XENON-TAGGING OF EBR-II DRIVER FUEL

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ABSTRACT

Twenty partially bonded EBR-II driver-fuel elements for an experiment were xenon-tagged with an evacuate-cryogenic transfer method. The xenon was frozen into the element plenum by immersing, in liquid argon, the sodium-loaded jacket complete with the fuel pin. More than 3 cm^3 (STP) of xenon were transferred in order to deliberately increase the plenum pressure so that release of tag upon cladding failure would be ensured. The equipment and procedures used are described, and the method is evaluated.

I. INTRODUCTION

Fabrication of some specially defected Mark-IA driver-fuel elements was required for an experiment in EBR-II. The desired defect was a partially bonded condition in one of two geometries (axial or circumferential). This experiment (for subassembly X149) was prepared to demonstrate that an initially unbonded or partially bonded element operates in a manner that does not compromise the safety of the reactor. The lifetime of these defected elements is expected to be appreciably shortened, however, by early cladding failure. For identification of these elements at failure, a xenon tag was added to each during fabrication. This report summarizes the effort required to tag the elements.

Xenon-tagging is a technique that has been perfected for the rapid and unambiguous identification of a subassembly that contains one or more defective fuel elements. Each fuel element in a "tagged" subassembly contains approximately 1 cm^3 of the same specific and unique isotopic mixture of xenon. Failure of the fuel cladding releases some of the xenon tag along with the gaseous fission products to the reactor cover gas. The reactor cover gas is continuously monitored for fission products. If a significant increase of gaseous fission products is noted, the cover gas is sampled and

analyzed isotopically for xenon. The "isotopic fingerprint" so obtained identifies the subassembly that contains the cladding failure. That subassembly is removed from the reactor, and normal operation is resumed.

Not all experimental subassemblies are tagged. Thus, if a tag has not been released, it is frequently necessary to search for the source of fission products by a "trial-and-error" method. Subassemblies suspected of releasing fission products to the primary coolant are transferred to the reactor storage basket. The reactor is then operated to determine if the fission-product source has been removed from the reactor. This search procedure, often involving several transfers of selected suspects between reactor grid and storage basket, is continued until the subassembly containing the fission-product source is identified. This identification method requires unnecessary handling of unfailed fuel experiments and thus adversely affects the reactor plant factor. Clearly, anything that can be done to simplify identification problems will improve plant factor.

Because xenon-tagging is a relatively recent concept, there are few documented procedures for tag placement in the literature. Placement with a hypodermic needle and syringe has been suggested;¹ this method, extended to include a cryogenic pressurization step, was used to tag oxide-fuel elements in EBR-II instrumented subassembly XX01.² An evacuate-backfill technique has been reported and a frangible-pellet technique proposed.³ One laboratory has submitted an evacuate-cryogenic transfer procedure, but this method has not been used for fueled experiments in EBR-II.⁴ An evacuate-cryogenic transfer technique is routinely used to prepare xenon-tag mixtures supplied to EBR-II experimenters.

II. ELEMENT FABRICATION

Final assembly of a Mark-IA driver-fuel element is initiated by inserting a length of sodium wire into the stainless steel jacket (the cladding) and placing the fuel pin on top of the wire. The sodium-loaded jacket with fuel pin is then heated at 120-150°C to submerge the fuel pin in the sodium and settle it to the bottom of the jacket. The top end restrainer is then inserted and seated on the jacket rim. Thus assembled, the element is allowed to cool to near ambient temperature. The final top end weld is then made with a stored-energy, capacitor-discharge arc welder, using argon as the shielding gas.

To ensure sodium wetting and the elimination of voids, the element is impact-bonded. It is heated to 500°C in a vertical position and lightly impacted approximately 1000 times from the bottom. Figure 1 shows a schematic drawing of an assembled Mark-IA fuel element.

