DOE-HTGR-86111
Revision 1

HTGR

FISSION PRODUCT PLATEOUT/LIFTOFF/WASHOFF TEST PLAN

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ISSUED BY GENERAL ATOMICS
FOR THE DEPARTMENT OF ENERGY
CONTRACT DE-AC03-88SF17367

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**FISSION PRODUCT
PLATEOUT/LIFTOFF/WASHOFF
TEST PLAN**

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San Diego, California 92138-5608

DOE Contract No. DE-AC03-88SF17367

GA Project 6300

MAY 1988

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PROJECT CONTROL DOCUMENT APPROVAL SUMMARY

TITLE FISSION PRODUCT PLATEOUT/LIFTOFF/WASHOFF TEST PLAN					PROJECT 6300	CODE PTS	DOCUMENT NO. PC- 000222	REV. 3
C.M. STAMP	REV.	PREPARED BY	RESOURCE/ SUPPORT APPROVAL	FUNDING PROJECT APPROVAL	APPLICABLE PROJECT APPROVAL	DESCRIPTION/ CWBS NO.
0	R. ACHARYA <i>R. Acharya</i> D. HANSON <i>D. Hanson</i> 5/19/86	<i>A. Baxter</i> A.M. BAXTER <i>R. F. Turner</i> R.F. Turner	 <i>gfb</i> G. BRAMBLETT		Initial Issue 6352100405
1	R. Acharya <i>R. Acharya</i> D. Hanson <i>D. Hanson</i> 6/24/86	<i>A. Baxter</i> A.M. Baxter 6/24/86 <i>R. F. Turner</i> R.F. Turner 6/24/86	<i>P. Connors</i> P. Connors <i>gfb</i> G. Bramblett		6216010303 GA changed to USDOE and section 4.5 revised.
2	R. Acharya <i>R. Acharya</i> D. Hanson <i>D. Hanson</i> 9/25/86	<i>A. M. Baxter</i> A.M. Baxter 9/25/86 <i>R. F. Turner</i> R.F. Turner 9/25/86	 <i>gfb</i> G. Bramblett		6216010303 Cost estimates from CEA added as Appendix
3	R. Acharya <i>R. Acharya</i> D. Hanson	<i>A. M. Baxter</i> A.M. Baxter 4/29/88 <i>R. F. Turner</i> R.F. Turner 4/29/88	<i>FSO for</i> G. Bramblett		7116012152 CEA Comments Incorporated DOE-HTGR-86111/Rev. 1		

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1. PURPOSE

A test program is planned in the COMEDIE loop of the Commissariat a l'Energy Atomique (CEA), Grenoble, France, to generate integral test data for the validation of computer codes used to predict fission product transport and core corrosion in the Modular High Temperature Gas-Cooled Reactor (MHTGR). The inpile testing will be performed by the CEA under contract from the US Department of Energy (DOE); the contract will be administered by Oak Ridge National Laboratory (ORNL). The primary purpose of this test plan is to provide an overview of the proposed program in terms of the overall scope and schedule.

The detailed test requirements for each of the planned tests will be documented in separate test specifications. The test specification for the first test (referred to as BD-1) has already been prepared. The test specification for the second test (BD-2) will be prepared after completion of the BD-1 irradiation and so forth for the final test (BD-3). In the interim, the test requirements for the BD-2 and BD-3 tests are sufficiently documented herein such that the CEA can prepare realistic cost and schedule estimates for these tests.

2. TEST OBJECTIVES

The primary objective of this test program is to obtain representative data on the release, transport, plateout, lift-off and washoff of condensible fission products in an in-pile test loop under conditions characteristic of normal operation and a spectrum of dry and wet depressurization transients. A secondary objective is to obtain representative data on fuel element corrosion by coolant impurities, primarily water, during normal operation and during large water ingress. A final objective is to obtain data on the transient thermal and fluid dynamic responses of the loop during depressurization transients. While a variety of valuable test data will be obtained, the primary emphasis is on the fission product transport aspects.

These data will then be used to validate that the MHTGR design methods used to predict fission product transport, core corrosion, and transient shear ratios have the required predictive accuracies. Typically, these design codes incorporate physical models that are derived from differential single effects tests performed in the laboratory or in inpile experiments. The purpose of these inpile loop tests is not to provide fundamental data from which such physical models may be derived but rather to provide integral test data to assess the validity of these models.

The primary objectives for the three tests can be summarized as follows:

1. To perform fission product release, transport, plateout and lift-off methods validation testing in an in-pile loop under conditions typical of normal operation and of a spectrum of depressurization transients of a MHTGR. This test will determine the lift-off fractions for key plated out fission product nuclides under nominal, dust-free conditions.
2. To obtain data on the effect of particulate matter or "dust" on fission product transport, plateout and lift-off under conditions similar to those in item 1 above.
3. To obtain data on the effect of water ingress on fission product release, transport, plateout, lift-off and/or washoff under conditions similar to those in item 2 above.

Data on fuel-element corrosion and on the transient thermal and fluid dynamic responses of the loop during depressurization transients will also be obtained in all three tests

3. JUSTIFICATION

The MHTGR design emphasizes passive safety, which includes compliance with Protective Action Guide (PAG) dose limits to preclude the

need for public sheltering or evacuation for all events with a frequency of $\geq 5 \times 10^{-7}$ /year. Use of a confinement building rather than a high-pressure containment building makes fission product liftoff and washoff during dry and wet depressurizations an issue. In the derivation of the limits on plateout activity and the corresponding fuel performance criteria for the MHTGR, it was assumed that $\leq 5\%$ liftoff of plated out fission products would occur during a rapid depressurization transient (Ref. 2) based on the available ex-situ blowdown testing and the single in-situ blowdown test data base (Ref. 3). This assumption needs to be confirmed.

