MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0366334 6

ornl

ORNL/NPR-91/25

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Core Conduction Cooldown Test Facility Shakedown Tests

OAK RIDGE NATIONAL LABORATORY
CENTRAL RESEARCH LIBRARY
CIRCULATION SECTION
4500N ROOM 175
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this report, send in name with report and the library will arrange a loan.
UCN-7969 (3 9-77)

R. N. Morris
J. L. Collins
W. A. Gabbard
J. C. Whitson

[redacted]

[redacted]

Approved for public release.
David R. Hamrin 6/17/2011

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401, FTS 626-8401.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/NPR-91/25

Metals and Ceramics Division

CORE CONDUCTION COOLDOWN TEST FACILITY SHAKEDOWN TESTS

R. N. Morris, J. L. Collins, W. A. Gabbard, and J. C. Whitson

Date Published—May 1992

[redacted]

Prepared for the
New Production Reactors Department
EG&G Idaho
under funding from DOE
62 70 35 20 1

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES

3 4456 0366334 6

TABLE OF CONTENTS

Page

LIST OF FIGURES v

LIST OF TABLE v

ABSTRACT 1

1. PURPOSE AND SCOPE 1

2. INTRODUCTION 1

   2.1 EXPERIMENTAL CONFIGURATION 3

3. RESULTS OF THE TESTING 4

   3.1 PHASE 1: FURNACE DURATION TEST IN THE HOT CELL WITH COLD FINGER 4
   3.2 PHASE 2: CESIUM TRACER TEST 6
   3.3 PHASE 3: FUEL LOADING/UNLOADING AND DEPOSITION CUP HANDLING 12
   3.4 PHASE 4: COLD TRAP AND RGA TEST 14
   3.5 PHASE 5: KRYPTON TEST AND COLD TRAP DETECTOR CALIBRATION 17

4. ADDITIONAL ITEMS 26

5. SUMMARY 26

6. ACKNOWLEDGMENTS 27

7. REFERENCE 27

LIST OF FIGURES

Figure		Page
1	Furnace temperature during one-day test	5
2	Lower furnace geometry for cesium tracer test	7
3	Total cesium mass balance for cesium tracer test	9
4	Released cesium location	9
5	Relative activity along fuel holder	10
6	Relative activity along fuel holder support	10
7	Relative activity along tantalum liner	11
8	Furnace temperature history for cesium tracer test	13
9	Effect of krypton migration on detected activity as a function of temperature	19
10	Furnace temperature during third krypton test	21
11	Trap 1 temperature and ratemeter 1 output during third krypton test	21
12	Trap 2 temperature and ratemeter 2 output during third krypton test	22
13	Flow history for third krypton test	22
14	Flow history for fourth krypton test	23
15	Trap 1 temperature and ratemeter output for fourth krypton test	23
16	Detected trap inventory as a function of time for the fifth krypton test	25

LIST OF TABLE

1	Freezing point of gases of interest for the CCCTF trap system	17

CORE CONDUCTION COOLDOWN TEST FACILITY SHAKEDOWN TESTS*

R. N. Morris, J. L. Collins†, W. A. Gabbard, and J. C. Whitson

ABSTRACT

This report describes the tests and the results of the tests used to determine the readiness and likely performance of the Core Conduction Cooldown Test Facility (CCCTF) in its upcoming series of fuel heating experiments. In general, the system performed as expected and demonstrated its ability to heat test samples and collect fission products. Both the furnace and the trap system have been operated for significant periods of time with good results.

1. PURPOSE AND SCOPE

The purpose of this document is to detail the tests that were performed on the Core Conduction Cooldown Test Facility (CCCTF) to evaluate its performance and its readiness to do the heatup of the HRB-17/18 particles. [1] The tests selected were those suggested by the CCCTF group and those determined to be necessary by the Readiness Review Committee (June 26, 1991, Oak Ridge, Tenn.). The tests fell into three categories: mechanical performance, control and operation, and radioactive material collection.

The scope of this document is to provide details of the selected tests and their results.

2. INTRODUCTION

The final phase of the CCCTF development is to devise a testing program to determine if the CCCTF can perform as intended and to locate any potential problems before operation with irradiated fuel is begun. In order to proceed with the testing plan, the areas of importance were identified. The areas were:

---

*Research sponsored through EG&G Idaho by the Office of New Production Reactors, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

†Chemical Technology Divison.

1. mechanical performance,
2. control and operation, and
3. radioactive material collection.

Because irradiated fuel is being handled, the furnace must be capable of being loaded by use of the hot cell manipulators. Since this is a time-consuming and often difficult process, care must be taken to ensure that the fuel can be moved from the fuel cask to the working table and from the working table to the furnace. In the case of the CCCTF, the furnace bottom is lowered by an elevator and pulled horizontally forward by the hot cell manipulators. In this lower forward position, the fuel is placed on the fuel holder support, the furnace bottom pushed horizontally back under the furnace, and the furnace bottom raised by the elevator to the closed position. Finally, a jack is moved into position under the furnace bottom and tightened up against the furnace bottom by the use of the manipulators. The major concerns for this operation are mechanical interferences, precise placement of the fuel holder support, and visual orientation for the manipulator operator.

In addition to fuel handling, the operation of the cold finger requires several mechanical operations. These operations require the use of the cold finger elevator, a gate valve, and the manipulators. Because the cold finger will be operated many times during an experimental run, confidence in its operation and reliability is necessary.

Control and operation of the furnace require that the performance of the furnace be predictable and within a specified tolerance for the periods of time of interest. The cold traps require temperature control, as well, to keep them within the desired temperature range. An additional problem arises within the cold trap system, and that is the problem of plugging due to trace moisture or gases in the system. The current configuration of the CCCTF has high-efficiency particulate air (HEPA) filters to remove the particulates and a desiccant followed by a condenser to remove any moisture that may have been introduced to the system from the specimen or during loading.

Efficient radioactive material collection is a major goal of the program. Tests are necessary to determine the efficiency of collection and the location of materials not collected by the deposition cup or cold trap. This is a complex task because reaction rates and vapor pressures depend on the material and temperature.

The goal of the testing program was to exercise each of these main areas to the extent possible without the use of irradiated fuel. Also, only the radioactive species of near-term interest

were examined as a first step toward the operation of the CCCTF. Thus, while several radioactive materials would be of interest for testing the collection efficiency of the CCCTF, only cesium-137 and krypton-85 were selected for this series of tests. As the demands on the CCCTF increase and operational experience is gained, further testing with other materials may become necessary.

2.1 EXPERIMENTAL CONFIGURATION

The testing of the CCCTF was on a subsystem-by-subsystem basis to provide flexibility for troubleshooting and procedure examination and changes. Thus, some tests were done with the furnace operating, while others were done with the furnace cold. All tests were done with high-grade helium as the furnace sweep gas. The reader is referred to ref. 1 for a detailed description of the CCCTF and its expected operation.

The specific testing done was organized into five separate phases to make maximum use of the available time and resources. An individual phase may cover more than one of the areas identified above. The phases were:

1. Furnace duration test in the hot cell with the operation of the cold finger. The purpose of this exercise was to run the furnace at approximately 1600°C as installed in the hot cell for a period of approximately 24 h to see that it functioned correctly and to provide experience for the generation of the operating procedures. The run was to include the operation of the cold finger under hot conditions but with only partial manipulator use. The cold traps were operated at room temperature.
2. Cesium tracer test. The purpose of this test was to operate the furnace at a temperature near 1600°C with a radioactive sample to test the collection efficiency of the cold finger and to determine the extent of the cesium migration within the furnace over the time scale of a few hours.
3. Fuel loading/unloading and deposition cup handling. This exercise was to verify that the furnace can be loaded and unloaded using the manipulators and that the deposition cup can be removed from the cold finger, placed into its shipping jar, and a new cup installed also using the manipulators without contaminating the cup. These tests were a general mechanical checkout of the furnace and manipulator operation along with the written procedures. The furnace was not heated, but helium was flowing through the furnace. The cold traps were at room temperature.

4. Cold trap duration and residual gas analyzer (RGA) test. This test phase scoped out the behavior of the cold traps. The furnace was unheated, and no radioactive materials were in the system, but helium was flowing at the specified experimental rate. The traps were cooled down to their operating temperature and the operation of the traps recorded. The written procedures were examined for consistency. In addition, the RGA was operated to verify that it would function in a satisfactory manner with the furnace in the hot cell environment.
5. Krypton test and cold trap detector calibration. This final phase involved operation of all the furnace components, except the cold finger, in their experimental test configuration with a radioactive test specimen. This phase was run in a manner similar to that of the upcoming experiments with the exception of an abbreviated heat-up program to save time and resources. The goals of this test were a system checkout of the CCCTF under powered conditions, calibration of the cold trap detector system for krypton-85, and an examination of the krypton retention properties of the traps.

In general, the results of these tests were satisfactory. In some cases, minor changes were found to be necessary to eliminate mechanical and visual interferences. Because of trap plugging by tramp moisture, significant changes were made in the cold trap system. The small inlet lines to the traps are susceptible to icing. This problem was solved by the addition of a condenser cooled to approximately -100°C in the line before the cold traps.

3. RESULTS OF THE TESTING

The following sections detail the testing conditions, the results, and any corrective action taken, if necessary, for a given test phase.

3.1 PHASE 1: FURNACE DURATION TEST IN THE HOT CELL WITH THE OPERATION OF THE COLD FINGER

This test was undertaken after the installation of the furnace in the hot cell. The purpose of the test was a general checkout of the furnace and its controller to ensure that the furnace was hooked up correctly and that the hot cell environment introduced no additional control concerns. Because the furnace had been tested in the lab during its development for a period of 100 h, a test length of approximately 1 d was selected as appropriate for the in-cell checkout. In addition, the furnace was tested with old internal components rather than new ones to conserve resources.

This use of old components led to some problems, as discussed below, but they allowed the testing of the potentially damaging emergency shutdown to be made at the end of the heating period.