The partially bonded, xenon-tagged Mark-IA fuel elements were assembled in a similar manner. Sodium wire (a reduced quantity in this case) was inserted into the jacket, followed by the fuel pin. The jacket was then heated at 120-150°C, and the fuel pin was pushed to the bottom of the jacket with a length of stainless steel welding rod. (Some of the elements were in a horizontal position.) The restrainer was then seated on the jacket rim to ensure fit and noninterference from the sodium within the jacket, and the assembled element was cooled to ambient temperature. The restrainer was then carefully removed, and the jacket was fitted to the gas-tagging apparatus. After the xenon had been frozen into the jacket, the restrainer was reinserted and the closure weld immediately made.

Bonding of the sodium-deficient elements was accomplished without impacting. Elements with sodium voids running the full length of the fuel pin were heated to 500°C while horizontal.

III. TAGGING APPARATUS

The gas-handling system used to manipulate the xenon tags is built around a commercially available capacitance manometer.* The manometer is operated in a differential mode, with the reference section connected to vacuum maintained at $<10^{-6}$ Torr.

The vacuum system consists of a mechanical forepump, a mercury diffusion pump, a liquid-nitrogen cold trap, and a valve network. Vacuum is monitored with a Bayard-Alpert ionization gauge installed upstream from the liquid-nitrogen cold trap. Vacuum integrity of new connections, including connections to the fuel-element jackets, is verified in the following manner. The system is first pumped down to the desired pressure. The pumping system is then isolated from the section under leak-test. After a period of time (typically 5 min), the section under test is again opened to the vacuum

*BARATRON Pressure Meter Type 77 with Type 77H-1000 Pressure Head, MKS Instruments, Inc., Burlington, Mass.

Fig. 1. Mark-1A Design of EBR-II Driver-fuel Element. (All dimensions are in inches)

system, and the ionization gauge is observed closely. Extremely small leaks in new sections of the vacuum system are readily detected by this method.

The xenon-gas manipulating system consists of the capacitance manometer, an insulated expansion chamber with a volume of $\sim 210 \text{ cm}^3$, an absolute-pressure gauge, and miscellaneous valves and connections necessary to manipulate the gas tags. Each section or component may be isolated from, or connected to, the vacuum system as desired. For this experiment, a separate vacuum line was run to the fuel jacket, and the xenon gas was introduced through its own gas line. This was necessary because of the long tubing lengths required to connect the external gas system to the fuel jacket inside a large argon-atmosphere glovebox. The location of the glovebox feedthroughs required over 8 ft of small-diameter tubing to connect the system. The evacuation and leak-checking time was kept short because neither the vacuum line nor the separate xenon-gas supply line had to be evacuated each time a new fuel jacket was connected. The residual gas in the xenon supply line could be used for tagging the following fuel element. Figure 2 shows an overall view of the gas-handling system.

Within the argon-atmosphere glovebox, the tagging system consists of three valves and a quick-connect vacuum coupling, all fitted to a coupling block. One valve connects to the vacuum line, the second connects to the xenon supply line, and the third vents the jacket to the glovebox atmosphere. Figure 3 shows the internal arrangement. The vacuum coupling holds the fuel jacket by means of an O-ring which is compressed around the jacket by turning the outer body of the coupling. No sealant was allowed on the O-ring, because it might have interfered with the final welding operation. To complete the system, a "Dewar" of the appropriate dimensions was fabricated from aluminum tubing and Styrofoam rings.

The liquid argon was piped directly to the "Dewar" in the glovebox. It went via 3/8-in. tubing from the liquid/gas supply Dewar (Linde LS-110) outside the glovebox, through a bulkhead connector, and then via flexible 1/4-in. tubing to a position just above the "Dewar" inside the glovebox. The liquid-withdrawal valve of the supply Dewar was the only control valve. To prevent air leakage into the glovebox, the line to the glovebox was purged with argon before final tightening of the bulkhead connection.

Fig. 2. Gas-handling System at Glovebox for Xenon Tagging.
Top of supply Dewar for liquid argon is hidden by the
plastic funnel in center of photo

Fig. 3. View of Tagging System Inside Glovebox.
The vacuum coupling is hidden by the argon Dewar.

