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FABRICATION OF LIGHT WATER REACTOR TRITIUM TARGETS

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FABRICATION OF LIGHT WATER REACTOR TRITIUM TARGETS

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INTRODUCTION

The mission of the Fabrication Development Task of the Tritium Target Development Project is: 1) to produce a documented technology basis, including specifications and procedures for target rod fabrication; 2) to demonstrate that light water tritium targets can be manufactured at a rate consistent with tritium production requirements; and 3) to develop quality control methods to evaluate target rod components and assemblies, and establish correlations between evaluated characteristics and target rod performance. Many of the target rod components: cladding tubes, end caps, plenum springs, etc., have similar counterparts in LWR fuel rods. High production rate manufacture and inspection of these components has been adequately demonstrated by nuclear fuel rod manufacturers. This summary describes the more non-conventional manufacturing processes and inspection techniques developed to fabricate target rod components whose manufacturability at required production rates had not been previously demonstrated.

FABRICATION

A documented technology basis, and a demonstration of production rate manufacturability for target rods and target rod components, are both natural products of fabrication development and demonstration activities. Large numbers of components and assembled target rods are required to achieve goal production in the LWR-NPR. An annual supply of 15,750 target rods including corresponding numbers of acceptable cladding tubes, upper and lower end caps, plenum springs, getter tubes and inner shrouds (approximately 189,000), and target pellets (7,182,000) are required. Although large quantities of components must be fabricated and assembled, many of the components have similar counterparts in LWR nuclear fuel rods (a typical PWR has 50,000 fuel pins employing 35,000,000 fuel pellets). Production and quality control of nuclear fuel rod counterpart components have been adequately demonstrated by nuclear fuel rod manufacturers. The focus of the manufacturability issue is related to: 1) demonstration of manufacturing rates for making thin-wall annular target rod pellets; 2) new fabrication processes for nickel plating of zircaloy getter tubes; and 3) application of aluminide permeation barriers to 20% cold worked 316 stainless steel target rod cladding tubes.

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Annular Target Rod Pellet

Two manufacturing options exist for fabrication of target rod pellets: isostatically press and sinter, or uniaxially press and sinter. Both processes have been demonstrated on a laboratory or limited manufacturing basis. Advantages and disadvantages exist for each process. With isostatic pressing one can produce longer and more uniformly dense pellets; therefore, fewer pellets are required. Pellet wall thickness, however, is more difficult to control and production rates are comparatively low. Production rates for uniaxially pressed pellets are very high and wall thickness is easily controlled. Uniform pellet density is more difficult to achieve and limits one to producing relatively short pellets. Powder constituency and characteristics must be closely controlled.

Nickel Plated Zircaloy (NPZ) Getters

Zircaloy is an excellent getter material and has a high absorption rate for tritium. Because zircaloy is a highly reactive metal, it also has an affinity for oxygen and oxide layers quickly form on exposed surfaces. Such surface oxide layers inhibit the absorption of tritium. A thin coating of nickel, which is oxidation resistant and highly permeable to tritium, placed on the surfaces of the zircaloy getter effectively allows the tritium access to the getter through an oxide-free surface. Electroplating is the fabrication process selected for placing a nominal 0.0127 mm (0.0005 in.) thick coating of nickel on the zircaloy getter tubes. Virtually no commercial experience base existed for electroplating nickel on zircaloy. A procedure was developed and demonstrated in the laboratory for electroplating nickel on zircaloy-4 getter tubes. The process employs an alkaline degrease cleaner, a sulfuric ammonium bifluoride etch, and a sulfamate nickel plating solution. In an effort to develop a commercial experience base for the electroplating of nickel on zircaloy-4, a contract was placed with a commercial electroplater to determine if this laboratory scale plating process could be scaled up to a production level process. Production scaleup to an intermediate level was demonstrated and full production scaleup is readily possible.

Cladding Aluminide Barrier

Stainless steel has good, well-demonstrated mechanical properties for use as target rod cladding, although it also has high permeability for tritium. A thin coating of aluminum or an aluminide compound layer on the 316 stainless steel surface proves to be a very effective tritium permeation barrier. A metal aluminide layer, applied by a pack diffusion coating process, has been demonstrated to be a highly effective tritium permeation barrier with no impact on the cladding's mechanical strength. During barrier development activities, both laboratory scale and commercial scale, barrier coatings have been evaluated using destructive and nondestructive techniques. Destructive evaluation has been performed using optical and electron microscopy and load-deflection testing. Nondestructive evaluation (NDE) has been done by eddy current and air gauge testing and deuterium permeation tests. A preliminary analysis of the data obtained from this barrier coating development indicates that a correlation exists between barrier aluminum concentration, barrier thickness, and barrier PRF.

