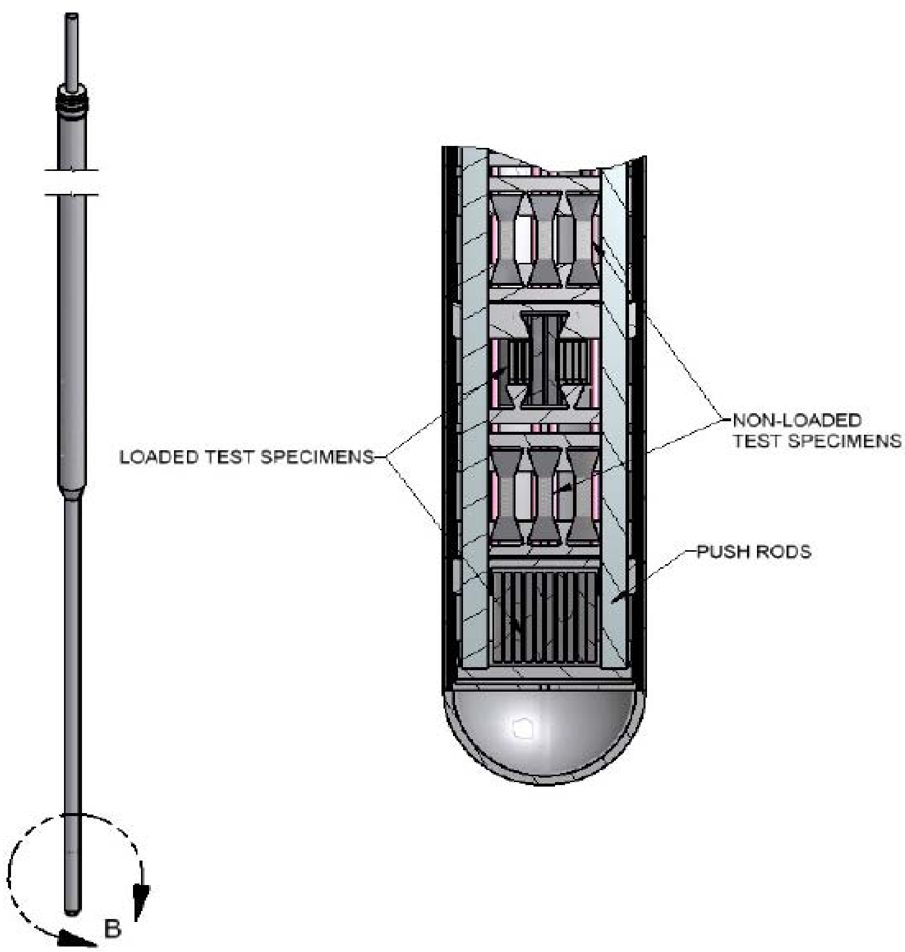

Figure 6. Vertical Sections of Tensile Test Capsule

The loaded and relaxed specimen layers are alternated through the core centerline. The specimens cover approximately 330 mm inches of the approximate 760 mm length of core that has the flattest neutron profile. This only accounts for 27% of the active core length (1.22 meter). The number of tensile loaded specimens is limited by the physical space above core for the cylinders and push rods and by the cylinder output force. The output force from the cylinders is determined by the cylinder size and supply pressure.

The pneumatic cylinders located in the equipment searches with a physical diameter of 25.4 mm are rated at 1.7 MPa with a output multiplier of 2.4 have a maximum output of 600 lb_f . Comparable sized hydraulic cylinders have an output of 2355 lb_f . Based upon the specimen gauge sections of 3mm x 6mm, the cross-sectional area for each test specimen is 1.8 x 10^{-5} m^2. Using this cross-sectional area for the test specimens, the load on a single specimen capable of producing desirable applied stresses is:

1 MPa (on single sample) = 4.03 lb_f

5 MPa (on single sample) = 20.15 lb_f

10 MPa (on single sample) = 40.3 lb_f

30 MPa (on single sample) = 121 lb_f

To achieve a maximum applied stress of 30 MPa over an entire sample layer, the pneumatic cylinder can only load 4 samples in a test layer while the hydraulic cylinders can achieve 18 samples (see Table 3). If the load is reduced to a more manageable 10 MPa/sample the pneumatic cylinders should be capable of loading a sufficient number of samples (12 samples/layer) even in the larger flux trap sample configuration. Additional unloaded specimens could be placed in the experiment test train as need.