For the reference MHTGR design without containment, it appears that the most constraining fuel performance requirements result from limiting the iodine plateout during normal operation in order to meet PAG dose limits during dry and wet depressurization accidents. The allowable core releases depend strongly on the assumed fractional liftoff and/or washoff, thus making validated liftoff and washoff models high-priority technology development needs (TDNs, Ref. 1). The subject inpile loop tests are required to confirm that the models to predict fission product liftoff and washoff have the required predictive accuracies.

4. TEST REQUIREMENTS

4.1 Physical Configuration

An inpile, fission product transport loop is required which can be blown down in situ through a depressurization train which collects quantitatively the condensible radionuclides carried out of the loop. The loop shall have facilities for the injection of pre-characterized particulate matter ("dust") and for the injection of steam and/or liquid water.

The three key components of the loop are a fuel element, a simulated reflector element and a heat exchanger. This discussion of the physical configuration will in general deal with only these components. The test

specifications (e.g., Ref. 4) will deal with all components of the loop in detail.

As a minimum, the fuel element shall represent a unit cell of an HTGR prismatic fuel element and shall contain LEU UCO/ThO₂ TRISO fuel particles in bonded fuel rods. The fuel element must have a known fission product source; consequently, selected fuel rods shall be seeded with a specified number of "designed-to-fail" UCO particles (standard UCO kernels with a thin pyrocarbon seal coat), and the matrix of selected rods shall be doped with Sr-84 in order to produce gamma-emitting Sr-85 by neutron activation (the latter is easier to measure than the beta-emitting fission products Sr-89 and Sr-90.)

The reflector element is required to obtain data on fission product deposition on core structural graphite and shall represent a unit cell of a replaceable reflector element in the MHTGR.

The heat exchanger design is more flexible. The primary requirements are that two materials of construction be used in the heat exchanger, that the flow characteristics be turbulent, and that the surface temperatures span the range of 300 °C to 700 °C. The heat exchanger shall also consist of two or more parallel tube bundles, and it shall be possible to remotely isolate one or more of these bundles prior to the in situ depressurizations in order to preserve the initial plateout distribution that prevailed prior to blowdown.

Instrumentation in the inpile loop shall be provided to measure specified operating parameters, including the operating temperatures in the graphite fuel body, the reflector and the heat exchanger. The instrumentation shall also include devices for the measurement of the helium impurity levels, for the injection and control of moisture levels, for the measurement of circulating noble gas activity, and for the measurement of the amount of circulating dust and condensible fission products (e.g., plateout probes).

4.1.1 Materials of Construction

reflector elements shall be manufactured from reference H-451 graphite. The two primary alloys used in the steam generators of the MHTGR are Alloy 800H and 2 1/4% Cr and 1% Mo low alloy steel. The heat exchanger in the loop shall contain tubing made from these alloys manufactured under material specifications ASME SA-213 for alloy T-22 and ASME SB-407 for alloy 800H (or French equivalent alloys provided they meet the applicable ASME specifications.)

4.1.2 Fabrication of Components

The fabrication of components for the test program will be a joint effort by General Atomics (GA) and CEA, the operators of the inpile loop facility. GA shall design and manufacture the fuel particles and the fuel elements; the heavy-metal loadings will be specified by CEA. CEA will be responsible for the design and manufacture of the heat exchangers from materials of construction and operating conditions specified by DOE. All the other loop components will be the responsibility of CEA.

4.1.3 Loop Assembly

Loop assembly and operation will be performed by CEA under contract to the USDOE.

4.2 Pre-operational Characterization

Pre-operational characterization will be an important activity in this test program. The fuel element, the designed-to-fail particles and the heat exchangers shall be carefully characterized. The fuel rods and fuel compacts shall be characterized by the standard battery of pre-irradiation measurements used for irradiation-capsule fuel. The free uranium in the unseeded fuel rods shall be measured. The amount of Sr-84 dopant in the matrix of selected fuel rods shall also be measured. The heat exchanger tubing shall also be subject to detailed character-

ization, inclusive of chemical composition and surface condition. Characterization shall include measurements of surface state, surface roughness and cleanliness prior to installation in the loop.

4.3 Operating Conditions

The loop operating conditions shall simulate the normal operation of the MHTGR. These conditions are described below.

4.3.1 Steady State Operation

The steady-state loop operating conditions which must be achieved are given below. These conditions largely envelop those in the MHTGR during normal operation.