NDE INSPECTION

Control of target rod quality necessitates assuring the quality of all target rod components and assembly activities. All target rod components except the barrier coated cladding can be inspected or evaluated using methods and techniques common in commercial industry. Inspection of the cladding ID barrier must be done nondestructively because the condition of the barrier is critical to permeation performance of the rod and a relatively small exposed clad surface area could result in a significant increase in tritium permeation. Inspection of the barrier is difficult because of the length/diameter geometry of the tube. Effectiveness of the permeation barrier during the process development phase was determined by real time deuterium permeation testing which is discussed in a companion paper. This nondestructive method of testing is effective but is extremely slow. A single deuterium permeation test requires from one to three weeks. In order to effectively control the quality of the target rod, all manufactured barriers must be nondestructively assessed. The NDE techniques, in order to be effective, must be able to assure assembly (dimensional characterization) and to assess performance related parameters. Performance related parameters in the barrier coating are barrier thickness and aluminide microstructure. Air gauge NDE techniques are used to provide the dimensional characterization and eddy current NDE techniques have been developed that can read barrier thickness and discriminate acceptable microstructures.

Air Gauge Testing

Air gauge testing is used to perform the dimensional characterization and determine size envelope acceptability. Air gauging is fast, precise, and readily automated. This inspection technique is well adapted to meet production rate requirements.

Eddy Current Testing

A dual frequency eddy current test system has been developed for evaluation of aluminide barriers on 316 stainless steel target rod cladding. Development of this system has closely paralleled the development of the aluminide barrier coating and has enhanced our ability to make rapid assessment of barrier coatings supplied by a commercial vendor. This NDE technique is fast, can precisely determine barrier thickness, and can discriminate between acceptable and nonacceptable barrier microstructures. This inspection technique is also well adapted to meet production rate requirements.

SUMMARY

All information contained in this abstract and accompanying viewgraphs refer to the Laboratory-scale development of fabrication processes necessary to support the assessment of the LWR-NPR option for tritium production. This work is sponsored by the Office of New Production Reactors, United States Department of Energy.

Fabrication of Light Water Reactor Tritium Targets

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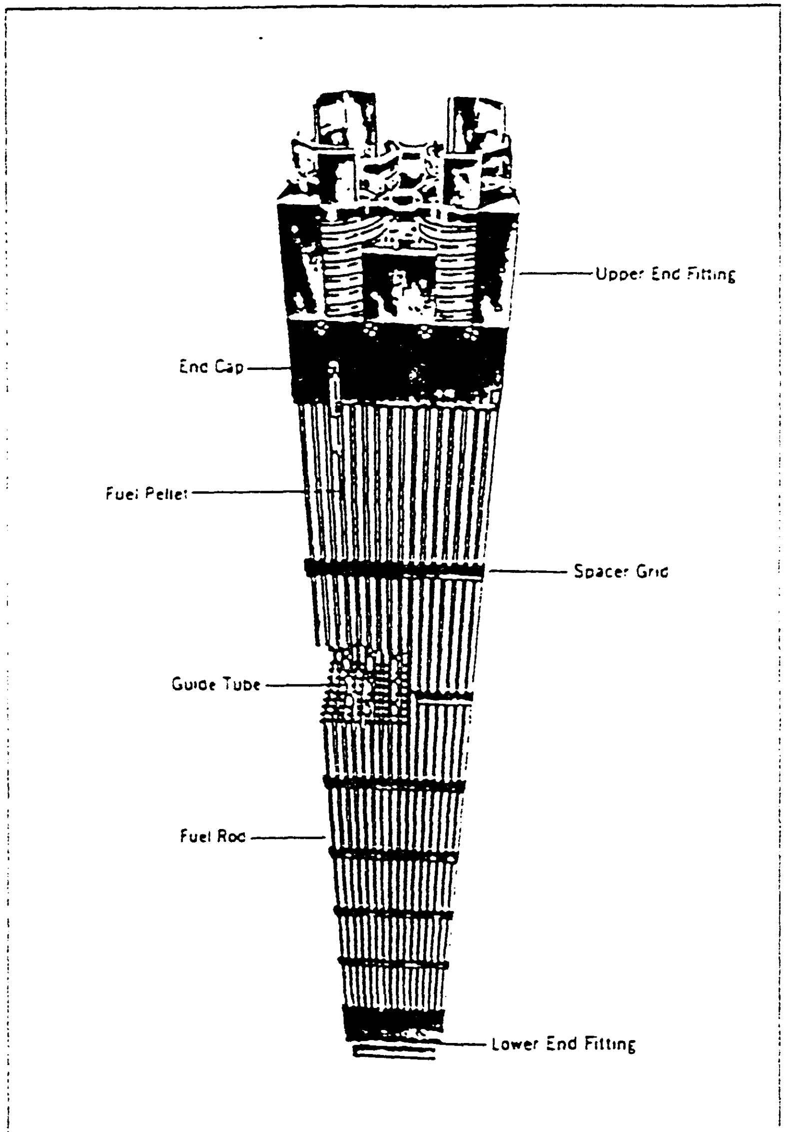
Background