Table 3. Samples per layer at a given MPa.

Stress (one sample)	**Pneumatic cylinders (@ 80% of 600 lb_f Capacity)**	**Hydraulic cylinders (@ 80 % of 2355 lb_f Capacity)**
1 MPa	118 samples/layer	464 samples/layer
5 MPa	24 samples/layer	93 samples/layer
10 MPa	12 samples/layer	46 samples/layer
30 MPa	4 samples/layer	15 samples/layer

The experiment will be an instrumented lead-type with separate active temperature monitoring and control of each capsule. All capsules will share a single temperature control gas. The temperature control gas, which will consist of a custom blended mixture of inert gasses, will be flowing in the outer region or temperature control gas annulus between the specimen holder and the outside capsule wall. The temperature control gas lines and thermocouples will be routed through the specimen holders. A minimum of two thermocouples per capsule will be used to monitor and control the temperature of the specimens. The capsules will also contain passive dosimetry (flux wires) for post-irradiation analysis to determine the precise fluence values. Several different flux wires located either in or around the specimen holder will be used to provide both the fast and thermal neutron fluence.

3.3 Post Irradiation Examination

Once the irradiation phase has been completed on each experiment, the test train will be shipped for disassembly and Post Irradiation Examination (PIE). A commercial cask (GE-2000) will be used that can interface with the Materials and Fuel Complex.

3.4 Identified Risks

Risk that were identified during this study are listed below. Mitigation of these risks should be considered during the next phase of the design.

1. High Temperatures: A thermal analysis of the proposed design has not been performed. The capsule components will need to be fabricated from composite materials that can withstand high temperatures. Modifications to the proposed designed may be needed to size the temperature control gas gap for proper temperature control. This dimension will not be known until reactor physics and thermal analysis have been performed.

2. Fabrication Tolerances: For each of the specimens to be loaded evenly, the specimens, specimen carriers, specimen holders and push rods will need to be fabricated to tight tolerances. If one the specimens is shorter than the others, that individual specimen will take to load intended for all the specimens in the holder. This could cause premature specimen failure or result in incorrect postulations in the test results.

3. Push Rods: The push rods will need to be supported to prevent bowing. Since part of the push rods will be in the high neutron flux, a thorough understanding of the heat and neutron interactions will need to be known.

4. Capsule Material Fabrication: The materials adjacent to the specimens will need to withstand high temperature and neutron fluence, and be fabricated to tight tolerances to provide a heat transfer path to the temperature control gas. The geometries needed accommodate the specimens and push rods will be complicated.

5. Hydraulic Fluid: Use of hydraulic fluids has not been used in test train designs in the part at ATR. There are fluids that are compatible with the primary system that may be approved for use.

6. Specimen Temperatures: Specimen temperatures in the 1000º C range have not been run in the ATR. Current experiments plan to operate in the 600º to 800º C range.

7. Reactor Top: There is limited space available in the reactor top area and limited penetrations to route gas lines, thermocouples and hydraulic or pneumatic lines from the reactor vessel to the equipment corridors. Core drilling of the three foot thick shield walls may be necessary if the present penetrations are filled by the current experiment programs.

4. Assumptions

The assumptions used in establishing the timescales and costs for the project activities have been identified and are listed below.

4.1 General Assumptions

Assumptions that apply to the experiment and the project in general have been identified and are listed below.

- Specimens will be loaded in an array with a constant gas gap and material mass in each capsule. This arrangement does not compensate for thermal gradients at the outside ends of the test train.

- The irradiation positions desired for these experiments will be available when needed.