The temperatures of the various furnace sensors are shown in Fig. 1. The unexpected failure of the optical pyrometer early in the run resulted in its replacement with a unit that was not calibrated for the system. The replacement unit was known to read about 65°C too high, but its use provided an independent sensor that indicated that the furnace temperature remained stable during the run. During the run, the Type C thermocouple failed as well. As stated above, this was an old unit that had been cycled many times before. This failure is clearly indicated in the data record and in Fig. 1. As the furnace was controlled by the boron graphite thermocouple (BGT), none of these events resulted in the loss of furnace temperature control. During the development of the CCCTF, the BGT was determined to be the most reliable and stable temperature-sensing element.

ORNL/DWG 92-5141

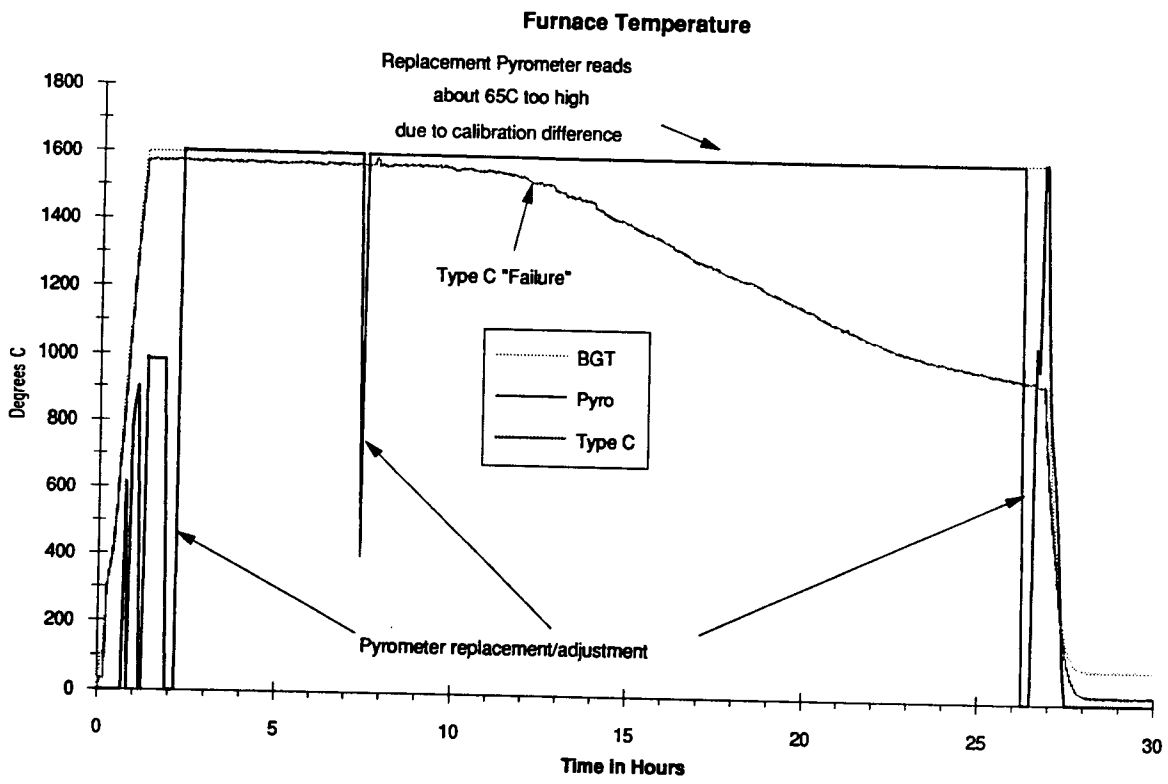

Fig. 1. Furnace temperature during one-day test.

The furnace was shut down after approximately 25 h by interrupting the cooling water supply to test the emergency shutdown system. The system worked as expected, and power to the furnace was removed. The resulting cooldown rate was higher than the already embrittled tantalum liner could withstand, and it cracked. This was the only damage caused by the sudden cooldown.

Other than the failures of the pyrometer and the Type C thermocouple, the furnace functioned as expected and no unusual problems were found. As was expected, the BGT was the most stable and reliable temperature sensor for this furnace.

This test showed that:

1. the furnace would function in the hot cell environment,
2. thermocouple failures/problems would clearly show up on the data record, and
3. the emergency shutdown system is functional.

The corrective action taken was:

1. the defective pyrometer was repaired and the damaged furnace parts replaced.

After the furnace parts were replaced and the pyrometer repaired, the next phase of testing was begun. Actual experimental tests will not use old and questionable parts.

3.2 PHASE 2: CESIUM TRACER TEST

The collection efficiency of the deposition cup and the fission product distribution within the furnace are both items that allow one to estimate the ability of the furnace to perform its intended task. In general, this is a complex problem to answer because both items depend on the specific chemistry of the released fission products, on the furnace temperature, and the local temperature gradients. To begin to address this set of needs, a test involving a single element at a constant temperature was selected. This is consistent with the first part of the experimental program for the CCCTF that involves old fuel held at a constant temperature.

The methodology employed was to select a cesium compound that would decompose at a temperature above 1000°C and prepare this substance using ^{137}Cs. The material would then be placed in the furnace and the furnace cycled through a short heating program. The cold finger would be inserted within the furnace and normally cooled. The compound selected for the test was cesium zirconate, and it was contained in a zirconia crucible with a platinum foil cover. A

small hole was punched in the cover for the outward diffusion of the released cesium. The sample was supported by a fuel holder and a fuel holder support that were the same as those to be used in the upcoming series of experiments with the exception of a larger hole in the fuel holder to contain the crucible. The geometry of the bottom half of the furnace is shown in Fig. 2; the deposition cup and cold finger are located in the upper half of the furnace, which is not shown.

ORNL/DWG 92-5142

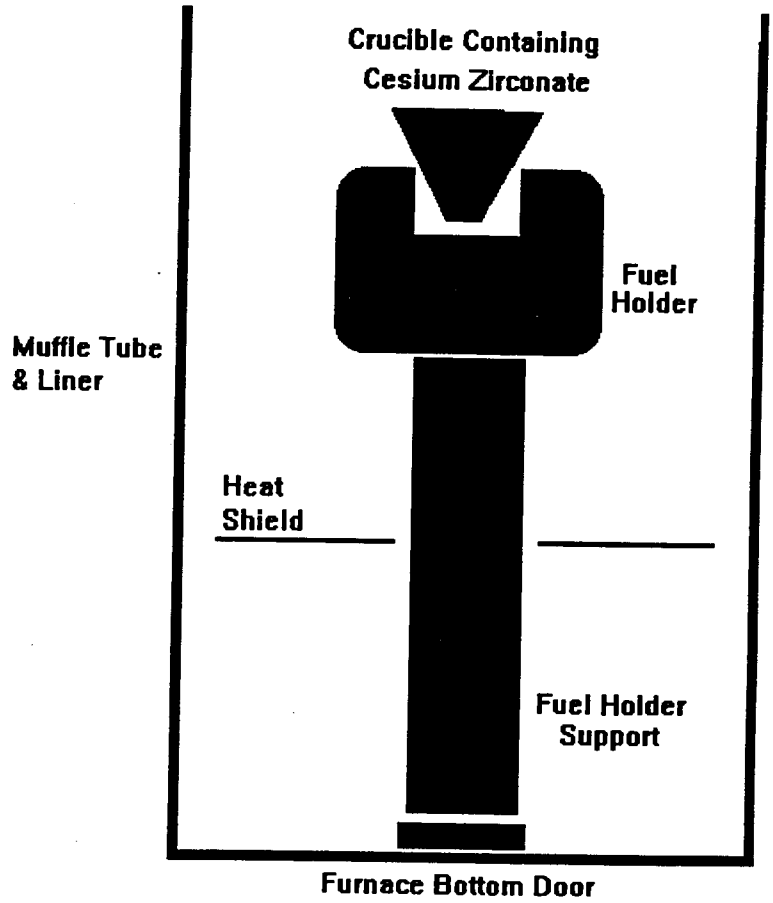

Fig. 2. Lower furnace geometry for cesium tracer test.

The results of the total cesium mass balance are shown in Fig. 3. All components were counted using an intrinsic germanium detector. The starting cesium inventory was 71 μCi (±5%) of ^{137}Cs. The majority of the cesium, 91%, was accounted for. The measurement error of up to 5% is due to the limited accuracy of the calibration of the gamma counting system used for these measurements; the additional error due to geometric effects has not been included or quantified. The low activity and cumbersome geometry of the furnace components introduced some error because point source geometry could not be maintained for the gamma counting in all cases, and self-shielding effects were not accounted for. More detailed gamma counting and self-shielding estimates were not pursued because of time and resource limitations. However, a 91% accounting of material for an apparatus of this nature is considered to be quite good.

The location of the released cesium is shown in Fig. 4. As can be seen, approximately half of the released material was collected by the deposition cup. The remainder of the material is located on the graphite parts or unaccounted for. Because the graphite parts were the most difficult to count and may require self-shielding and geometric corrections, the amount of cesium unaccounted for may be overestimated. The tantalum liner had only a trace of material on it, as did the furnace bottom and cold finger support cylinder.

The relative axial activity profiles along the components were determined by the use of a slotted shield and a detector. The relative activity profile of the fuel holder is shown in Fig. 5. As was expected, the location nearest the crucible exhibited the greatest activity. The total measured activity of the fuel holder was 14.79 μCi (±5%). The relative activity profile of the fuel holder support is shown in Fig. 6. The small drop in activity at the 0.5-in. mark is due to the fact that the top of the fuel holder support plugs into the bottom of the fuel holder and is thus shielded from the furnace atmosphere to some extent. The total activity of the fuel holder support was 5.71 μCi (±5%). Note the rapid dropoff past the thermal shield and the very low level of activity at the furnace bottom. This is beneficial as the furnace bottom does not appear likely to become contaminated to a large extent, and this fact will make furnace maintenance much easier.