IV. TAGGING PROCEDURE

Injection of the xenon tag was based on an evacuate-cryogenic transfer technique. The prepared jacket, containing the fuel pin and partial bond, was coupled by the vacuum coupling to the tagging system in the glovebox. The jacket was then evacuated to 3×10^{-6} Torr and leak-checked. Xenon gas was then introduced into the system, and the system pressure was measured. The jacket was then immersed in liquid argon, to cryo-pump the xenon gas into the jacket, while the system pressure was observed. When the desired decrease in pressure was achieved, the jacket was isolated and allowed to remain in the liquid argon for an additional five minutes. The jacket was then vented to the glovebox atmosphere, removed from the system, fitted with the top end restrainer, and welded.

The use of liquid argon in the glovebox presented a problem deserving mention. The glovebox system used has a volume of approximately 230 ft³ and is fitted with 48 glove ports. At each end of the system is a transfer port fitted with a vacuum pump. The two pumps may be interconnected by opening one valve. When liquid argon was in the glovebox, one transfer port was opened to the glovebox atmosphere. An individual was assigned to prevent extreme over-pressure of the glovebox system by pumping argon gas from the open transfer port. At times, when a liquid-argon spill occurred, both vacuum pumps were required to remove the excess argon gas. The rubber gloves at these times were pushed out almost horizontal by the increased gas pressure.

The volume of the original gas-manipulating system was calibrated by expanding gas into cylinders with known volumes. Pressure-volume relationships were subsequently used to calibrate the volume of each additional section of the system. Five partially bonded, depleted fuel elements were used to determine the typical volume of the fuel-element plenum. Since bellows-seal valves (Kel-F seats) were used in the system, care was given to opening and closing valves in a reproducible manner so that precalibrated volumes were duplicated.

The quick-connect coupling originally used was a stock brass coupling for 3/16-in.-dia tubing. Repeated leaks during early procedure tests suggested replacement with a stainless steel duplicate having the same expansion coefficient as the fuel jacket. A supply of Buna-N O-rings, to replace the original Viton O-ring, was also obtained for the coupling. This combination

worked very well, as pressures of less than 3×10^{-6} Torr were easily obtained. The size (0.187 in. dia) of the coupling allowed the fuel jacket (0.174 in. dia) to be readily removed from the coupling, even at liquid-argon temperature. The same Buna-N O-ring could be used repeatedly. The fuel jacket was carefully handled, however, as its thin wall (0.009 in.) could easily develop a crimp while clamped in the vacuum coupling.

After the prepared fuel jacket was connected to the gas-tagging system, it was evacuated through the vacuum line until a pressure of less than 3×10^{-6} Torr was reached. Pressures even lower than this were usually achieved in less than five minutes. A leak-test was then conducted with the fuel jacket isolated by closing the vacuum-line valve located within the glovebox. A timer was used to standardize this isolation time period. The valve was then opened, and the effect of this isolated section on the ionization gauge was observed. Since the observation was made with the gauge set at a full-scale deflection of 1×10^{-5} Torr, extremely small leaks could be easily detected. Deflections of less than 5% (5×10^{-7} Torr) indicated sufficient vacuum integrity.

The volume of the xenon-tagging system, including the fuel jacket, was about 260 cm^3 . Xenon gas was introduced into this volume, through a metering valve between the xenon supply cylinder and the insulated expansion chamber, until a pressure of approximately 20 Torr was reached. At this pressure and system volume, the quantity of xenon within the system was $6\text{--}7 \text{ cm}^3$ (STP). The equilibrium pressure was then determined to the nearest 0.01 Torr by the capacitance manometer.

The Dewar inside the glovebox was then raised to submerge the fuel jacket in liquid argon. Because the Dewar was raised as high as possible and had an inside diameter of only 1 in., it was difficult to observe the liquid level and keep it constant. The Dewar was covered with a cardboard Styrofoam lid, and liquid argon was added through a hole in the lid until splashing from under the lid indicated that the Dewar would hold no more liquid. The system pressure would drop rapidly toward the desired pressure of approximately 10 Torr. When this pressure was reached, the fuel jacket was isolated from the rest of the system by closing the xenon-line valve within the glovebox. At this time, the equilibrium pressure was again determined to the nearest 0.01 Torr.