- Active temperature monitoring and control is required, and a new gas temperature control system will be needed for this experiment.

- At least two thermocouples will be included in each capsule. The specimen temperatures will need to be extrapolated as the thermocouples will need to be placed out of the hot regions of the experiment.

- Instrumentation (thermocouples) located within the experiment that fails during irradiation will not be replaced.

- The temperature will be maintained within ±5°C of the specified temperature during irradiation.

- Neutron flux measurement wires for both the thermal and fast spectrum will be needed.

- Flux wires will be analyzed only at the end of irradiation.

- ATR's operating schedule is assumed to be a nominal seven reactor cycles per calendar year with availability (percentage of operating time per year) of 60%. The full power days will vary depending on the exact operating schedule during each year.

- Occasional short high power cycles may increase the power in the area adjacent to the experiment, and if the increased power will adversely affect the experiment, then the experiment may be removed during the short cycle. These removal and re-insertion costs are not included in this estimate.

- A mock-up test for each reactor irradiation position will serve as both the nuclear back-up test and can also be used to verify the reactivity worth of the experiment in the ATR Critical (ATRC) facility. This estimate includes the costs and schedule for an ATRC test.

- A mockup of the equipment used to tensile load the specimens will be needed.

- All work will be performed in accordance with INL safety processes, quality requirements, and work control procedures.

- The costs for the irradiations are expressed in INL Fiscal Year 2006 dollars with an annual cost escalation of 3%. The 3 % escalation is historically what has been used in the Irradiation Unit charges, but is subject to change. The other charges for labor and materials will be escalated as future labor rates are set at INL.

5. Project Timescale

The Milestones and Deliverables for each task have been identified and listed below. Each project Milestone and associated date is identified with a list of Deliverables. Mismatches in the ATR operating cycles may cause delays in the insertion of the experiments.

5.1 Schedule, Milestones, and Deliverables

Milestone 1: Design Requirements—6 weeks after funding is received at INL (Project Month 2)

Deliverable:

- Final Draft Test Train Design Requirements Document

Milestone 2: Preliminary Design Review—Project Month 6

Deliverables:

- Preliminary Experiment Test Train Engineering Drawings
- Preliminary Temperature Control System Engineering Drawings/Software
- Preliminary Tensile Load Control System Engineering Drawings/Software
- Preliminary Thermal Analysis
- Preliminary Neutronics Analysis
- Preliminary Stress/Seismic Analysis
- Preliminary Design Review Report

Milestone 3: Final Design Review—Project Month 10

Deliverables:

- Final Draft of Test Train Engineering Drawings
- Final Draft of Temperature Control System Drawings/Software
- Final Draft of Tensile Load Control System Engineering Drawings/Software
- Final Draft of Thermal Analysis
- Final Draft of Neutronics Analysis
- Final Draft of Stress/Seismic Analysis
- Final Design Review Report

Milestone 4: Mockup Testing of Tensile Load Equipment—Project Month 14

Deliverables:

- Report of Mockup Test

Milestone 5: Start of Fabrication—Project Month 15

Deliverables:

- Signed and Released Test Train Engineering Drawings
- Signed and Released Temperature Control and Tensile Load Control System Drawings/Software
- Signed and Released Final Analyses

Milestone 6: Start of Experiment Irradiation—Project Month 22

Deliverables:

- Completed and Assembled Tensile Test Train
- Completed ATRC Experiment Irradiation and Data
- Completed and Tested Temperature Control System
- Completed and Tensile Load Control System
- Approved Experiment Safety Assurance Package

Milestone 6: Complete Irradiation of Tensile Experiment—Project Month 47

Deliverables:

- Specimens Irradiated for Approximately 556 EFPD in ATR.
- Preliminary As-Run Analysis of Specimens

Milestone 12: Project Close-out—Project Month 50

Deliverables:

- Final Project Report
- Project Documentation Close-out

6. Cost Estimate Summary

The rough order of magnitude costs for the experiment have been estimated and are identified below. A preliminary risk screening was performed to identify uncertainties in the cost estimates. Appropriate contingencies have been added to account for these uncertainties. This estimate is based on a single standalone experiment.