The furnace tantalum liner, while having very low total activity, did have enough activity to allow an estimate of the activity profile. The total activity was estimated to be considerably less than 1 μCi. The tantalum liner activity profile is shown in Fig. 7. Note the peak in activity near the cold finger. The lack of activity near the 14-in. mark may not be meaningful because readings in that vicinity were near the background level. The tantalum heat shield exhibited only a trace

ORNL/DWG 92-5143

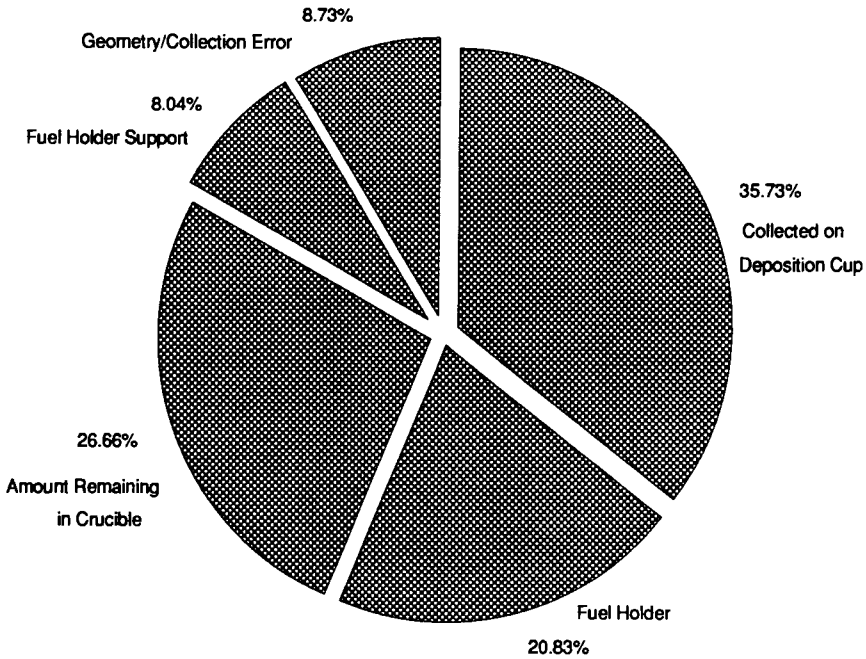

Fig. 3. Total cesium mass balance for cesium tracer test.

ORNL/DWG 92-5144

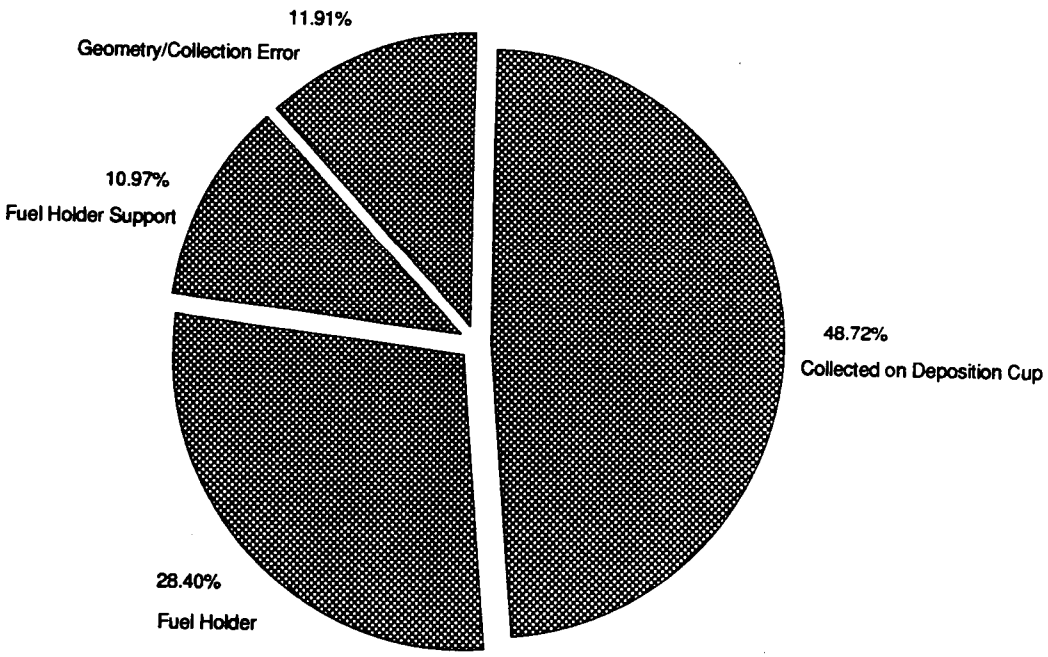

Fig. 4. Released cesium location.

ORNL/DWG 92-5145

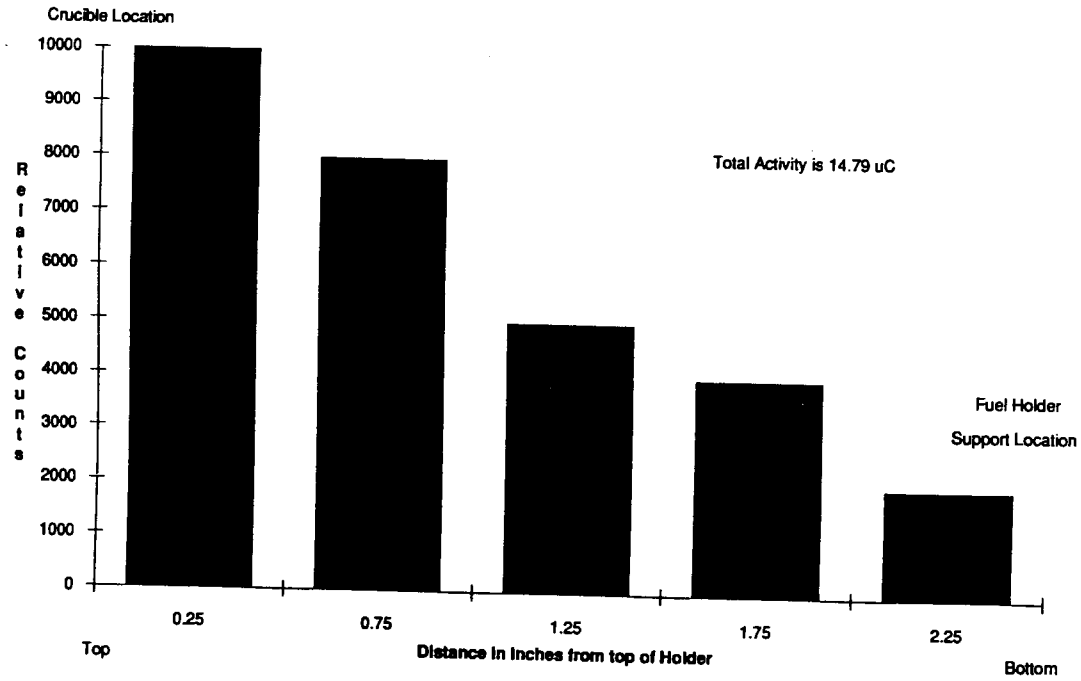

Fig. 5. Relative activity along fuel holder.

ORNL/DWG 92-5146

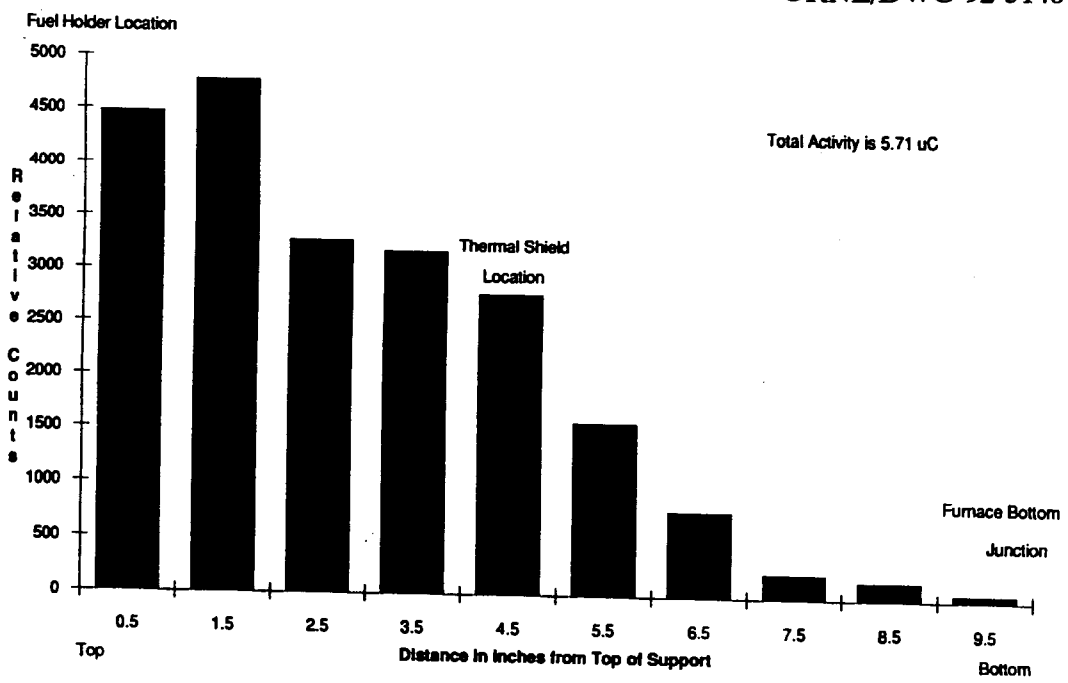

Fig. 6. Relative activity along fuel holder support.