The difference between the initial and final quantity of xenon is the amount cryo-pumped into the fuel jacket. Appendix A is a worksheet showing a typical calculation of the xenon quantities. The xenon transferred, of course, was frozen into the fuel jacket. The speed with which the xenon was cryo-pumped was another indication of the vacuum integrity of the system and the purity of the xenon supply.

A number of times during the cryo-pumping step, the fuel jacket could not be isolated quickly enough, so too much xenon was cryo-pumped into the fuel element. On these occasions, the Dewar was lowered, and some of the xenon was allowed to boil out of the jacket and back into the gas system.

The isolated fuel jacket was kept submerged for an additional five minutes to ensure that all the xenon would be solidified within the jacket. The jacket was then vented to the glovebox atmosphere through the vent valve. The vacuum coupling was then loosened, and the Dewar, containing the element, was lowered. A restrainer was quickly seated in the jacket, the assembled element was immediately transferred to the welding station, and the final seal weld was made. The time between venting of the fuel element to the glovebox atmosphere and making the final weld was never longer than 30 sec. More often, the weld was made within 20 sec.

In this procedure, more than the required amount of xenon gas is used deliberately to increase the pressure in the fuel-element plenum. This increased plenum pressure should be sufficient to overcome the EBR-II sodium-coolant pressure and thus ensure a gas release regardless of the location of cladding failure.

The actual xenon-tagging procedure submitted to the EBR-II Irradiations Office is given as Appendix B.

V. RESULTS OF TAGGINGS

Before the enriched fuel was tagged, five fuel elements containing depleted fuel were prepared. These elements were "tagged" with natural xenon to check the xenon-tagging procedure. The "tagged" elements were then destructively tested for xenon retention. Table I gives the results of these tests.

TABLE I. Results of Procedure Test with Elements
Containing Depleted Fuel Pins

Element Designation	Xenon Transferred, cm ³ (STP)	Xenon Recovered, cm ³ (STP)	Yield, %
Test 1	1.77	1.24	70.1
Test 2	1.28	0.85	66.4
Test 3	2.17	0.89	41.0
Test 4	3.14	1.36	43.3
Test 5	^a	1.98 ^b	--

^aNot recorded.

^b4.63 cm³ Xe + Ar.

The yield was erratic because air was leaking into the valve on the natural-xenon cylinder. This leakage was discovered after test No. 4. Test No. 5 and subsequent tagging operations were run with xenon supplies having low enough pressures to be opened directly into the gas system without using a pressure regulator.

Although the early test yields were erratic, all the xenon recoveries were above the 0.75 cm³ minimum required by the EBR-II Irradiations Guide.⁵ Since there was a time limit on the use of the glovebox facility (it was scheduled for shutdown and movement to another laboratory), the decision was made to proceed immediately with the tagging of enriched fuel. Twenty elements were prepared by the tagging procedure. As required by the EBR-II Irradiations Office, the initial and final elements fabricated were submitted for determination of xenon retention. Two additional elements were submitted because of suspected weld defects and the need for more elements to characterize the bond-void pattern. The purchase of an additional capacitance-manometer system made it possible to conveniently determine the total gas quantity (xenon plus argon) contained in the fuel element. Table II gives the results of these determinations.

The first attempt to weld element EW54 closed was unsuccessful; a visible hole was observed in the weld area. Additional welds were required to seal the element. Welds were also repeated on elements EW62 and EW70, because the operator was dissatisfied with the appearance of the initial welds. These initial welds however, apparently did not have holes through which the contained gas could escape.