6.1 Flux Trap Tensile Test Experiment Cost Estimate

The summary ROM estimated costs for an instrumented lead experiment for the NGNP Tensile Test materials are listed below. These costs are not informal costs for Project Controls purposes. They are offered as part of this report for estimation purposes only to give the Material and Controls group an understanding of the costs associated with irradiation test at the ATR.

The activities for each task are listed to provide some insight into the activities needed. Following the cost estimate summary is a breakdown of the activities with the approximate time and costs necessary to complete each task. The labor and material costs will be similar for either a Flux Trap or Large B position. These costs do not include the reactor usage (irradiation unit (IU) charges). The estimated IU charges for the Flux Trap and Large B positions are given below. Again, the IU costs are expressed in INL Fiscal Year 2006 dollars with an annual cost escalation of 3%. The 3 % escalation is historically what has been used in the Irradiation Unit charges, but is subject to change.

Table 4. ROM estimated costs for an instrumented lead experiment for the NGNP Tensile Test materials

	Cost per Effective Full Power Day	**Cost for 1 year irradiation @ 60% Reactor Utilization**
Center Flux Trap Position (Based on 27 MW Lobe Power	\$12,929/EFPD Based on 24.5 MW lobe Power	\$2,831,410
Large B Position (Based on 25 MW Power)	\$83.7/EFPD Based on 24 MW lobe Power	\$18,330

ACTIVITY/TASK	**COSTS (\$K)**
Preliminary Design and Review	**1,217**
Draft experiment drawings	
ATR Tensile Test Train	
ATRC reactivity measurement capsules	
Preliminary supporting analyses	
Thermal hydraulic	
Reactor physics	
Stress, seismic & vibration	
Experiment safety	
Draft temperature control system drawings	
Draft tensile loading system drawings	
Preliminary design review and report	
Project management & technical support	
Final Design and Review	**880**
Completed experiment drawings	
ATR Permeation Test Train	
ATRC capsules	
Final supporting analyses	
Thermal hydraulic	
Reactor physics	
Stress, seismic & vibration	
Experiment safety	
Completed temperature control system drawings	
Completed permeation experiment purge system drawing	
Final Design Review and Report	
Project management & technical support	
Fabrication and Assembly	**2,515**
Fabrication work packages	
Development of special processes (brazes, plating, etc.)	

Assembly Procedures	
Fabricate and Assemble test train	
Installation & Testing of Temperature Control System	
Installation & Testing of permeation experiment purge system	
Project management & technical support	
Irradiation	**817**
ATRC Test Plan, experiment operation, & data reduction	
Training of operators on control system	
Reactor Insertion Procedures	
Experiment handling	
Reactor irradiation charges	
Reactor operator support	
Experiment engineering support	
As-Run Analysis for temperature and neutron damage	
Irradiation reports	
Project management & technical support	
Handling and Packaging	**442**
Two experiment transfers to Canal (1 for each test rig)	
Procedures for disassembly	
Canal disassembly to ship for PIE (twice)	
Canal tooling	
ORIGEN analysis to ship for PIE (twice)	
Cask rental and shipping (twice)	
Flux Wire Measurements (twice)	
Project management & technical support	
GRAND TOTAL	**5,871**