Keep Subtitle

Pressurized Light Water Reactor Fuel Assembly



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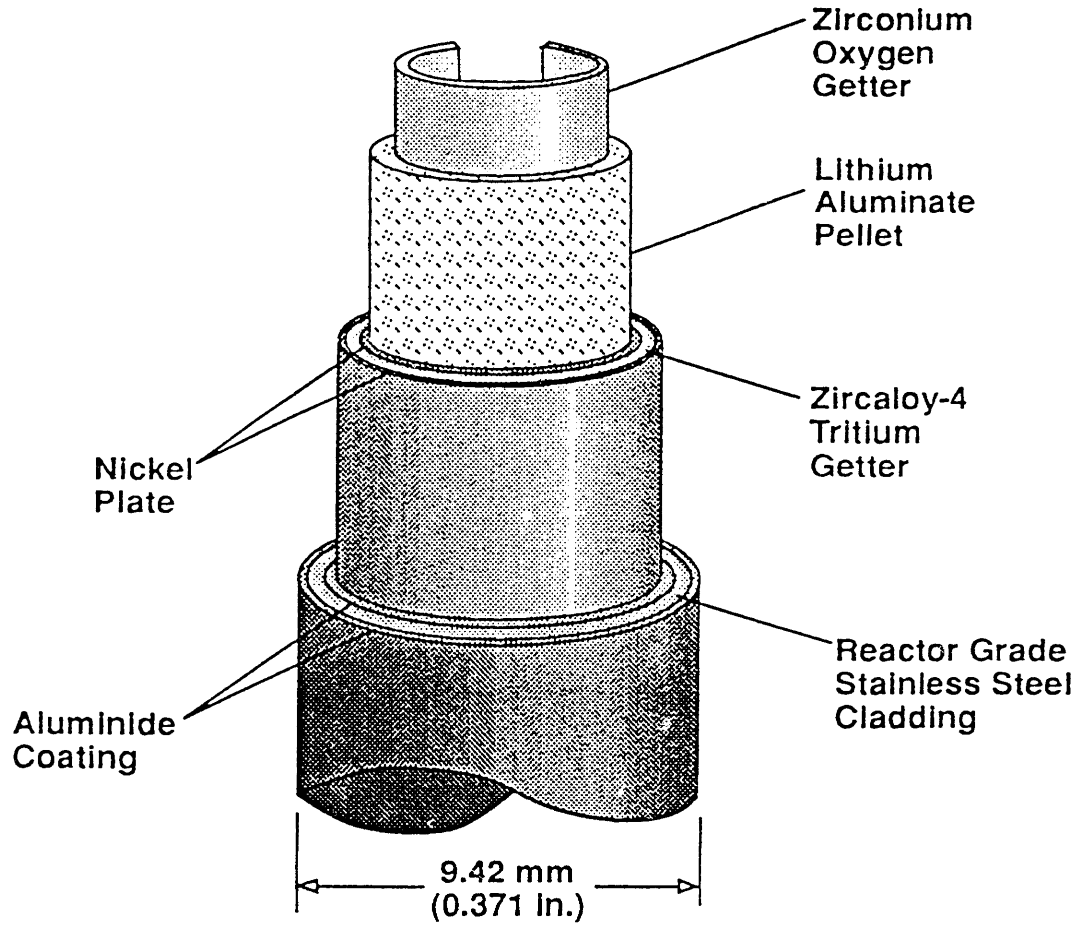
Light Water Reactor Tritium Target Rod



Not to Scale

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Objectives

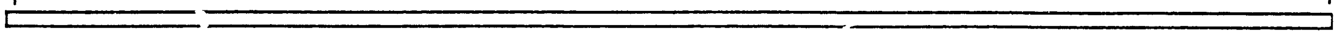
- Fabrication
  - Determine/demonstrate target rods can be manufactured at a production rate of 15,750/year

- Inspection
  - Establish NDE technology to assure target rods meet performance (product retention) criteria

Fabrication

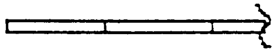
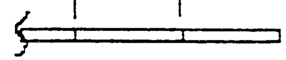
Assemblies – 15,750/year

9.42 mm (.371-in.) dia. x 3.81 m (150.1-in.) long



Getter Pencils – 189,000/year

8.13 mm (.320-in.) dia. x 304 mm (12-in.) long

 12 Getter Pencils per Target Rod 

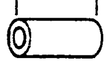
Target Pellets – 1,134,000/year (isostatic press)

50.8 mm (2-in.)