Normal Operation (Initial Conditions prior to Blowdown)

Reactor Coolant	Helium
Thermal Neutron Flux	$> [10^{17}]^* \text{ n/m}^2\text{-sec}$
Fuel Temperature	$[1000 - 1250 \text{ }^\circ\text{C}]$
Graphite Temperature	$[900 - 1200 \text{ }^\circ\text{C}]$
Duration of Steady State Operation	$\geq 3 \text{ months}$
Primary Coolant Temperature Range	$300 \text{ to } 700 \text{ }^\circ\text{C}$
Heat Exchanger Surface Temperature Range	$300 \text{ to } 600 \text{ }^\circ\text{C}$
Primary Coolant Pressure	$\geq [10] \text{ atm}$
Reynolds Number (in Heat Exchanger)	≥ 5000
Coolant Impurities	$[126] \text{ } \mu\text{atm H}_2\text{O}$
	$[315] \text{ } \mu\text{atm CO}$
	$[126] \text{ } \mu\text{atm CO}_2$
	Total Oxidants $< [630] \text{ } \mu\text{atm}$
	$[630] \text{ } \mu\text{atm H}_2$
Surface Loading (in Heat Exchanger)	
Cs-137	$\geq 10^{-7} \text{ Ci/cm}^2$
I-131	$\geq 10^{-7} \text{ Ci/cm}^2$

Dust Characteristics (Tests #2 & #3 only)

Composition	[ferritic metal oxide, graphite]
Particle Size Distribution	[0.1 - 10 x 10 ⁻⁶] m
Gasborne Concentration	[3 x 10 ⁻³] g/m ³
Surface Loading	[5] g/m ²

* The square brackets [] indicate that the enclosed values are the current best estimates but are subject to revision.

The core inlet temperature in the MHTGR is ~300 °C, and the outlet temperature is ~700°C. The majority of the condensible fission products are expected to plateout at the low temperature end of the heat exchanger because of the large available surface area associated with the low temperature. The primary coolant helium during normal operation will contain less than 630 μ atm of total oxidants, which includes H₂O, CO and CO₂.

It will be impractical to obtain full burnup of the fuel in the inpile test loop since the loop is located in the reflector location of the Siloe' reactor. Consequently, the fuel will be seeded with sufficient "designed-to-fail" particles, such that enough fission products can be released in a reasonable period of time for integral releases and plateout loadings in the heat exchanger to be representative of the MHTGR (Ref. 7). In this sense, the test program is an accelerated one. Accelerated testing is judged acceptable when the real-time testing is prohibitively expensive. It is assumed that the experiment can be designed such that steady state irradiation can be completed with a minimum irradiation time of three months.

4.3.2 Depressurization Transients

A spectrum of possible depressurization transients has been identified for the MHTGR plant. These depressurization transients can be effectively enveloped by blowdown tests with different shear ratios (the ratio of the wall shear stress during the blowdown to that during

normal operation). The range of shear ratios chosen for the test program will envelop all the depressurization transients identified for the MHTGR. Details of the blowdown tests for the BD-1 test are documented in the test specification (Ref. 4). A preliminary test envelope is given below.

4.3.2.1 Blowdown Under Dry Conditions

Environment	Helium
Blowdown Duration	[1 to 10] min
Shear Ratios	0.5, 1.0, 2.0, 3.0
Initial Reynolds Number	> 5000
Pressure Range	> [10] to 1 atm
Initial Coolant Temperature Range	300 to 700 °C
Coolant Impurity Levels	[126] μ atm H ₂ O [315] μ atm CO [126] μ atm CO ₂ [630] μ atm H ₂ <630 μ atm total oxidants

4.3.2.2 Blowdown Under Wet Conditions

Environment	Helium
Blowdown Duration	[1 to 10] mins
Shear Ratio Range during Test	< [1]
Reynolds Number (Initial)	> 5000

Pressure Range	> [10] to 1 atm
Coolant Temperature Range	300 to 700 °C
Coolant Impurity Levels	[10%] by Volume of H ₂ O
	[TBD] CO
	[TBD] CO ₂
	[TBD] H ₂

4.4 Post-Irradiation Examination

The following is a preliminary set of postirradiation examination (PIE) requirements.

4.4.1 Fuel Element

1. Weight and metrology of the fuel element. These measurements will be compared to pre-irradiation measurements, to determine the extent of oxidation of the graphite block.
2. Axial profile of the gamma activity of the fuel element. This will provide the axial power profile in the fuel element.
3. Fission product activity profiles in the graphite web between the fuel rod and the coolant channel at at least [5] different locations with at least [5] radial measurements per profile. This data will provide information on the transport of fission products in fuel element graphite.
4. The strontium profile, i.e., beta activity, will also be measured in the web portion of the block at at least [3] locations with at least [5] radial measurements per profile.
5. Each stack of fuel rods will be gamma scanned for obtaining the power profile in the fuel element block.

6. Density profiles in the graphite web between the fuel rod and the coolant channel at at least [5] different locations. This data will provide an indication of the burnoff profile in fuel element graphite.
7. Burnup measurements will be performed on deconsolidated fuel particles.
8. Fission products in the matrix material will be measured to obtain an overall mass balance and to determine the partition coefficients for fission metals at the fuel rod/graphite block interface.

4.4.2 Reflector Element

1. Weight and metrology of the reflector block for comparison to the pre-irradiation measurements.
2. Axial and radial profiles of fission product activity in the reflector element; the latter shall be taken at a minimum of [3] different locations with at least [5] radial measurements per profile.
3. Density profiles in the graphite web between adjacent coolant channels at a minimum of [3] different locations with at least [5] radial measurements per profile. These data will provide an indication of the burnoff profile in the reflector graphite.

4.4.3 Heat Exchanger

The following shall be the minimum PIE requirements on the tubes from each of the multiple heat exchanger tube bundles.