TABLE II. Retention of Xenon Tags in Elements
Containing Enriched Fuel Pins

<u>Element Designation</u>	<u>Xenon Transferred, cm³(STP)</u>	<u>Total Gas Recovered, cm³(STP)</u>	<u>Xenon Recovered, cm³(STP)</u>	<u>Xenon Yield, %</u>
EW51	3.518	3.515	2.259	64.2
EW54	3.393	0.570	0.502	14.8
EW62	3.122	3.063	2.677	85.7
EW70	3.461	5.021	2.299	66.4

The elements were tested for xenon retention with the same gas-handling system used during the tagging operation. Each element was placed into a quartz tube and attached to the vacuum system. The tube was then evacuated, and the element jacket was punctured with a pulsed laser beam. The total gas pressure was then measured, and the xenon was subsequently separated cryogenically. The xenon was then allowed to expand back into the calibrated volume, and its pressure was measured. A worksheet from the retention measurement, showing the values measured and the resulting calculations, has been included as Appendix C.

VI. EVALUATION OF PROCEDURE

It should be stressed that this xenon-tagging procedure has not been optimized. Some of the steps were arbitrary, because the entire tagging operation was conducted within a stringent time requirement. The fabrication schedule was governed more by the ability to achieve the desired sodium-void characteristics than the ability to xenon-tag.

In spite of lack of developmental effort, the performance of this evacuate-cryogenic transfer method was more than satisfactory. More than 3 cm³ (STP) of xenon gas were easily transferred into the plenum of 20 fuel elements, and except for one obvious weld failure (EW54), more than 2 cm³ (STP) were retained in the element plenum. The entire procedure was performed without interfering with standard procedures for fabrication of Mark-IA fuel elements.

Had time been available, the effect of the restrainer placement (while at ambient temperature) could have been evaluated. The difficulty

of maintaining a constant liquid-argon level in the Dewar in the glovebox caused another unknown: the location of the frozen xenon in the plenum. The extra five minutes of cryogenic pumping time was an arbitrary step. Judging from the pumping speed exhibited, this extra time might not have been necessary.

The attractive feature of this method is that xenon placement is positive. The evacuate-backfill and the hypodermic needle-syringe techniques both depend upon slow diffusion rates; one must assume xenon placement. With a cryogenic transfer technique, the decrease in pressure is measurable.

This procedure should be suitable for use with EBR-II Mark-II driver fuel. The Mark-II design, with a longer, larger plenum, a stronger jacket wall, and a top end plug that does not occupy significant plenum space, would allow better transfer and retention of xenon than the Mark-IA design.

APPENDIX A

Xenon-tagging Worksheet

Experiment: Bond Void (Mark-IA) Date: 10-1-71

Capsule: EW62 Tag Designation: 1X4917 Operator: ML

Remarks: Initial pressure 1.6×10^{-6} Torr

INITIAL CONDITION:

System Volume: 259.71 cm^3 @ 24°C Ambient Temp.: 21.6°C

Corrected Volume:

$$259.71 \text{ cm}^3 \times \frac{294.6^\circ\text{K}}{297^\circ\text{K}} = 257.61 \text{ cm}^3 \text{ @ } 21.6^\circ\text{C}$$

System Pressure: 21.22 mm

Gas Content:

$$\frac{273^\circ\text{K} \times 21.22 \text{ mm} \times 257.61 \text{ cm}^3}{760 \text{ mm} \times 294.6^\circ\text{K}} = 6.665 \text{ cm}^3 \text{ (STP)}$$

FINAL CONDITION:

System Volume: 249.97 cm^3 @ 24°C Ambient Temp.: 21.6°C

Corrected Volume:

$$247.97 \text{ cm}^3 \times \frac{294.6^\circ\text{K}}{297^\circ\text{K}} = 247.95 \text{ cm}^3 \text{ @ } 21.6^\circ\text{C}$$

System Pressure: 11.72 mm

Gas Content:

$$\frac{273^\circ\text{K} \times 11.72 \text{ mm} \times 247.95 \text{ cm}^3}{760 \text{ mm} \times 294.6^\circ\text{K}} = 3.543 \text{ cm}^3 \text{ (STP)}$$