Preliminary Design and Review

Internal Use Only

Discipline/Task	Labor Hours @ Hourly rate	Material Costs ($K)	Total Costs ($K)
Design Requirements			
Mech. & Elect. Engr	380@150/hr		57.0
Mechanical Engineering/Design			
Tensile Test Train	640@$150/hr		96.0
ATRC Capsules	100@$150/hr		15.0
Tensile Loading System	640@$150/hr		96.0
Temperature System	300@$150/hr		45.0
Drafting	400@$75/hr		30.0
Electrical Engineering/Design			
Temperature System	300@$150/hr		45.0
Tensile Loading System	640@$150/hr		96.0
Experiment Capsules	75@$150/hr		11.3
Drafting	400@$75/hr		30.0
Analysis			
Thermal/Hydraulic	400@$150/hr		60.0
Reactor Physics	500@$170/hr		85.0
Stress/Vibration	200@$150/hr		30.0
Safety/ESAP	160@$150/hr		24.0
INL Design Review			
12 Reviewers for Approx. 2 days each	250@$150/hr		37.5
Project Management and Reactor Interface (6 months)			
Project Manager	800@$150/hr	5.0	125.0
Technical Support	250@$150/hr		37.5
Admin Support	200@$80/hr		16.0
Travel		20.0	20.0
Subtotal			956.3
Contingency (20%)			191.3
Safeguards & Security (3%)			34.4
DOE FAC (3%)			35.5
Total for Prelim. Design			**$1,217.4**

Final Design and Review

Internal Use Only

Discipline/Task	Labor Hours @ Hourly rate	Material Costs ($K)	Total Costs ($K)
Mechanical Engineering/Design			
Tensile Test Train	480@$150/hr		72.0
ATRC Capsules	100@$150/hr		15.0
Tensile Loading System	480@$150/hr		72.0
Temperature System	200@$150/hr		30.0
Drafting	320@$75/hr		24.0
Mockup Test			
Mech. Engr.	200@$150/hr		30.0
Elec. Engr.	100@ $150/hr		15.0
Drafting	200@$75/hr		15.0
Electrical Engineering/Design			
Temperature System	200@$150/hr		30.0
Tensile Loading System	480@$150/hr		72.0
Experiment Capsules	75@$150/hr		11.3
Drafting	340@$75/hr		25.5
Analysis			
Thermal/Hydraulic	180@$150/hr		30.0
Reactor Physics	200@$170/hr		51.0
Stress/Vibration	100@$150/hr		15.0
Safety/ESAP	260@$150/hr		45.0
INL Design Review			
12 Reviewers for 2 days each	250@$150/hr		37.5
Project Management and Reactor Interface (4 months)			
Project Manager	400@$150/hr	5.0	65.0
Technical Support	160@$150/hr		24.0
Admin Support	120@$80/hr	1.5	11.1
Subtotal			690.4
Contingency (20%)			138.1
Safeguards & Security (3%)			24.9
DOE FAC (3%)			25.6
Total for Final Design			**$878.9**

Fabrication and Assembly

Internal Use Only

Discipline/Task	Labor Hours @ Hourly rate	Material Costs ($K)	Total Costs ($K)
Experiment Fabrication			
Machinist	1000@$80/hr	2000.0	180.0
Welder	300@$80/hr		24.0
Crafts Planning	160@$80/hr		12.8
Engineering Support	160@$150/hr		24.0
TTAF Experiment Assembly			
Engr. Procedures	80@$150/hr		12.0
Tech's (Development)	160@$100/hr		16.0
Tech's (Assembly)	400@$100/hr		40.0
QA Inspector	260@$80/hr		20.8
Engr. Support	260@$150/hr		39.0
ATRC Test Fabrication			
Machinist	120@$80/hr	1000.0	19.6
Welder	60@$80/hr		4.8
Crafts Planning	60@$80/hr		4.8
Engineering Support	80@$150/hr		12.0
TTAF ATRC Test Assemblies			
Engr. Procedures	50@$150/hr		7.5
Technicians	100@$100/hr		10.0
QA Inspector	50@$80/hr		4.0
Engr. Support	50@$150/hr		7.5
Temperature Control Systems			
Elect. Engr. Support	320@$150/hr		48.0
Instrument Tech's	320@$80/hr	75.0	100.6
Electricians	500@$80/hr	50.0	55.0
Mech. Engr. Support	320@$150/hr		48.0
Fitters	400@$80/hr	75.0	107.0
Welders	400@$80/hr	15.0	47.0
Tensile Loading System (1 each)			
Elect. Engr. Support	320@$150/hr	175.6	223.6
Instrument Tech's	320@$80/hr		25.6
Electricians	300@$80/hr		24.0
Mech. Engr. Support	320@$150/hr		48.0
Fitters	400@$80/hr		32.0
Welders	400@$80/hr		32.0