1. Axial profiles of gamma activity along the lengths of the tubes.

2. Sr-89 and Sr-90 specific activities of selected tubes (≥ 2 tubes per tube bundle) at the entrance, middle and exit of the heat exchanger.
3. Total fission product loading on the tubes.
4. Fission product penetration profiles into selected tubes (≥ 2 tubes per tube bundle) at the entrance, middle and exit of the heat exchanger.
5. Characterization of the surface state of the tubes prior to and after irradiation, in particular the amount and nature of surface films or deposits.

4.5 Quality Assurance Requirements

The data generated by this test program will be used by GA in the final design and licensing of safety-related equipment and therefore shall be obtained under conditions that fully satisfy the requirements of 10CFR50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants" as follows:

1. CEA shall have a formal QA program that complies with the intent of 10CFR50, Appendix B.
2. Work shall be performed to GA Test Specifications which will invoke applicable requirements of 10CFR50, Appendix B.
3. Test procedures shall be prepared by CEA and shall be accepted by USDOE.
4. A USDOE representative shall witness selected key operations and tests and shall review the related test program activities as stipulated in the test specification.

5. USDOE shall receive all data and test reports and shall perform an independent evaluation of the test results.
6. CEA shall be audited by a USDOE representative at the onset of the test program and annually thereafter to assure that the implemented quality assurance program complies with the intent of 10CFR50, Appendix B.

5. DESCRIPTION OF CEA COMEDIE LOOP AND CAPABILITIES

A description of the CEA COMEDIE loop and the planned test program follows.

5.1 Physical Configuration

The CEA COMEDIE loop is an inpile test facility in the SILOE' materials test reactor in Grenoble, France. This loop was designed with the specific goal of characterizing the release, transport, deposition and liftoff of fission products in HTGRs during normal operation and during rapid depressurization transients. The loop is capable of providing engineering-scale, integral test data under realistic reactor operating conditions to validate the methodology used to predict MHTGR source terms.

The loop consists of an in-pile section and an out-of-pile section as shown the sketches in Figures 1 and 2. The in-pile section includes a fuel element which is the source of fission products and also produces nuclear heating to operate the loop components at the desired temperatures. In any future test, the fuel element would be very similar to the SR fuel elements (Ref. 5) shown in Figure 3. The fuel element would contain fuel rods and would be designed to simulate a unit cell of the prismatic fuel block of the modular reactor core.

Immediately downstream of the fuel element, a graphite reflector element would be placed to determine the deposition of condensible fission products on core structural graphite. This graphite block,

which has essentially the same exterior dimensions and internal coolant holes as the fuel element, would represent a replaceable reflector block in the MHTGR. The graphite block is followed by a plateout section where condensible fission products are deposited. The plateout section is a straight tube, counter-flow, gas-to-gas heat exchanger/recuperator simulating the steam generator and the other metallic components (hot duct, etc.) in the primary circuit of the MHTGR.

Downstream of the plateout section is a full-flow filter to trap condensible radionuclides, including iodines, and any circulating particulate matter. This filter would facilitate the operation under "clean" conditions during the first test, but it would have to be eliminated for the second and third tests wherein dust will be deliberately added. The loop also includes an in-pile electrical heater to control the temperature of the gas to the inlet of the in-pile section.

The out-of-pile section contains additional filters, a helium cooler, a blower and facilities for gas analysis, gas purification and injection of desired impurities. The loop is designed with four gas sampling points to make it possible to analyze the noble fission gas release and impurity levels in the helium coolant. The instrumentation of the loop provides for measurement of temperature, gas flow rate, gas pressure and analysis of noble fission gases. Analysis of noble fission gases would provide a measure of the time-dependent, fission product release during the steady-state part of the irradiation during which a typical plateout profile would be established prior to the blowdown tests.

5.2 Operational Capabilities

The main loop characteristics, as designed for the SR test program (Ref. 5), are given below.

Fuel Element Thermal Power

30 kW

Operating Pressure Range	20 to 70 atms
Useful Diameter for Fuel Element	70 mm
Helium Mass Flow Rate	16 to 45 g/sec
Fuel Surface Temperature	800 to 1100 °C
Re Number (in SR heat exchanger)	< 6000
Plateout Section Length	2800 mm
Heat Exchanger Inlet Temperature	850 °C

5.3 Operating Experience

A series of five loop tests, referred to as the SR program (Ref. 5) were planned in this facility under the former GA/CEA Accord. The first two tests were completed, prior to the termination CEA HTR program in 1978. The first test in the series SR0 was a cold, unfueled shakedown test to determine the operating characteristics and capabilities of the loop. The second test SR was a hot, fueled shakedown test. The third test SR2 was to be a benchmark test under nominal HTGR operating conditions to provide reference data. The fourth test, SR3, would have included a series of in-situ loop blowdowns to determine the extent of fission product liftoff at various shear ratios. The fifth test would have repeated the fourth test with a pre-characterized aerosol continuously added to the loop during operation to determine the effect of dust on fission product liftoff.

Two experiments have been completed in the COMEDIE loop. These tests have demonstrated the operational reliability of the loop. In addition, the procedures for rapid loop disassembly and measurement of the deposition profiles of various fission products (Ag-110m, I-131, Cs-134 and Cs-137) was demonstrated. The filter efficiency was determined to be high, such that a good fission product mass balance

could be established. Overall, the operating experience with the COMEDIE loop has been good, increasing the confidence that high quality experimental data would be obtained from any future test program.