Initial Content: 6.665 cm^3 (STP)

Final Content: 3.543 cm^3 (STP)

XENON TRANSFERRED:

3.122 cm^3 (STP)

APPENDIX B

Xenon-tagging Procedure for Mark-IA Partially Bonded Fuel Elements

Objective

The objective of this procedure is to place a unique isotopic xenon-gas mixture into the plenum of a group of EBR-II Mark-IA fuel elements. The fuel elements are partially sodium-bonded and are expected to develop flaws during irradiation. The xenon-gas tag should identify this group of elements at the time of cladding failure and thus eliminate search-mode operation of the reactor. This procedure places the gas-tag mixture inside the fuel jacket without interference with the standard fuel-fabrication procedure.

Reference Documents

1. "Guide for Irradiation Experiments in EBR-II," Revision 4, (February 1971): Section IX, Xenon Tagging.
2. "Product Specification for the EBR-II Driver Fuel Elements," FCF-1, Revision 7 (March 1, 1970).

Technique

The method used to xenon-tag the fuel elements is an evacuate-cryogenic transfer method. The procedure transfers and freezes about 3 cm³ (STP) of xenon gas in an EBR-II Mark-IA fuel element just prior to final seal-welding in an inert atmosphere. The gas-handling system used external to the welding chamber is that system used to blend xenon-gas tag mixtures for supply to EBR-II experimenters. Three cubic centimeters are desired (1 cm³ is standard) in order to produce an increased plenum pressure, thereby ensuring a gas-tag release regardless of failure mechanism.

The open fuel jacket containing fuel and sodium is connected to the gas system, which is then evacuated. The appropriate amount of xenon gas is then expanded into the gas system. The fuel element is then contacted by liquid argon (B.P. -186°C), which cryogenically pumps the xenon gas (B.P. -107°C) into the fuel jacket. The top end fitting of the fuel jacket is then

rapidly placed and welded while the xenon gas remains frozen in the fuel jacket.

Procedure

All piping added to the gas-handling system will be precalibrated during procedure checkout. Xenon-tag supply will be attached and system leak-checked. All electronics will be powered early enough such that instrument drift is minimized.

Caution: The introduction into the enclosed welding chamber of quantities of liquid argon and the possibility of rapid vaporization require the ability to remove large volumes of gas quickly to maintain the enclosure integrity. The use of transfer-port evacuation pumps to pump directly from the enclosure to an exhaust plenum is advised.

Refer to Fig. 4

1. Install fuel jacket in system and close valve No. 1.
2. Open valves Nos. 2, 3, 5, and 6 and evacuate system (valve No. 4 closed) to $<3 \times 10^{-6}$ Torr. Valve No. 5 is used to speed pumping of the entire system prior to introduction of the xenon-gas tag. Once xenon has been introduced into the expansion volume, this valve remains closed for the entire tagging procedure.
3. Close valves Nos. 2, 5, and 6 and prepare to observe the vacuum condition after a period of time (~ 5 min), using the ionization gauge to check for possible leaks. This leak-check is made by temporarily opening valve No. 6 to observe the effect of the isolated, evacuated system on the ionization gauge.
4. Open valve No. 2, expand xenon gas into the expansion volume by means of valve No. 4 until the desired pressure is obtained (Baratron gauge), which places the desired quantity of gas in the expansion volume plus fuel jacket.
5. Raise Dewar to submerge fuel jacket to desired level. Maintain the liquid-argon level until the desired quantity of xenon gas has been cryogenically pumped into the fuel jacket (Baratron gauge). A typical pressure drop is from 20 Torr to 10 Torr for a 260 cm^3 system volume.

Fig. 4. Schematic of Xenon-tagging System

NOTE: The cryogenic pumping should proceed rapidly. The desired pressure drop may be difficult to catch. If an overshoot of this type occurs, remove the liquid-argon Dewar and carefully vent off to supply system (using valve No. 2) the excess xenon gas. Then continue the procedure as per Step 6.