Fabrication and Assembly (cont)

Internal Use Only

Discipline/Task	Labor Hours @ Hourly rate	Material Costs ($K)	Total Costs ($K)
Mockup Testing			
Mech. Engr. Support	200@$150/hr	50.0	50.0
Elec. Engr. Support	200@$150/hr		30.0
Instrument Tech.	120@$75/hr		9.0
Fitters	120@$80/hr		9.6
Machinist	200@$80/hr		16.0
Material Costs		40.0	40.0
Project Management and Reactor Interface (8 months)			
Project Manager	1000@$150/hr	5.0	155.0
Tech Support	120@$150/hr		18.0
Admin Support	120@$80/hr	1.5	11.1
Subtotal			1,823.3
Contingency (30%)			547.0
Safeguards & Security (3%)			71.1
DOE FAC (3%)			73.2
Total for Fabrication and Assembly			**$2,515**

Irradiation

Internal Use Only

Discipline/Task	Labor Hours @ Hourly rate	Material Costs ($K)	Total Costs ($K)
Irradiation Unit Charges			
Does Not Include IU charges			
Experiment Insertion into ATR (2 insertions)			
Reactor Operators	40@$80/hr		3.2
Craft Support	80@$80/hr		6.4
Engr. Procedures	120@$150		18.0
Engineer	80@$150/hr		12.0
Irradiation Support (12 months)			
Training Prep. for Ops	80@$90/hr		7.2
Training for Ops	100@$90/hr		9.0
ATRC Plan, Ops, & Data	200@$140/hr		28.0
Reactor Operators (1/4)	600@$80/hr		48.0
Experiment Engr. (1/4)	600@$150/hr		90.0
As-Run Analysis (both stages)			
Thermal	160@$150/hr		24.0
Physics	600@$170/hr		102.0
Project Management			
Project Manager (1/2)	1600@$150/hr	20.0	260.0
Tech Support	400@$150/hr		60.0
Admin Support	400@$80/hr		32.0
Subtotal			699.8
Contingency (10%)			70.0
Safeguards & Security (3%)			23.1
DOE FAC (3%)			23.8
Total for Irradiation			**816.7**

Handling and Packaging

Internal Use Only

Discipline/Task	Labor Hours @ Hourly rate	Material Costs ($K)	Total Costs ($K)
Canal Transfers (1transfer)			
Rx Operators	20@$80/hr		1.6
Canal Operators	30@$80/hr		2.4
Equip. Operators	40@$80/hr		3.2
RadCon Support	20@$80/hr		1.6
Procedures	120@$150/hr		18.0
Engineer	20@$150/hr		3.0
Tooling (Canal Transfer & Disassy)			
Machinist	150@$80/hr		12.0
Welders	50@$80/hr		4.0
Engineer	75@$150/hr		11.3
Canal Disassy Preparations for Shipment			
Canal Operators	90@$80/hr		7.2
RadCon Support	30@$80/hr		2.4
Canal Procedures	60@$150/hr	7.0	16.0
Engr. Support	40@$150/hr		6.0
Canal Shipments			
Canal Operators	40@$80/hr		3.2
Equipment Operators	40@$80/hr		3.2
RadCon Support	40@$80/hr		3.2
Rad Engr.	40@$150/hr		6.0
Shipper	40@$150/hr		6.0
Physics (ORIGEN)	40@$170/hr		6.8
Engr. Support	40@$150/hr		6.0
Cask & Truck Rentals	1 rental@$84.0K each	`	84.0
Project Management (6 months total)			
Project Manager (1/2)	900@$150/hr	5.0	140.0
Tech Support	100@$150/hr		15.0
Subtotal			362.1
Contingency (15%)			54.3
Safeguards & Security (3%)			12.5
DOE FAC (3%)			12.9
Total for Handle & Package			**442**