5.4 Current Status

After the termination of the French HTR program in 1978, the COMEDIE loop was mothballed. In 1987, the CEA began to refurbish the loop under a \$100K contract from ORNL in preparation for subject test program. The status of the loop as of February, 1988, is discussed in Ref 6.

6. DESCRIPTION OF PROPOSED COMEDIE LOOP TESTS

Three inpile tests in the CEA COMEDIE loop are planned to satisfy the fission product plateout, liftoff and washoff TDNs described in Section 2.2:

- 1) The first test is designed to measure liftoff under nominally clean conditions. Fission products would be plated out in the heat exchanger during the steady-state operation to represent typical MHTGR conditions. The loop would be operated with $< [630] \mu\text{atm}$ total oxidants and essentially free of circulating dust. After a four month irradiation, one of the three heat exchanger tube bundles would be isolated prior to blowdown testing. Then the remaining two tube bundles and the rest of the loop would be subjected to a series of in-situ blowdowns at shear ratios ranging from 0.5 to 3.0 in predetermined steps. This test would provide the base case data on the liftoff of fission products.
- 2) The second test is designed to determine the effect of dust on fission product plateout under normal operation and liftoff during blowdown conditions. The loop operation and blowdown tests would be essentially identical to the first test, except for the continuous introduction of a quantity of pre-characterized dust into the coolant during the irradiation.

- 3) The third test would emphasize the effect of moisture on fission product transport in the primary circuit and the extent of washoff. The operation of the loop would be similar to the second test, but water would be injected into the loop prior to blowdown being performed. Initially, steam would be injected and the gas temperatures would be maintained sufficiently high to prevent condensation. The loop would be depressurized through the sampling train and the amount of steam scrubbing would be determined.

Next a slug of water would be injected to simulate a major water ingress. Further analysis is required to specify the quantity of water to be injected, but it would be sufficient to produce a significant quantity of liquid water within the loop. After a specified contact time, the liquid water in the loop would be sampled for radiochemical analysis, and then the loop would be subjected to a series of in-situ blowdowns at shear ratios ranging up to [1.0] in predetermined steps, and the quantity of radionuclides released from the loop would be determined. A vapor-liquid separator would be included in the depressurization train to determine partitioning of the condensible radionuclides between the liquid water and the gas.

While the current intention is perform the water ingress test (BD-3) last, the overall test sequence will be reviewed upon completion of the first test. Based upon the probabilistic risk assessments that have been performed for the MHTGR, events involving water ingress plus pressure relief are currently perceived to dominate the MHTGR safety risk. Therefore, there is considerable interest in obtaining relevant test data as early as practical which implies that the BD-3 should perhaps be the second test. However, the planned BD-3 test is the most complex and also poses the greatest risk for damaging loop components, such as the circulator, which argues for performing it last.

6.1 Test Data to be Determined

The primary test data are the liftoff and washoff fractions for various nuclides for the various blowdown conditions as defined by a range of shear ratios. The list below details the experimental data that can be expected from this program.

- 1) Plateout distributions of key fission products nuclides - I-131, Sr-90 (and Sr-85), Cs-137, Cs-134, and Ag-110m - under normal operating conditions typical of the MHTGR. These plateout distributions will be a function of the heat exchanger materials, surface condition and temperature distribution. These plateout distributions are the initial condition for the liftoff and washoff tests which follow the normal operation phase of the experiment.
- 2) Liftoff fractions for the above fission products as a function of shear ratio. Shear ratios in the range of 0.5 to 3.0 will be used in the test program, representing a spectrum of possible rapid depressurization transients in the MHTGR.
- 3) The effect of recirculating dust on the plateout and liftoff of key fission product nuclides. Once again, the liftoff tests will be performed at various shear ratios representing a spectrum of rapid depressurization transients.
- 4) The effect of steam and of liquid water ingress on the plateout and reentrainment of key fission product nuclides.
- 5) Fuel element corrosion as a result of trace coolant impurities from the BD-1 and BD-2 tests, and fuel-element corrosion as a result of large water ingress from the BD-3 test.
- 6) The transient thermal and fluid dynamic responses of the loop during the series of depressurizations performed at the end of each of the three tests.

Although a complete discussion of the test methods is beyond the scope of this test plan, a short summary is given below. This description will provide an overview of the tasks involved.

The test methods to be used are similar to those used in the earlier SR series of tests (Ref. 5) in the inpile loop. The test fuel element will contain prototypic fuel rods with LEU UCO TRISO particles, seeded with a predetermined number of "designed to fail" fuel particles. These "designed-to-fail" particles will be UCO kernels coated with a single, thin, pyrolytic carbon coating, which will fail early in the irradiation. These designed-to-fail particles will provide a nearly constant source of fission products (with the exception of the neutron activation products Ag-110m and Sr-85) for release into the coolant during the normal operation and thus deposit on the heat exchanger tubing surface.

Determination of the strontium activity in the fuel and heat exchanger is typically expensive, because the two isotopes of highest abundance, Sr-90 and Sr-89, are beta emitters requiring costly destructive sampling and measurement techniques. Strontium release and plateout measurements can be obtained more easily by doping the matrix of selected fuel rods with Sr-84, which activates to Sr-85 under neutron irradiation, the latter is an easily measured gamma emitting isotope.