6. Close valve No. 2 to isolate the fuel jacket from the tag supply system. Maintain the liquid-argon level for 5 min to ensure complete freezing of the xenon into the jacket. Prepare to make final seal weld.

7. Open valve No. 1 to equalize the internal fuel-jacket pressure to that of the welding chamber. Do not remove liquid-argon Dewar.

8. Remove fuel jacket from coupling, insert top end restrainer, remove from liquid-argon Dewar, and weld according to Ref. 2. Weld should be made within 30 sec after removing jacket from liquid argon.

9. The next fuel element is xenon-tagged by connecting the jacket to the system, closing valve No. 1, opening valve No. 6, evacuating the fuel-jacket volume, and then proceeding as in Step 3 (valves Nos. 2 and 5 remain closed).

NOTE: Special tools should be used to handle the open fuel jacket while at liquid-argon temperature.

This procedure interfaces with the special requirements for handling reactor fuel and with the equipment operation in the argon-atmosphere chamber. The addition of the xenon gas and chilling of the fuel and jacket to liquid-argon temperature does not interfere with the welding procedure of Ref. 2.

APPENDIX C

Xenon-tagging Worksheet - Yield Determination

Experiment: Bond Void (Mark-IA) Date: 10-7-71

Capsule: EW62 Tag Designation: 1X4917 Operator: ML

Remarks: Initial pressure 5.0×10^{-7} Torr

LASER OPERATION: Lens: 100 mm

Four holes, 2 shots each @ 5.75 keV.

INITIAL CONDITION:

System Volume: 287.48 cm^3 @ 24°C Ambient Temp.: 23.75°C

Corrected Volume:

$$287.48 \text{ cm}^3 \times \frac{296.75^\circ\text{K}}{297^\circ\text{K}} = 287.24 \text{ cm}^3 \text{ @ } 23.75^\circ\text{C}$$

System Pressure: 8.81 mm

Gas Content:

$$\frac{273^\circ\text{K} \times 8.81 \text{ mm} \times 287.24 \text{ cm}^3}{760 \text{ mm} \times 296.75^\circ\text{K}} = 3.063 \text{ cm}^3 \text{ Xe + Ar (STP)}$$

XENON SEPARATION:

Start: 0620 hrs Finish: 0900 hrs Total Time: 2 hr 40 min.

Remarks: Xe cryo-pumped into cylinder #42 (10.61 cm^3 @ 24°C) with LN_2 .

FINAL CONDITION:

System Volume: 254.42 cm^3 @ 24°C Ambient Temp.: 24.3°C

Corrected Volume:

$$254.42 \text{ cm}^3 \times \frac{297.3^\circ\text{K}}{297^\circ\text{K}} = 254.68 \text{ cm}^3 \text{ @ } 24.3^\circ\text{C}$$

System Pressure: 8.70 mm

Xenon Content:

$$\frac{273^\circ\text{K} \times 8.70 \text{ mm} \times 254.68 \text{ cm}^3}{760 \text{ mm} \times 297.3^\circ\text{K}} = 2.677 \text{ cm}^3 \text{ (STP)}$$

Remarks: Xe + Ar = 3.063 cm^3 (STP)

Xe = 2.677 cm^3 (STP)

Ar = 0.386 cm^3 (STP)

XENON YIELD:

Initial Tag Volume: 3.122 cm³ (STP) Source: ANL Tag Worksheet*

Recovered Tag Volume: 2.677 cm³ (STP)

Remarks: $\frac{2.677}{3.122} \times 10^2 = 85.75\%$ yield

XENON ANALYSIS:

Date: 10-11-71

¹²⁴ Xe	1.02 Mol %
¹²⁶ Xe	0.777
¹²⁸ Xe	17.19
¹²⁹ Xe	50.46
¹³⁰ Xe	4.30
¹³¹ Xe	13.35
¹³² Xe	10.45
¹³⁴ Xe	1.73
¹³⁶ Xe	0.717

*Appendix A of this report--Ed.

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