ORNL/DWG 92-5147

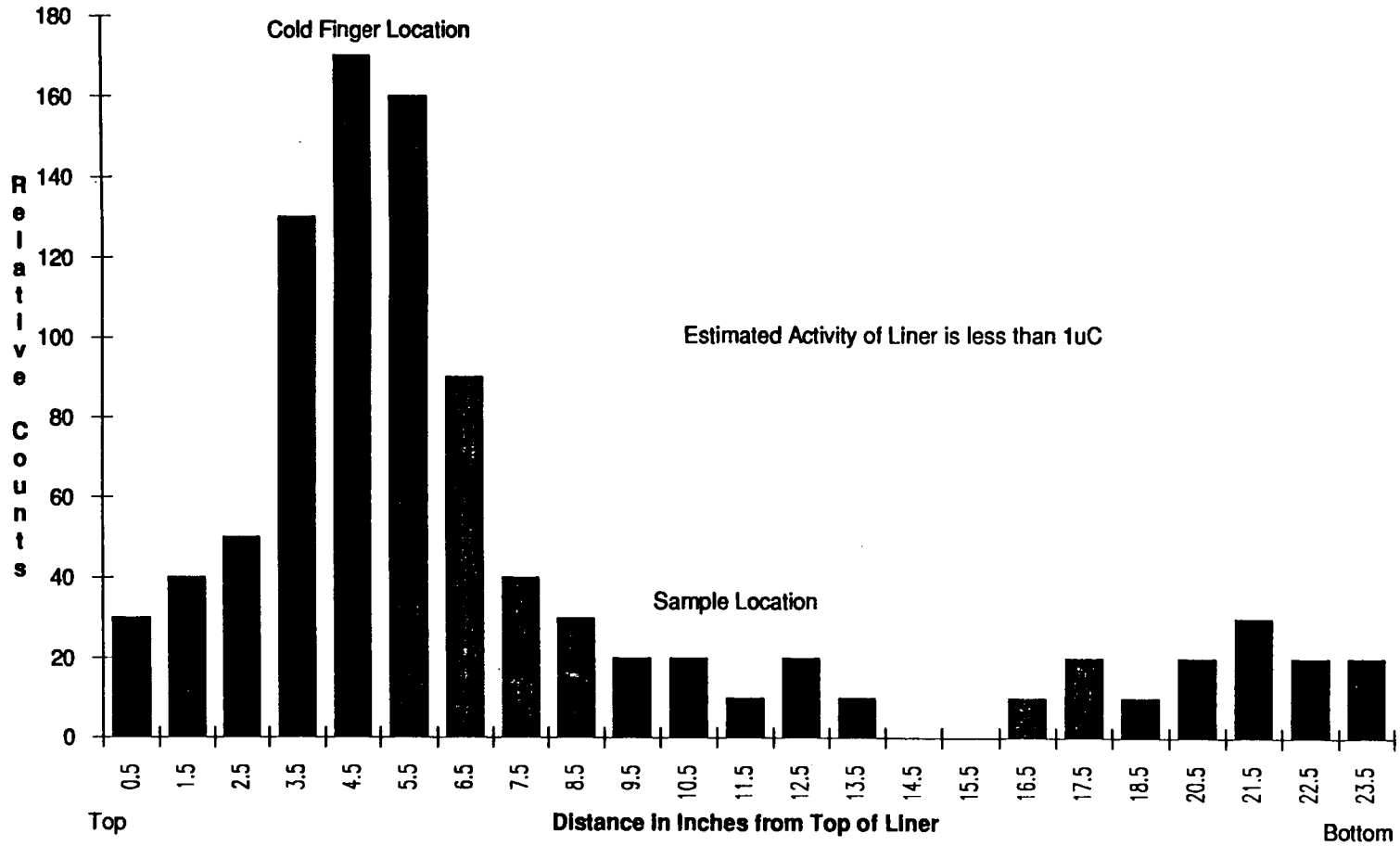

Fig. 7. Relative activity along tantalum liner.

of activity as well. A trace of activity was noted on the "O" rings that sealed the furnace flanges. No activity above background was found on the graphite muffle tube in the heating region. A trace of activity was found on the cold finger cylinder and the "O" rings that engage it.

The furnace temperature history is shown in Fig. 8. The furnace was started up under the control of the Type C thermocouple to see if this mode of control would be suitable for startup. The large thermal inertia of the graphite components resulted in the slow heating of the sample, even though the muffle tube was rapidly heating up. When this was apparent, control was switched to the BGT. This is the source of the spike in the startup of the temperature ramp; otherwise, the furnace operation was normal. The overall time at temperature was approximately 2 h with the crucible reaching a temperature of 1500°C. The furnace was heated up and cooled down with the cold finger in the furnace. No attempts at changing the deposition cup were made.

As was stated above, a more detailed analysis of the low-activity furnace parts was not pursued; it was not clear that additional effort would have resulted in more useful data because of the good mass balance and the relative activity data about the axial cesium distribution along the furnace components already obtained. It must also be remembered that this test involved a relatively short heating time as compared to experimental times of interest. Thus, the distribution of cesium in the furnace may vary with longer heating times. The first fuel-heating series of experiments should provide more information about long-term effects.

The results of this test were:

1. the deposition cup collects a significant portion of the released cesium,
2. the furnace liner does not collect a significant amount of cesium,
3. as expected, the graphite support components absorb a large share of the released cesium (in the short term), and
4. no important furnace contamination took place.

After the test, the liner, muffle tube, "O" rings, fuel holder, fuel holder support, and deposition cup were replaced. The rest of the furnace was cleaned with soft cloths. Wipes were taken of the furnace top and bottom, which indicated essentially no activity.

3.3 PHASE 3: FUEL LOADING/UNLOADING AND DEPOSITION CUP HANDLING

The goal of this set of operations was to practice loading a fuel sample and changing a deposition cup. The operations were done with a cold furnace but with helium flowing. A

ORNL/DWG 92-5148

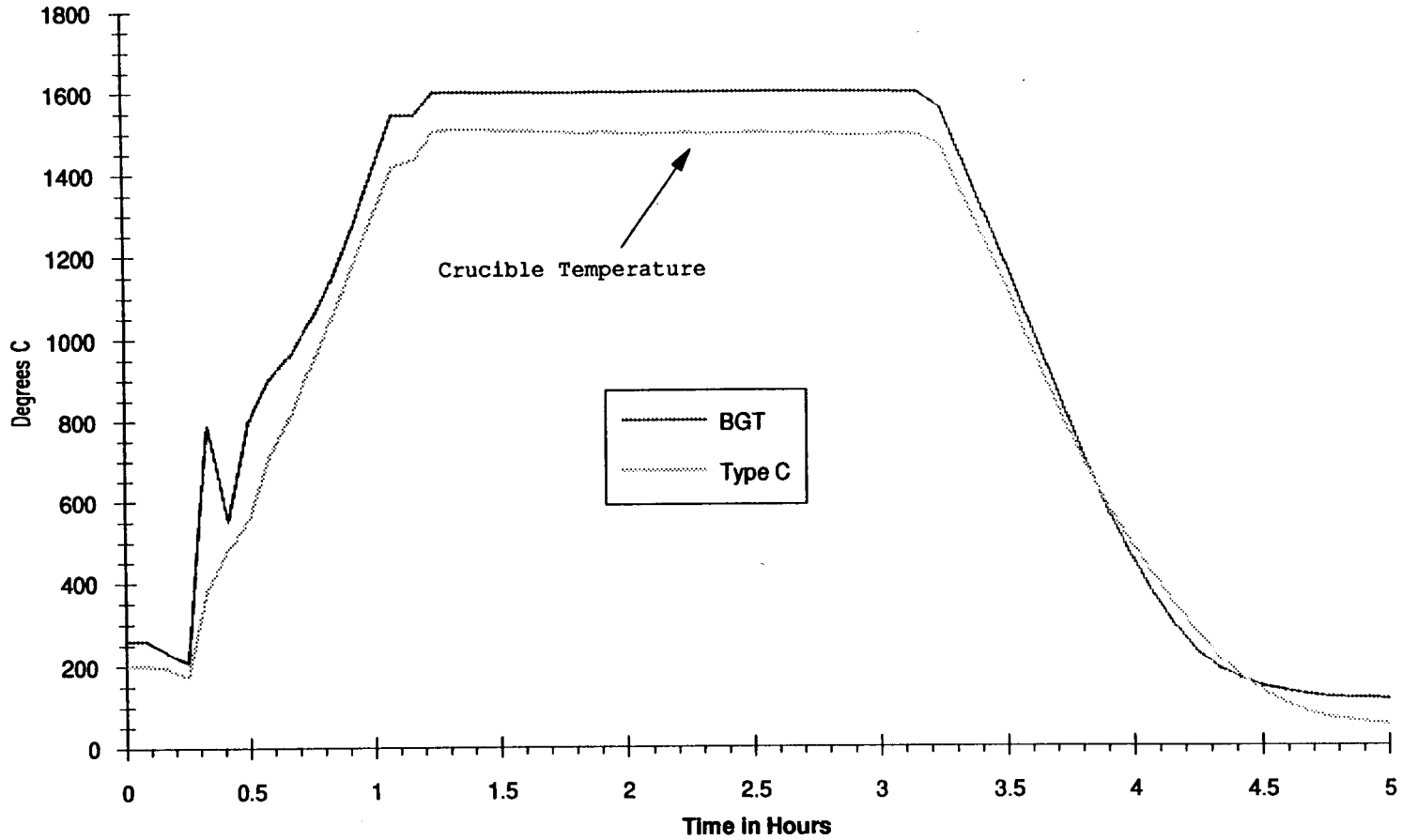

Fig. 8. Furnace temperature history for cesium tracer test.

dummy fuel holder was used in this exercise. The holder was manually placed in the cell, rather than transported in a lead cask, because of possible contamination of the dummy holder. The draft operational procedures were followed and additions/deletions noted as they were checked against actual operation. The lower jack was remotely operated, the furnace bottom door lowered by the elevator, a dummy fuel holder placed on and removed from the fuel holder support, the furnace bottom door raised back into position, and the jack locked in place. There were some minor mechanical problems, which were quickly isolated and dealt with. The problems were some mechanical interferences, lighting problems, hanging wiring, and some stiff connectors. These problems were corrected by additional wiring supports, larger gripping surfaces for the manipulators, and the addition of a spotlight. Practice with the system made the process go more smoothly.