7.64 mm (.301-in.) dia. x 1 mm (.040-in.) wall

7,182,000/year (uniaxial press)

8 mm (.316-in.)



7.64 mm (.301-in.) dia. x 1 mm (.040-in.) wall

Fabrication

- Conventional manufacturing processes – components routinely fabricated for nuclear fuel rods or have demonstrated manufacturability
  - End caps
  - Plenum springs
  - Cladding tubes
  - Getter tubes
  - Liner tubes

- Nonconventional manufacturing processes components requiring fabricated process development to meet production rate and quality requirements
  - Target pellets
  - Nickel plated zircaloy (NPZ) getters
  - Aluminide barrier coated cladding

Target Pellets – Lithium Aluminate, 95% TD

Two Manufacturing Options

- Isostatic pressing
  - \+ Long pellets (fewer required)
  - \+ Uniform density
  - – Wall thickness/size control (O.D. grind on mandrel)
  - – Lower production rate

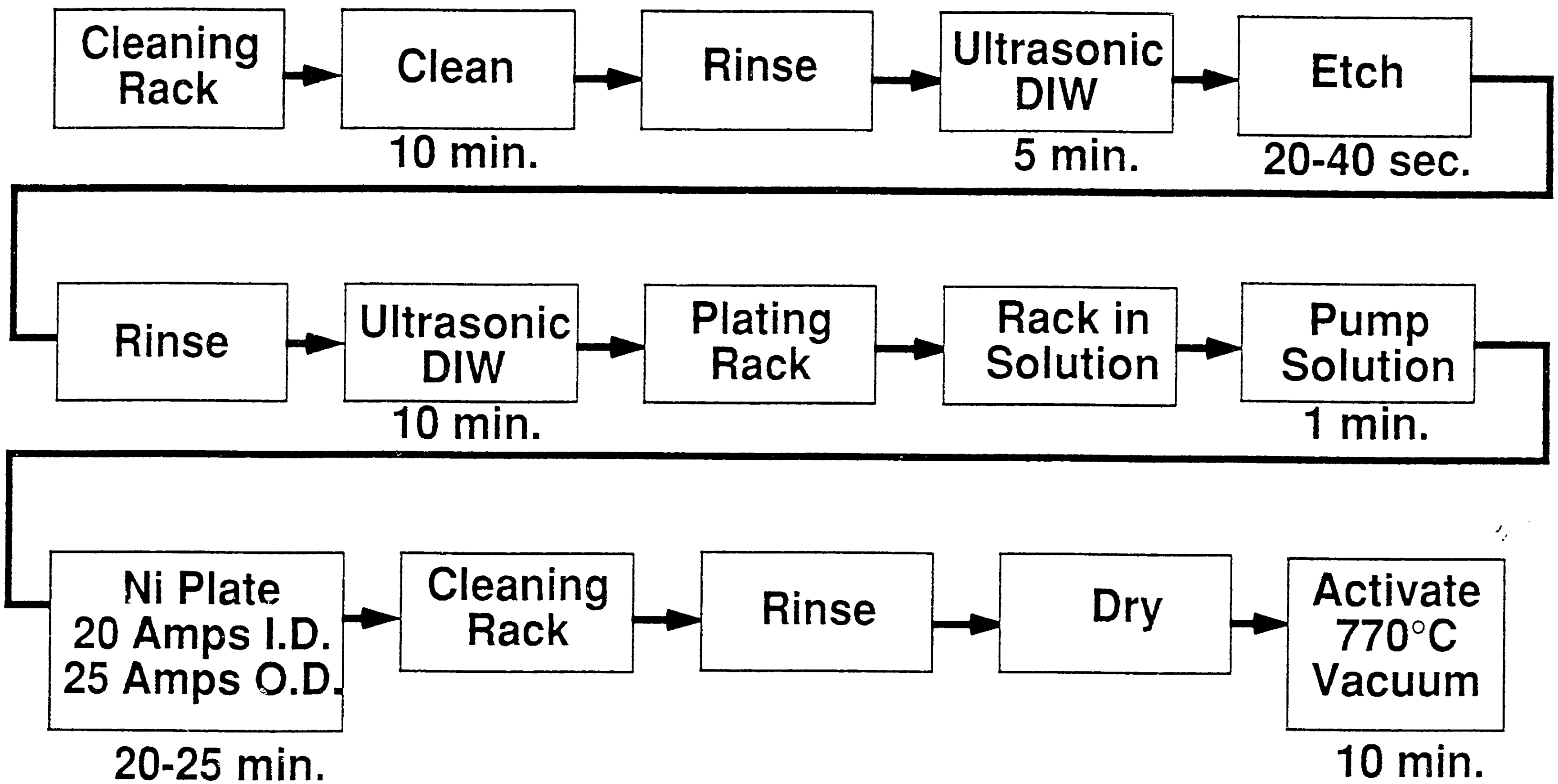
- Uniaxial pressing
  - \+ High production rate
  - \+ Wall thickness/size control (centerless grind)
  - – Short pellets/density control (hourglassing)
  - – Powder constituency (die lubricants)