The test fuel element will be irradiated in the inpile loop at nearly constant thermal power at specified operating temperatures for a predetermined time such that typical fission product plateout profiles are established in the heat exchanger (Computer analysis with transient diffusion codes are planned to select the optimal time-temperature combination to give the required fission product release). The inlet gas temperature of the helium coolant will be controlled with the auxiliary electrical heater to maintain constant operating conditions. The irradiation will be continued until sufficient amounts of key fission products are released from the fuel and deposited in the heat exchanger. The planned irradiation schedule for each test will consist of four reactor cycles, with each cycle of 21 days of operation followed by

eight days of shutdown in the SILOE' reactor. The release of fission gases will be monitored continuously, and the release of condensible fission products will be measured periodically with plateout probes specifically designed for that purpose.

After the irradiation, one of the three tube bundles of the heat exchanger will be isolated, and the remainder of the loop subjected to a series of in-situ blowdown tests at increasing shear ratios and the resulting fission product liftoff will be measured as outlined above.

The impurity concentration in the helium gas determines the oxidation potential of the gas which in turn determines the surface state of the heat exchanger tubes. The surface state of the metal components is expected have a significant impact on the plateout behavior of fission products. The normal operation phase of the experiment will include maintenance of the required helium coolant chemical composition. The loop includes instrumentation for measuring gas composition, i.e., concentration of H_2 , H_2O , CO , CO_2 and CH_4 . During the irradiation, the total oxidants must be $< 630 \mu atm$ to represent the normal operation of the MHTGR. The desired concentrations of the impurities will be maintained by using the helium purification system and the impurity injection system.

To obtain information on the effect of dust, predefined dust, i.e., particles of iron oxide and graphite will need to be injected into the loop. Appropriate instrumentation (e.g., cascade impactors) will be used to measure the amount and size distribution of the circulating dust during the irradiation.

6.2 Materials of Interest

The following reactor internal materials are included in the test program. These materials are used in the construction of the core, steam generator and other components of the reactor, where significant fission product plateout is anticipated during normal operation.

- 1) UCO/ThO₂ TRISO Particles and "designed to fail" UCO particles in Fuel Rods
- 2) H-451 Graphite
- 3) Alloy 800H
- 4) 2 1/4% Cr, 1% Mo low-alloy steel (ASTM T22)

6.3 Operating Conditions and Limitations

6.4 Loop Refurbishment

Some work will be involved in bringing the loop from its present mothballed state to operational state, and this refurbishment activity is already in progress (Ref. 6). This reactivation process would require a final mock-up test, i.e., a test run without fuel in the loop to qualify the design for isolating the tube in the heat exchanger prior to blowdown.

7. RANGES AND POINTS OF MEASUREMENT

During the performance of the test, a number of variables need to be measured and controlled. The primary variables of interest during the steady state operation are:

1. Fuel element power
2. Fuel element maximum temperature
3. Helium coolant flow rate
4. Coolant temperatures around the loop
5. Fission gas release rate/birth rate (R/B)
6. Coolant impurity concentrations, i.e., H₂O, CO, CO₂, CH₄ and H₂
7. Neutron flux
8. Plateout section flow rate
9. Plateout section temperature profiles
10. Concentration of dust in the coolant

8. CEA SCOPE OF SUPPLY

The CEA scope of supply will include the COMEDIE loop in the SILOE' reactor in Grenoble, France, and all the needed support facilities and staff. GA will fabricate the fuel element and reflector element and supply the materials of construction for the heat exchanger. CEA will design and fabricate the other loop components. The irradiation effort would be the responsibility of CEA under contract to ORNL. All operational measurements including thermal-hydraulic measurements, helium impurities levels (both measurement and control within specifications), neutron fluxes, fluence measurements, and fission gas R/B measurements would be performed by the CEA.

Radioactivity measurements to obtain the fission product plateout profiles, liftoff measurements during the blowdown testing along with initial data collection and data reduction and analysis would be performed by the CEA. The CEA would perform the complete PIE of the graphite reflector block, the heat exchanger, the full-flow filer, and the other metallic components of the loop. Initial metrology and gamma scanning of the fuel element would be performed by the CEA, but the fuel element would then be shipped intact to ORNL for the detailed destructive examination of the fuel particles and the graphite fuel body.

The progress of the test program would be carefully monitored by DOE and its contractors from inception to completion. The intention would be to have a DOE representative on site in Grenoble during the critical testing periods, particularly during the in situ blowdown tests.

9. SCHEDULE AND MILESTONES

A preliminary schedule with appropriate milestones for the planned USDOE-sponsored test program in the COMEDIE loop is given below. This schedule assumes an initial period to refurbish the loop and to perform preliminary mock-up tests or experiments, to be followed by three in-pile tests. The first test is designed to measure liftoff under

nominally clean conditions, and the second test is designed for determination of the effect of dust. The third and final test will emphasize on the effects of moisture or the washoff measurements. A significant amount of post irradiation examination (PIE) is planned in support of the plateout and liftoff measurements. The PIE milestones are also included in the schedule.

The progress of the test will be carefully monitored; inspection of the schedule indicates that the test specification for test BD-2 would not be issued until the essential results from test BD-1 were available and similarly for test BD-3.