The cold finger was lowered into the furnace, removed from the furnace, the deposition cup removed from the cold finger, and the cup replaced. The jar/jig for transporting and holding the cup was used in this exercise. This process went well, and no problems were noted.

The results of this test were:

1. the furnace can be loaded and unloaded with fuel by using remote techniques, and
2. the deposition cup can be replaced remotely and placed in a sealed storage container.

Modifications made included:

1. improved lighting,
2. rerouting of some wiring,
3. additional gripping surface added to a line connector, and
4. minor changes to the procedures.

After this exercise, the mechanical operation and thermal operation of the furnace were considered acceptable.

3.4 PHASE 4: COLD TRAP AND RGA TEST

One goal of this series of tests was to determine if the cold traps could be operated for long periods of time with no operator intervention or dysfunction. A series of cold furnace tests with helium flowing were performed with the trap system operational. The test duration varied from several to approximately 70 h. The liquid nitrogen supply to the traps was under computer

control so that a constant temperature could be maintained with minimal consumption of liquid nitrogen. The tests revealed that the system could hold the traps at the proper temperature and that the best control method was to use a thermocouple that monitored the liquid level in the traps rather than the internal charcoal temperature. The tests also revealed that trap plugging could occur under some conditions.

The RGA successfully monitored the exhaust gas of the furnace during some of these tests. The gases of primary interest were CO_2, CO, N_2, O_2, and H_2O. No significant problems were found with this unit. Because of the design of the unit, it was unable to measure very low (parts per million) levels of impurities in the furnace exhaust gas. A more sophisticated instrument will be required to detect low levels of impurities and will be added in the future. However, the RGA is useful as a relative indicator of furnace sweep gas quality and is easy to operate. As with the other tests, the draft procedures were followed, and minor corrections were made. The most significant additions to the trap system and its procedures were the addition of a final leak check to the instruction sequence before startup, the addition of an improved temperature control system for the cold traps, and the addition of a cooled moisture trap between the desiccant and the cold traps.

A major concern with the original system was plugging of the cold trap inlet lines by moisture, and a major goal was to eliminate this problem. Significant amounts of moisture will be brought into the furnace system whenever the furnace is opened or a sample loaded. The lines to the trap inlets are small and easily plugged by even small amounts of moisture. Early test runs suffered from line plugging, but the recent addition of a moisture condenser has eliminated this problem. The original trap system contained only a calcium sulfate desiccant to remove moisture from the furnace sweep gas. Initial tests revealed that the moisture removal rate was insufficient for the trap design, and plugging of the cold traps occurred. The plugging was determined to be water by examining the temperature at which the flow resumed after the traps were slowly warmed up. The temperature was found to be approximately 0°C. A dry-ice-cooled moisture condenser was added to the system to determine if freezing out the moisture would be adequate. Results with this unit were encouraging, but it was difficult to maintain a constant operating temperature low enough for good performance. Theory also indicated that a somewhat lower operating temperature than could be obtained by dry ice would be required for the long term. Based on the results of the condenser test and the results predicted by theory, a liquid-nitrogen-cooled, computer-controlled condenser was designed and implemented. It was designed

to be operated in the temperature range of -80 to -120°C, and current operation is at -100°C and stable within approximately 2 degrees. This condenser is located in the line just before the cold traps. The dry-ice-cooled moisture condenser suffered from large temperature variations that made it less efficient in freezing out the moisture from the sweep gas. The new trap can also be operated at lower temperatures and requires much less operator attention. Also added to the trap system at this time was an improved control system for the cold traps. This system greatly improved the temperature stability of the traps, reducing the temperature variations from 20°C to less than 5°C.

A 70-h test was conducted after the installation of the new condenser, and full flow was maintained for this period of time with no indication of line plugging.

The new liquid-nitrogen-cooled condenser is a long tube, approximately 1 in. in diameter, filled with copper turnings and surrounded by a liquid-nitrogen-cooled jacket. The entire unit is enclosed in an evacuated cylinder for insulation. By controlling the rate at which cold gas or liquid is introduced into the jacket, the temperature of the condenser can be held at the desired point to ensure the freezing out of the moisture.

All the sources of moisture are not quantified at this time, but it appears that one source may be the furnace materials outside the hot zone, most likely the carbon felt insulation. A large amount of the carbon felt insulation never reaches a high temperature, even under bakeout conditions, so the trapped moisture in the material can only be incompletely removed. Since both the furnace hot zone region flows and furnace body purge flows are combined together before entry into the traps to ensure that all the fission gas releases are captured, the cold traps may be exposed to some moisture even though the fuel sample is not. It should be noted that the amount of water responsible for line plugging can be very small because of the local nature of the freezing and the small line size, so that even moisture levels in the tens of parts per million or lower can cause problems over time; a large amount of moisture is not necessary.

More efficient chemical desiccants were not pursued because they are hazardous to handle and could represent a safety problem.

The results of this test series were:

1. long-term operation of the cold trap system is possible, and any moisture introduced into the system can be removed from the helium sweep gas before it enters the cold traps; and
2. the RGA can sample the furnace gas.

Modifications to the system were:

1. the addition of an actively controlled moisture condenser in the line before the cold traps, and
2. an improved temperature control system for the traps.

One uncertainty at the present time is the possibility that the trap system could be plugged by a low-freezing-point gas such as carbon dioxide. Experience will be necessary to determine how important this issue is. In the long term, it may be necessary to redesign the trap system to accommodate minor amounts of frozen trap gases. Table 1 summarizes the melting and boiling points of the gases of interest for the cold trap system.

Table 1. Freezing point of gases of interest for the CCCTF trap system[a]

Gas	Melting point (°C)	Boiling point (°C)
Krypton	-156.6	-152.3
Oxygen	-218.4	-182.96
Nitrogen	-209.86	-195.8
Xenon	-111.9	-107.1
Carbon monoxide	-199	-191.5
Carbon dioxide	-78.5 (sublimes)	--
Water	0	100

[a]Source: *CRC Handbook of Chemistry and Physics*, 56th ed., CRC Press.

3.5 PHASE 5: KRYPTON TEST AND COLD TRAP DETECTOR CALIBRATION

This series of tests involved the operation of all the furnace systems except the cold finger. The furnace operation was an abbreviated temperature heatup program lasting a few hours. The goal of the test was to heat and consequently break a glass vial containing krypton-85 and catch the released krypton in the cold trap system. A total of five tests were performed. The first three of these tests were conducted before the more efficient moisture condenser was installed;

the first two of these tests were conducted before the improved trap temperature control system was installed. These early tests were drivers for the development of the condenser.

The first two krypton tests, KR-1 and KR-2, did not achieve their objectives. The first test (KR-1) was conducted with cold trap temperatures above -160°C and resulted in considerable migration and some loss of the krypton. Preliminary tests with stable krypton had indicated that retention of the krypton was possible at these temperatures, but actual results at normal furnace flow rates proved otherwise. This test provided evidence that temperatures below the freezing point of krypton were necessary to retain it in the CCCTF trap system. An indication of the behavior of the krypton migration as a function of trap temperature is shown in Fig. 9. The ratemeter curve shows that the krypton is initially captured at the base of the trap and then migrates up through the trap to the exit. After this was observed, the trap temperature was lowered, and the results for two temperatures are shown on the graph. Low temperatures are required for even relativity short-term retention. One disadvantage of the trap system is the rather high flow rate through the trap system. This may enhance migration because solid krypton still has a substantial vapor pressure even at liquid nitrogen temperatures. More details on migration will be presented in the following sections.

The second krypton test (KR-2) provided no useful information because of a leak in the desiccant containers that bled off about 90% of the flow. After this problem was detected, procedures were modified to check for this condition before starting an experimental run.

The third test (KR-3) resulted in the desired calibration information. This test was conducted with an initial inventory of 381 μCi (±5%) of krypton contained in a small glass vial held by a fuel holder in the normal heating zone of the furnace. The furnace was in its normal configuration with both traps operational. The traps were operated just above liquid nitrogen temperature at -180°C. As the furnace was heated up, the vial containing the krypton broke in the neighborhood of 200 to 300°C, and essentially all the krypton travelled to the first trap within 30 min. The trapped krypton was measured approximately 1 h into the experiment and the trap inventory calculated to be 372 μCi (±3.7%) using a point source model for the krypton deposition in the trap. The trap held the krypton until the liquid nitrogen supply ran out, for a total time of approximately 26 h. At the time of the initial release of krypton from the first trap, the measured quantity in the first trap was 368 μCi. The small difference between the first and final measurement appeared to be due to some migration within (but not through) the trap as indicated by the fact that no krypton was in the second trap. This measurement can be used to