Both options have been demonstrated on a laboratory or limited manufacturing basis – will require trade off studies to support selection of process

NPZ Getters – Nickel Electroplated Zircaloy-4

- Development a commercial nickel plating process for zircaloy-4 getter tubes
  - Produce getters that meet performance (gettering rate) criterion
  - Produce 0.0076 mm (0.0003-in.) to 0.018 mm (0.0007-in.) thick Ni plate on internal and external tube surfaces
  - No visible blisters or defects
  - Plate must be adherent (not separate from tube when cut or bent)
  - Process at least ten parts simultaneously
  - Capable of scaleup to 480 tubes/shift (two shift basis)

NPZ Getters – Process Schematic



NPZ Getters – Process Solutions

Clean (alkaline degrease)	
Macdermid soak 028	69-90 g/L
Water	Balance
Temperature	80-100°C
Etch (Sulfuric ammonium bifluoride)	
Ammonium bifluoride ($NH_4 \cdot HF_2$)	12-18 g/L
Concentrated sulfuric acid (H_2SO_4)	0.3-0.6 ml/L
Deionized water	Balance
Temperature	Ambient
Plate (sulfamate nickel)	
Nickel (metal equivalent)	62-82 g/L
Nickel chloride ($NiCl_2 \cdot 6H_2O$)	2-10 g/L
Nickel sulfamate ($NiSO_4 \cdot 6H_2O$)	280-340 g/L
Boric acid (H_3BO_3)	38-45 g/L
Water	Balance
Temperature	45-55°C

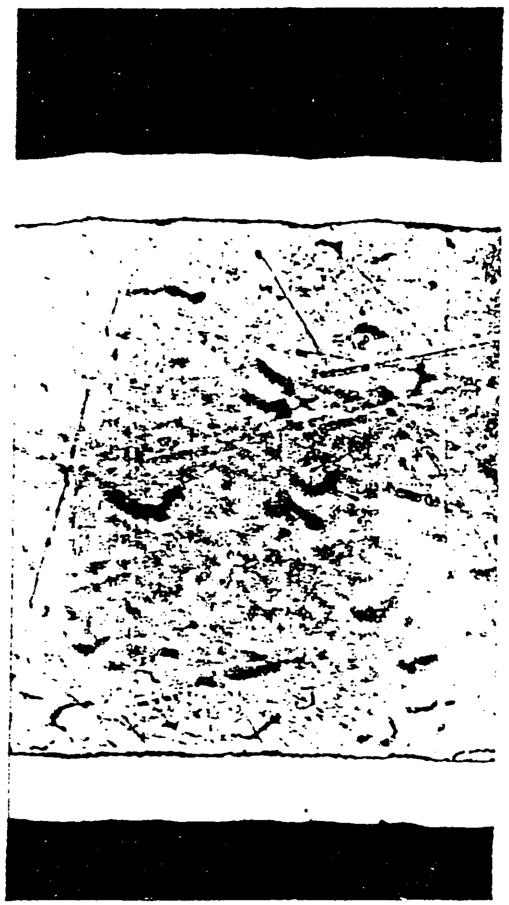
Note: Plating solution filtered through a carbon filtration system.

NPZ Getters – Process Development Notes

- Etching
  - Variations of ASTM B614-77 (nitric-hydroflouric) zircaloy bright etch – little or no nickel plate adherence
  - Sulfuric ammonium biflouride – produces black residue, when removed, exposes a matte surface – good nickel plate adherence
- Plating
  - Platinized titanium (nonconsumable) anodes were used for I.D. electrodes
  - Nickel (consumable) anodes were used for O.D. electrodes
  - Ten tubes/rack
  - Plating solution circulated (pumped) through tubes