SCHEDULE AND MILESTONES

<u>Task</u>	<u>Resp Org.</u>	<u>Date</u>
Issue Test Plan	GA	6/86
Issue Cost Estimate	CEA	8/86
Issue Draft Test Specification for Test BD-1	GA	9/87
Commitment to Proceed with Tests	DOE	12/87
Issue Final Test Specification for Test BD-1	DOE	9/88
Complete Loop Refurbishment & Mockup Tests for Test BD-1	CEA	8/89
Complete Test BD-1:		
Irradiation & In Situ Blowdowns	CEA	12/89
Preliminary PIE	CEA	4/90
Final PIE	CEA	12/90
Issue Test Specification for Test BD-2	DOE	1/90
Complete Test BD-2:		
Irradiation & In Situ Blowdowns	CEA	12/90
Preliminary PIE	CEA	3/91
Final PIE	CEA	12/91
Issue Test Specification for Test BD-3	DOE	1/91

Complete Test BD-3:

Irradiation & In Situ Blowdowns	CEA	12/91
Preliminary PIE	CEA	3/92
Final PIE	CEA	12/92

Issue Final Report	DOE	6/93
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10. COST ESTIMATE

The cost estimate for the CEA part of the test program is given in Ref 8. CEA has agreed to provide the neutrons free of charge. The total cost for the CEA part of the program is estimated to be 31,440,000 French Francs, as of August 1986 and is subject to updating during the course of the test according to a formula to be drawnup between USDOE and CEA. The detailed cost estimate provided by CEA (Ref. 8) is attached as Appendix.

11. REFERENCES

1. Fuel/Fission Product Technology Development Plan, Document No. HTGR-86-027/Rev. 1, April 1987.
2. "Functional Analysis Report," HTGR-86-002/Rev. 3, January 1988.
3. Downey, K. W., "Summary of Fission Product Liftoff Data Base," GA Document 908332/0, September 27, 1985.
4. Acharya, R. T., "Specification for COMEDIE Test BD-1," GA Document No DOE-HTGR-87095, Revision 1, April 1988.
5. Strong, D., "Summary of SR Experiments in COMEDIE Loop," GA Document Number 904151/1, Dec 4, 1980.
6. Millunzi, A. C., and J. C. Mailen, "Report of Foreign Travel February 19-25, 1988, to France," ORNL/FTR-2815, March 10, 1988.
7. Acharya, R. T., "Fission Product Plateout Analysis for 350 MW(t) MHTGR," GA Document No 908817/0, June 1986.
8. Letter, Veyrat, J. F., and M. Blanchard, to A. J. Neylan, "Cost and Schedule of the Proposed GA Test plan in COMEDIE Loop," P1/SEDII/619/86, September 3, 1986.

FIG. 1

GENERAL LOOP LAY-OUT

FIG: 2
HELIUM LOOP COMEDIE
IN PILE SECTION

FIGURE 3
CROSS SECTION OF SR EXPERIMENT TEST SECTION

APPENDIX

CEA COST AND SCHEDULE OF THE PROPOSED GA TEST PLAN IN COMEDIE LOOP

RÉPUBLIQUE FRANÇAISE
COMMISSARIAT A L'ÉNERGIE ATOMIQUE

Pc-000222/3

CENTRE D'ÉTUDES NUCLÉAIRES DE GRENOBLE

AVENUE DES MARTYRS - 38 - GRENOBLE

ADRESSER LA CORRESPONDANCE :

TÉL. 76.88.44.00

85 X

38041 GRENOBLE CEDEX

TÉLEX : ENERGAT GRENO N° 320.323

M. J.F. VEYRAT
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GRENOBLE, LE September 3, 1986

RÉFÉRENCE A RAPPELER :

PI/SEDTI/619/86

VOTRE RÉP.

VOTRE LETTRE DU

Y/Ref : GA/M 052-86

Project 7700 - June 24, 1986

SUBJECT : COST AND SCHEDULE OF THE PROPOSED GA TEST PLAN IN COMEDIE LOOP

Dear Mr. NEYLAN,

We thank you for your letter referenced above requesting us for a cost evaluation and schedule of the in-pile test plan to be run for GA Technologies in the COMEDIE loop, in the SILOE reactor in Grenoble.

We also duly received the order from GA Technologies enabling us to draw up this evaluation under the most satisfactory conditions.

We are therefore enclosing the following documents in reply to your enquiry :

1) A document setting out the comments arising from the technical specifications of your test plan.

2) A schedule of the proposed test plan.

3) A cost estimate.

In this respect, we confirm that the CEA, on account of the importance of the test plan scheduled by GAT, is proposing to supply the neutrons free of charge. We would furthermore point out that the overall amount of the estimate is in full accordance with the cost forecasts which have been supplied to GAT since 1979.

We hope that these documents will contribute to a positive decision to carry this test plan out being taken in October 1986.

We look forward to hearing from you, and remain at your disposal for any further information you may require.

Sincerely yours

DOE-HTGR-86111/Rev. 1

J.F. VEYRAT

R. BLANCHARD

COST OF CARRYING OUT THE GAT TEST PLAN IN THE COMEDIE LOOP -----

GENERAL:

1) The prices given hereafter are in French Francs, as of August 1986. They will be updated during the course of the test plan according to a formula to be drawn up.

2) The CEA is supplying the neutrons for the plan free of charge.

A) Recommissioning the loop and the associated analysis means. 1 000 000 F

B) Study and tests.