ORNL/DWG 92-5149

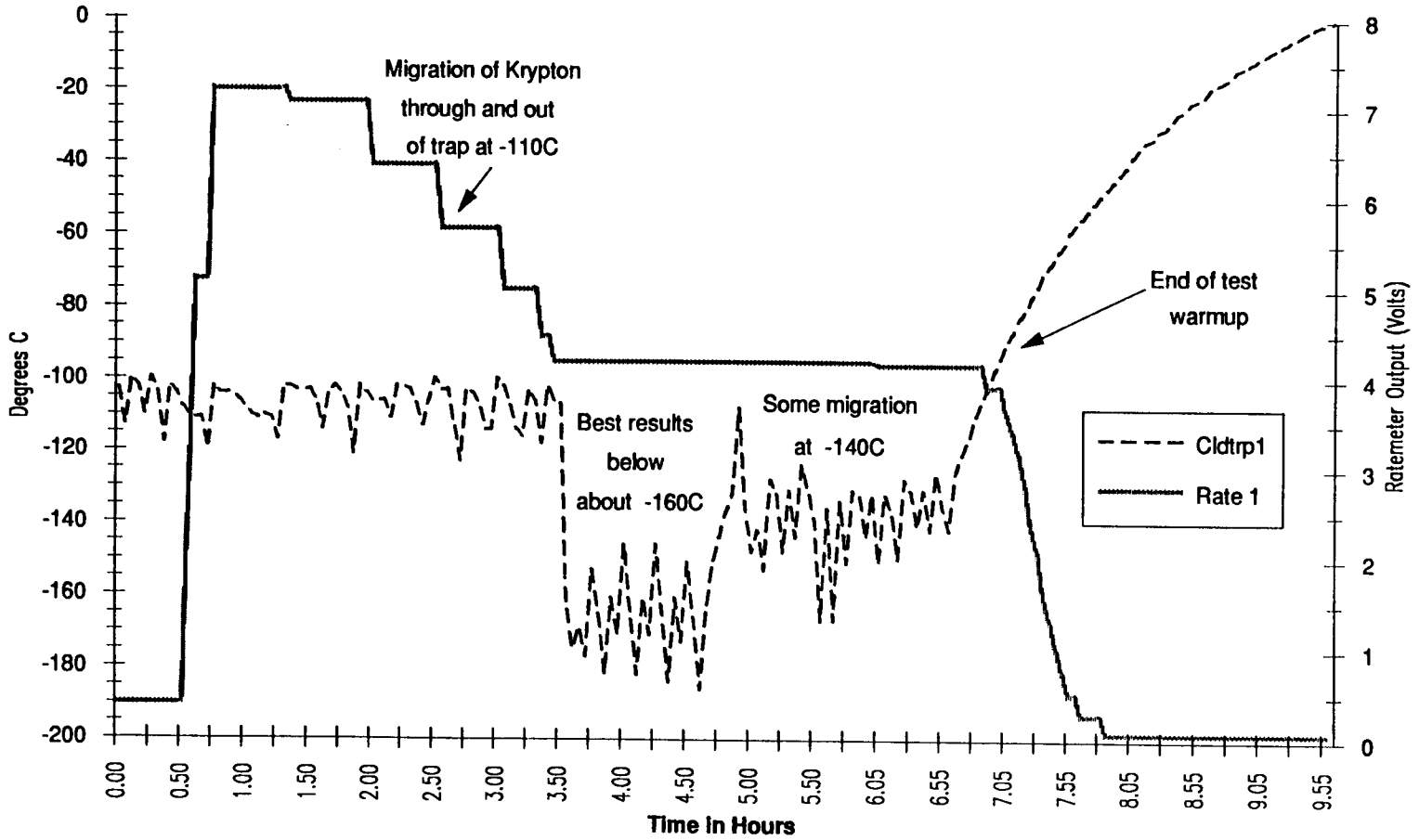

Fig. 9. Effect of krypton migration on detected activity as a function of temperature.

estimate the effect of the migration rate of the krypton within a trap (only a 1% difference in measured activity after 24 h). A later test confirmed this estimate. During this time, the flow through the traps dropped off considerably due to icing; the final flow was about 40% of the beginning flow. In this case, it was the entry lines to the dry-ice-cooled condenser that froze up. The furnace temperature profile is shown in Fig. 10, trap 1 temperature and ratemeter 1 output are shown in Fig. 11, trap 2 temperature and ratemeter 2 output are shown in Fig. 12, and the flow history is shown in Fig. 13. The short heatup time prevented all the thermocouples from coming to thermal equilibrium, and this is evident in Fig. 10. Note the sudden drop in ratemeter 1 as trap 1 warms up and the accompanying spike in the output of ratemeter 2; both traps warmed up at the same time.

The final two tests, KR-4 and KR-5, were conducted after the improved moisture condenser was installed in the system. Prior to the installation of the new condenser, it was not possible to run the trap system for long periods of time without some plugging due to moisture freezing. Cold furnace testing of the improved trap system gave confidence that the system could be run for long periods of time with no water freezing problems. The improved control system also provided stable trap temperatures.

Test four (KR-4) was a short-term test to provide further information about the detector calibration of the trap. Results of this test were similar to the third test with the exception of a possible new flow problem. The sample size for this test was 41.7 μCi (±5%), and 39.5 μCi (±3.7%) was captured in trap 1. This sample size is roughly the ^{85}Kr inventory of four high-burnup, highly enriched uranium (HEU) particles. After the krypton had been released, the flow began to decrease indicating a blockage. To free the blockage, trap 1 was slowly warmed up. At approximately -145°C, nominal flow returned and normal trap cooling was then immediately resumed. After the brief warmup, the amount of krypton in the trap was then measured to be 37.2 μCi, indicating that this operation had only a minor effect on detected krypton inventory due to migration of the krypton and that trap recovery during an experiment was feasible. The history of this operation is shown in Figs. 14 and 15. The material causing the blockage was not determined, but it is possible that it was xenon or carbon dioxide because they were part of the carrier gas for the krypton. Carbon dioxide may also be produced by furnace components if they have been exposed to air prior to heating. Even though both substances melt at a temperature higher than -145°C, they are likely candidates because the blockage probably occurs in the small inlet line to the trap, which runs at a considerably higher temperature than

ORNL/DWG 92-5150

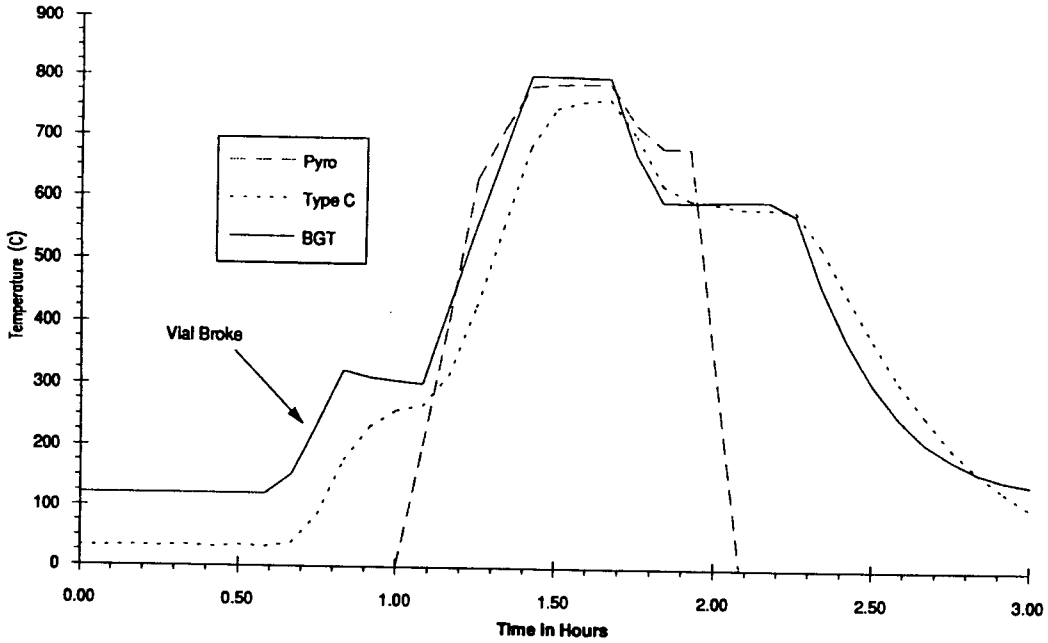

Fig. 10. Furnace temperature during third krypton test.

ORNL/DWG 92-5151

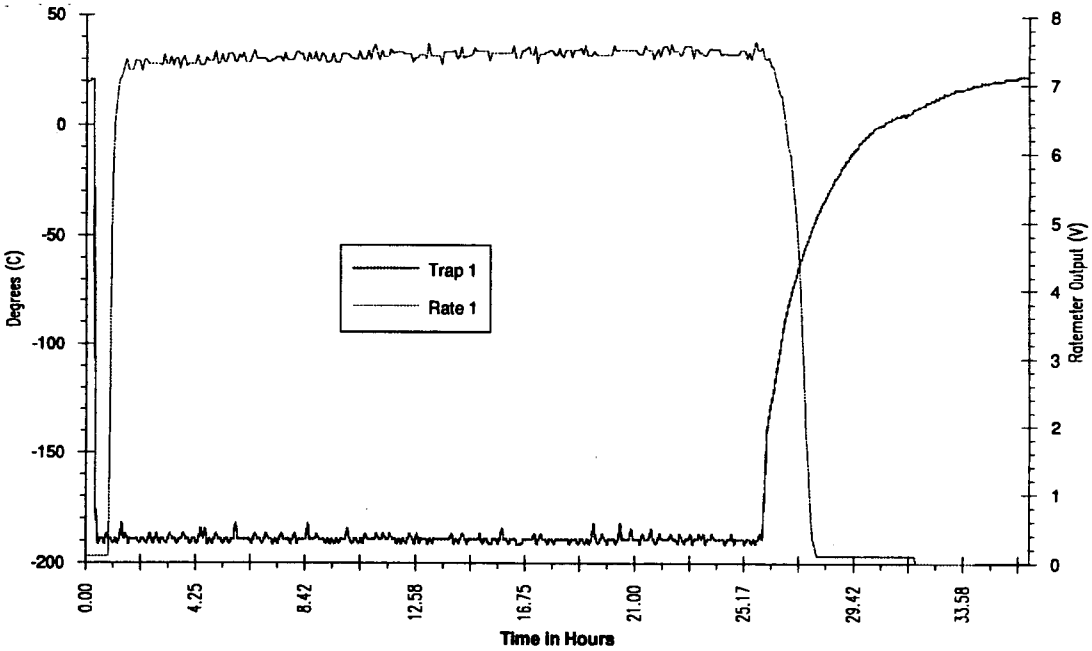

Fig. 11. Trap 1 temperature and ratemeter 1 output during third krypton test.