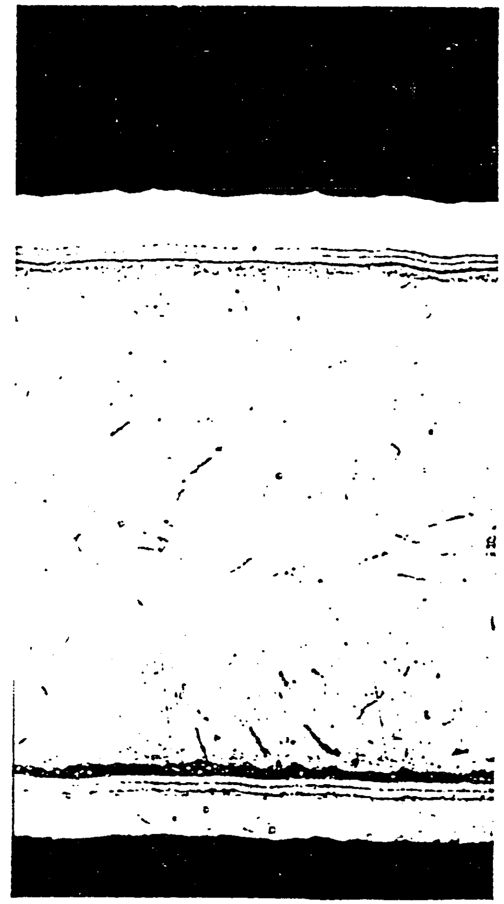
NPZ Getters

Before Heat Treatment



500 x Tube EO

After Heat Treatment

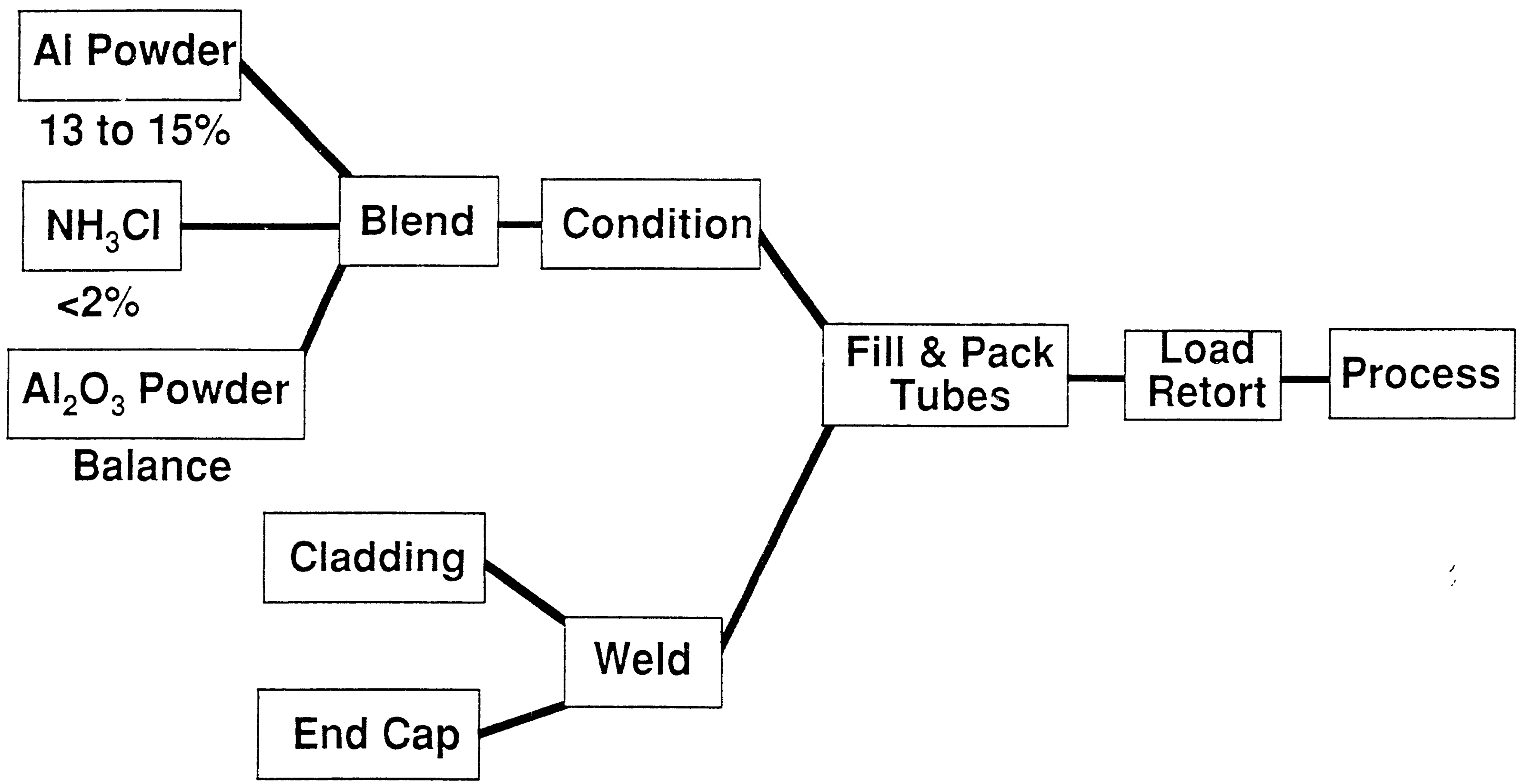


500 x Tube EO

Aluminide Barrier

- Develop/demonstrate application of a tritium barrier coating for 316 stainless steel target rod cladding
  - Produce a barrier coating that meets target rod performance criterion (high permeation reduction factor-PRF)
  - Barrier to be reproducible under production rate manufacturing conditions (50/shift on single shift basis)
  - Barrier shall have adequate ductility and abrasion resistance to survive target rod assembly activities
  - Barrier capable of application on cladding subassemblies (one end cap in place)
  - Barrier and application process must not degrade cladding
  - Barrier must not be degraded by environment

Aluminide Barrier – Process Schematic