B.1. Depressurization system including 700 000 F

producing a test model and making the corresponding loop modifications

B.2. Dust injection system including 700 000 F

fitting the dust injection system for the loop

C) Characterization study including 500 000 F

irradiation of fuel samples in capsule,
analysis of the gases and gamma spectrometry
examinations of the fuel giving the power

D) Lift-off experiment in nominal conditions 3 950 000 F

D.1.

- supply of COMEDIE loop loading except for the fuel
- supply of the deposit section except for the tubes
- supply of the filter adapted to a depressurization test
- unloading the fuel in the SILOE hot cell after irradiation and its transfer to the analysis cells
- data acquisition and experiment reports
- availability of the loop for 1 adjustment cycle + 3 irradiation cycles followed by a depressurization test
- neutron flux and gamma heating measurements during irradiation

D.2. Gamma spectrometry examinations

in situ on the in-pile filter at the end of each irradiation cycle for a measurement set of 3 spectra, 280 000

D.3. Fission gas analysis 1 050 000

During one adjustment cycle + 3 irradiation cycles, data acquisition and scientific interpretation of the data

D.4. Post-irradiation examinations 1 700 000

(see details

E) Lift-off experiment with dust and fission products

E.1. See D1 3 950 000

For the depressurization test, a single SR value possible

E.2. See D2 280 000

E.3. See D3 1 050 000

E.4. See D4 1 700 000

F) Lift-off experiment with water vapor injection and fission products

F.1. See D1 3 950 000

For the depressurization test, a single SR value possible

F.2. See D2 280 000

F.3. See D3 1 050 000

F.4. See D4 1 700 000

G) Progress reports and other files writing 2 500 000

Total cost of the plan 26 340 000

Post-irradiation examinations1. Fuel element

in accordance with GAT/PC-000222/1/page 12 4.4.1.7. excluded

2. Graphite

in accordance with GAT/PC-000222/1/page 13

3. Deposit section - Exchanger

in accordance with GAT/PC-000222/1/page 13

4. Filter

Dismantling in hot cell, gamma spectrometry on the filter

Total cost of post-irradiation examinations per experiment 1 700 000

TECHNICAL COMMENTS ON GA DOCUMENT REFERENCE PC 000222, REV 01. HEAT EXCHANGER

1.1. The measured capability of the COMEDIE heat exchanger is the following :

SILOE	running	reactor	scramed
loop pressure (bar)	60		35
inlet gas temperature (°C)	700		60
Outlet " (°C)	350		60
bundle number	3		3
tubes bundle	7		7
tubes inner diameter (mm)	8		8
He speed inside tubes (m/s)	8.7		7
Re number	6880		13090

Comments : To avoid disturbances of the gas composition after the SILOE scram, we don't realise adding or reducing of the gas. It's why the loop pressure is reduced from 60 to 35 bar.

The measured inlet temperature under irradiation corresponds to a graphite temperature of 900°C and a flow of 9.15 l/s. It is the maximum flow realised with a blower speed of 9000 r/min.

1.2. Estimated capability of the heat exchanger under irradiation with a bundle of 7 or 4 tubes.

tubes/bundle	7	4
loop pressure (bars)	60	60
inlet gas temperature (°C)	700	700
outlet " " "	350	350
bundle number	3	3
tube inner diameter (mm)	8	10.3
He speed (m/s)	8.7	9.15
Re number	6880	9320

The benefit of reducing the tubes number is to increase the Re number.

2. BLOWDOWN UNDER DRY CONDITION

One of simple possibilities is to use only one bundle to realise one blow down condition. Consequently the maximum realisable blow downs is two, the third bundle being kept as representative of the initial conditions.

In this case the maximum SR values realised in the bundle on line is :

tube/bundle	7	4
loop pressure (bars)	35	35
gas temperature (°C)	60	60
tube inner diameter (mm)	8	10.3
He speed (m/s)	7	7.4
Re number	13090	17820
SR	6.8	6.8

It's possible to reduce the shear ratio by reducing the He speed inside the on line bundle inside the range of 0.5 to 3.0

In our case a cartridge filter will be located on the outlet of every bundle. It seems impossible to replace the cartridge filter between two blow down.

3. POST IRRADIATION EXAMINATION

The burnup measurements can not be performed on deconsolidated fuel particles inside the CEN Grenoble hot cells.

PRELIMINARY SCHEDULE AND MILESTONES

<u>Task</u>	<u>Resp.Org.</u>	<u>Date</u>
Issue Test Plan	GA	6/86
Let \$ 10K Contract to CEA for Detailed Cost Estimate	GA	6/86
Issue Cost Estimate	CEA	8/86
Issue Draft Test Specification for Test # 1	GA	9/86
Formal Commitment to Proceed with tests	DOE	10/86
Issue Final Test Specification for Test # 1	DOE	9/86
Complete Loop Refurbishment & Mockup Tests for Test # 1	CEA	12/87
Complete Test # 1 :		
Irradiation & In Situ Blowdowns	CEA	9/88
Preliminary PIE	CEA	12/88
Final PIE	CEA	9/89
Issue Test Specification for Test # 2	DOE	10/88
Complete Test # 2 :		
Irradiation & In Situ Blowdowns	CEA	9/89
Preliminary PIE	CEA	12/89
Final PIE	CEA	9/90
Issue Test Specification for Test # 3	DOE	10/89
Complete Test # 3 :		
Irradiation & In Situ Blowdowns	CEA	9/90
Preliminary PIE	CEA	12/90
Final PIE	CEA	9/91
Issue Final Report	DOE	3/92

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