ORNL/DWG 92-51-52

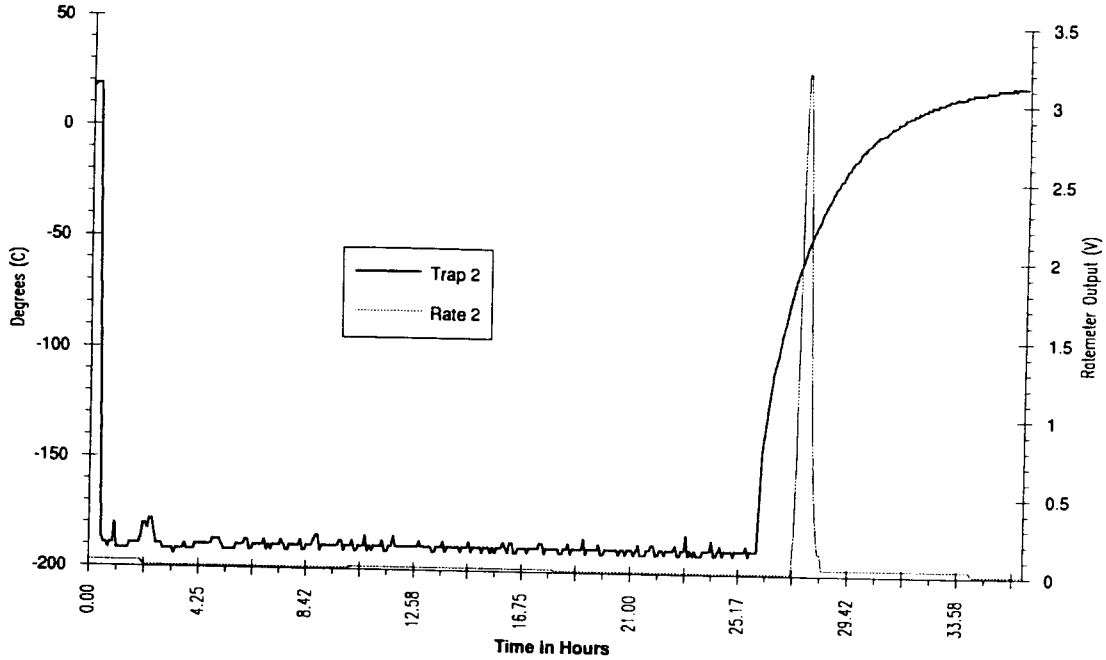

Fig. 12. Trap 2 temperature and ratemeter 2 output during third krypton test.

ORNL/DWG 92-5153

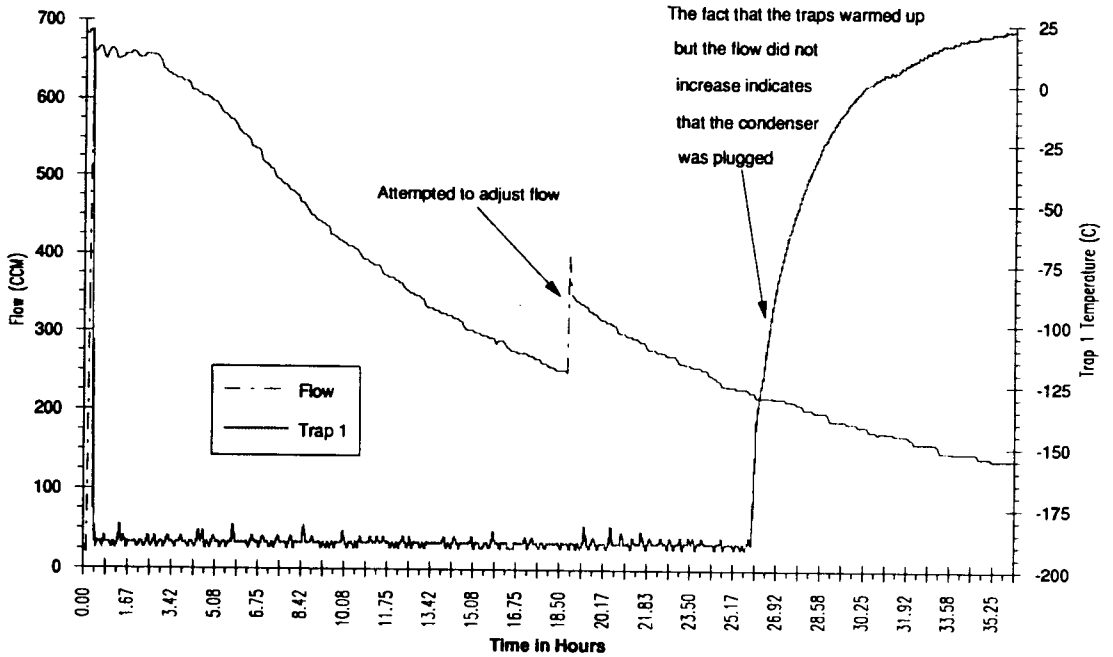

Fig. 13. Flow history for third krypton test.

ORNL/DWG 92-5154

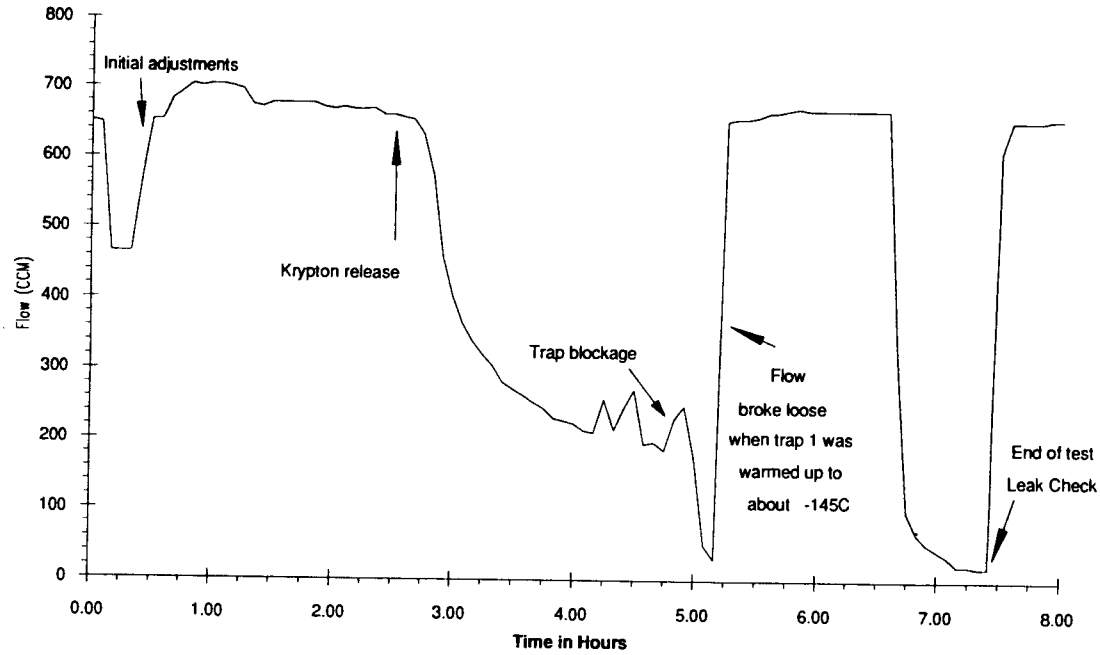

Fig. 14. Flow history for fourth krypton test.

ORNL/DWG 92-5155

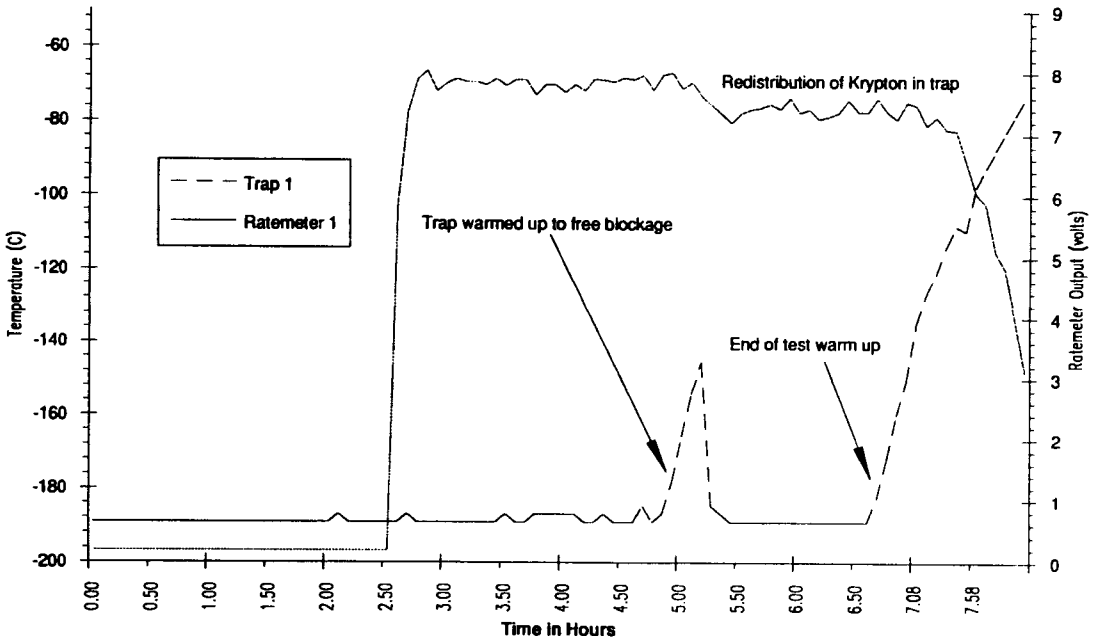

Fig. 15. Trap 1 temperature and ratemeter output for fourth krypton test.

the trap body. Previous blockage did not free up until the trap temperature approached 0°C, indicating water. Complete elimination of these gases prior to the cold traps may not be possible because their vapor pressure is still substantial even at liquid nitrogen temperatures.