Aluminide Barrier – Coating Evaluation Matrix

Barrier Goal Aluminum Content

MAl_x	I.D. Coating Thickness		
MAl_1	0.013 mm 0.0005 in.	0.038 mm 0.0015 in.	0.64 mm 0.0025 in.
MAl_2	0.025 mm 0.001 in.	0.064 mm 0.0025 in.	0.102 mm 0.004 in.
MAl_3	0.025 mm 0.001 in.	0.064 mm 0.0025 in.	0.102 mm 0.004 in.

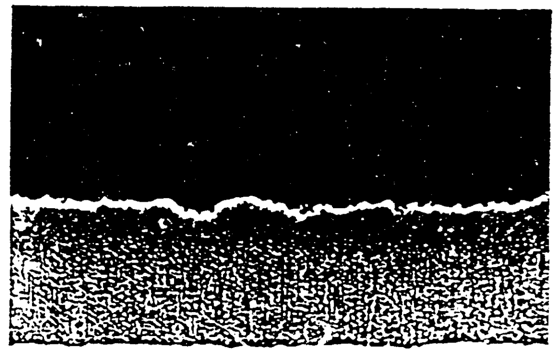
M = Fe+Cr+Ni+Mo+Si atoms in the aluminide coating
Al = Number of aluminum atoms in the aluminide coating

Aluminide Barrier – Evaluation Techniques

- Nondestructive
  - Eddy current scan (thickness and homogeneity)
  - Air gauge (dimensional consistency)
  - Deuterium permeation (bulk permeation)
- Destructive
  - Optical microscopy (microstructure)
  - Electron microscopy (composition)
  - Load-deflection (ductility)

Aluminide Barrier – Destructive Evaluation (Optical Microscopy)