Test 5 used a sample size similar to that of test 3 but was conducted for a longer period of time using the improved trap system. In this test, no problems with the flow occurred. The longer test time and the maintenance of the trap flow at its nominal rate allowed a better estimation of the effect of the krypton migration.

The fifth krypton test (KR-5) was conducted with a 303 μCi (±5%) krypton sample. The furnace was operated as in previous tests, and 284 μCi (±3.7%) was measured in trap 1 about 2 h after the release. After about 50 h, 277 μCi was measured in trap 1. The overall test lasted approximately 85 h. Originally, the test was planned to run for only about 24 h as in the third test, but a last-minute change made a larger supply of liquid nitrogen available, and a decision was made to take advantage of this supply. The trap krypton measurement at the termination of the test was not available because the collection system had not been prepared for a run of this duration. However, ratemeter data were collected for the duration of the test, and no large or sudden changes in inventory were observed.

The trap temperature was stable for the entire time period, and the detector temperature stabilized and remained stable after an 8-h cooldown time. The measured inventory of trap 1 versus time is shown in Fig. 16. As can be seen, the measured inventory very slowly decreased with time. It is not known if an asymptote is approached at a greater time; a much longer term experiment will be required to determine this. Also, this effect may be sensitive to the quantity of captured krypton. No krypton was seen in the second trap, so the effect is a diffusion and redistribution of the krypton within the trap. At the present time, this effect is not considered to be a serious problem.

A summary of the last three krypton tracer test runs is:

Test number	Sample Size	Collected	Difference
KR-3	381 μCi	372 μCi	2.4%
KR-4	41.7 μCi	39.5 μCi	5.3%
KR-5	303 μCi	284 μCi	6.3%

The accuracy of the sample measurements is approximately ±5%. This measurement assumes that geometric effects are small compared to instrument calibration uncertainty. The trap detection system is calibrated to within ±3.7% using a standard point source and is repeatable from test to

ORNL/DWG 92-5156

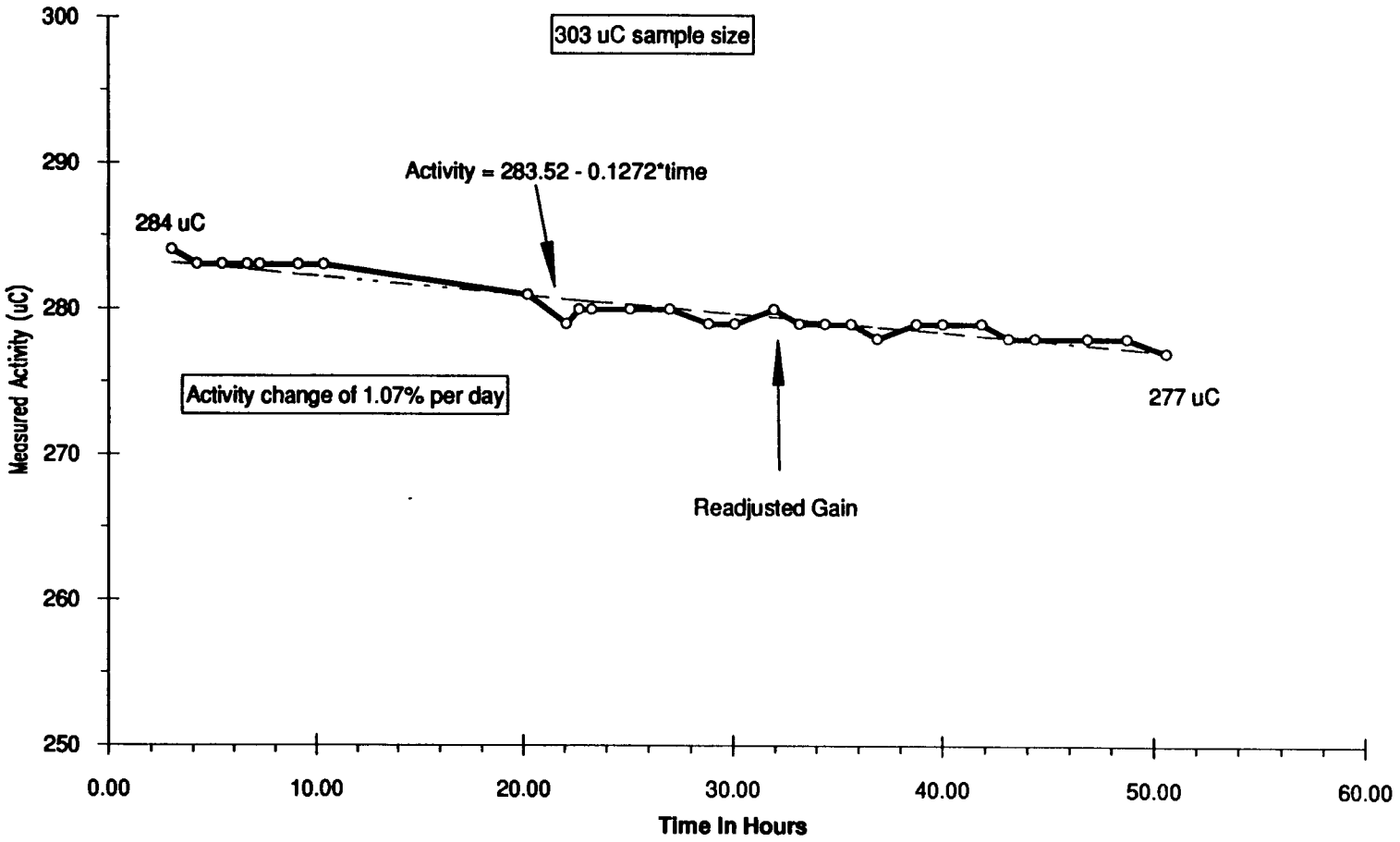

Fig. 16. Detected trap inventory as a function of time for the fifth krypton test.

test (due to the assembly and reassembly tolerances of the trap system) of within ±2%. The average uncertainty of 4.7% between the sample measurements and the collected krypton measurements (assuming a point source model) is considered to be quite good. The calibration of the detector system was examined both before the fourth test and after the fourth test, and it was within the 2% repeatability error indicating that the thermal cycling of the system, both detector cooldown and trap warmup, did not have any adverse effects. The root mean square uncertainty for this system would be approximately 8%. If several days migration of krypton is added to the uncertainty, the total uncertainty will still be within about 10%.

The major results of this series of experiments were:

1. the krypton can be caught and held in the traps with only a minimal migration through the trap over the time periods of interest for near-term experiments;
2. the point source model for the deposition of krypton within the traps appears to be a good approximation even for long periods of time; and
3. the trap plugging problem is largely solved, but a redesign of the cold traps may be necessary to totally eliminate the problem.

This test, along with the cesium tracer test, indicate that the CCCTF can collect the released fission products in an accurate way.

4. ADDITIONAL ITEMS

Several other items, not hardware related, were addressed during this time period as well. These items included:

1. labelling of the major valves and switches of the CCCTF subsystems; and
2. a detailed examination of the procedures, the quality control issues, and experimental plans for the CCCTF.

The procedures have been subject to numerous reviews, and the other issues will become input for program and task-level documents.

5. SUMMARY

A series of tests were performed on the CCCTF to determine if the CCCTF can perform its intended function and meet program goals. In general, the subsystems performed well, demonstrating the control of the furnace and cold traps, the collection of metallic fission products,

and the collection of gaseous fission products. The cold trap system was modified to solve an icing problem and may need additional design work to increase its reliability, but its most serious problems have been solved. After the first series of experimental runs using irradiated fuel is complete, the performance of the system will be evaluated and changes made to the equipment and procedures as necessary. The much longer running times of the planned experiments will also provide a check as to the applicability of the shorter tracer test running times.

6. ACKNOWLEDGMENTS

The authors wish to acknowledge the following people for their help and support during this process: C. A. Baldwin, M. J. Kania, C. M. Malone, M. F. Osborne, O. M. Stansfield, and J. L. Wright. The authors also thank S. M. Wilson for final report preparation and K. Spence for editing.

7. REFERENCE

1. R. N. Morris, C. A. Baldwin, J. L. Collins, L. C. Emerson, W. A. Gabbard, C. M. Malone, B. F. Myers, M. F. Osborne, M. L. Peters, J. C. Whitson, and J. L. Wright, *The Core Conduction Cooldown Test Facility: Current Status and Issues*, ORNL/NPR-91/7, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., May 1991.

INTERNAL DISTRIBUTION

1-2. Central Research Library
3. Document Reference Section
4-5. Laboratory Records Department
6. Laboratory Records, ORNL-RC
7. ORNL Patent Section
8. ORNL NPR-RMS-DCC-RC
9-11. M&C Records Office
12. E. C. Beahm
13-17. J. L. Collins
18. G. L. Copeland
19-23. W. A. Gabbard
24. F. J. Homan
25. H. Jones
26. M. J. Kania
27. J. C. Mailen
28. R. C. Martin
29-33. R. N. Morris
34. D. L. Moses
35. N. H. Packan
36. P. L. Rittenhouse
37. P. S. Sklad
38. O. M. Stansfield
39. R. P. Wichner
40-44. J. C. Whitson

EXTERNAL DISTRIBUTION

45-47. CEGA, P. O. Box 85608, San Diego, CA 92138-5688

D. L. Hanson
D. W. McEachern
W. J. Scheffel

48-52. IDAHO NATIONAL ENGINERING LABORATORY, P. O. Box 1625, Idaho Falls, ID 83415

L. J. Kay
R. K. McCardell
M. L. Russell
R. K. Southworth
H. J. Zeile

53. DOE OAK RIDGE FIELD OFFICE, P. O. Box 2001, Oak Ridge, TN 37831

Office of Assistant Manager for Energy Research and Development