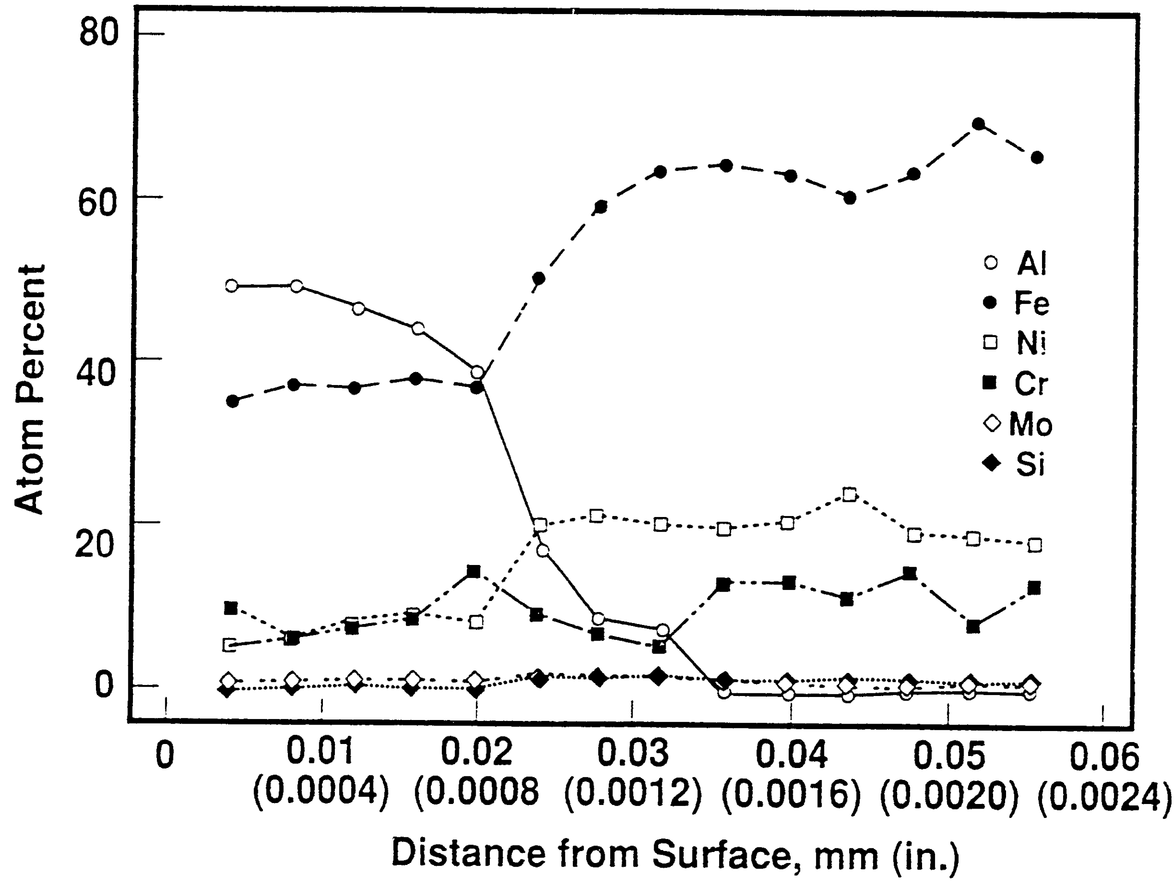
Tube 23
648 °C/4 hr 871 °C/2 hr



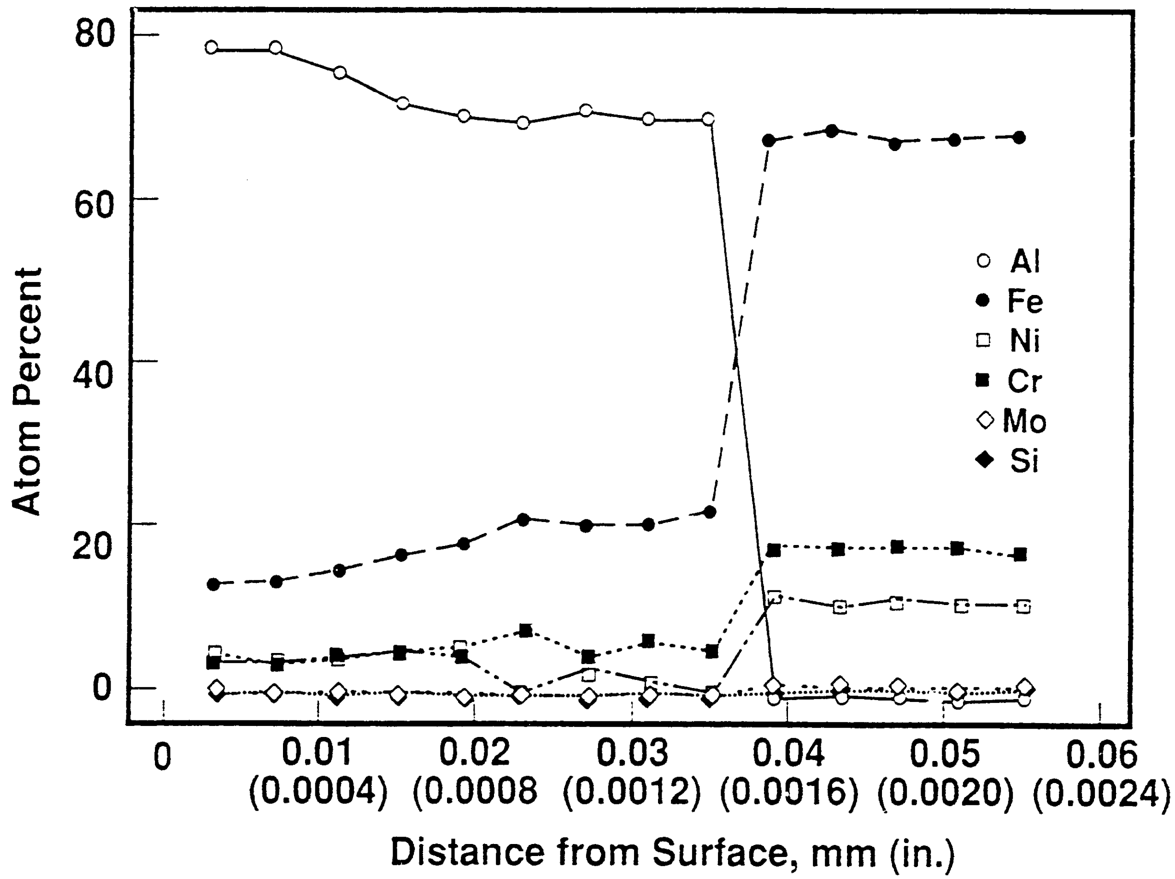
Tube 128
677 °C/6 hr

Metallography at 500 x

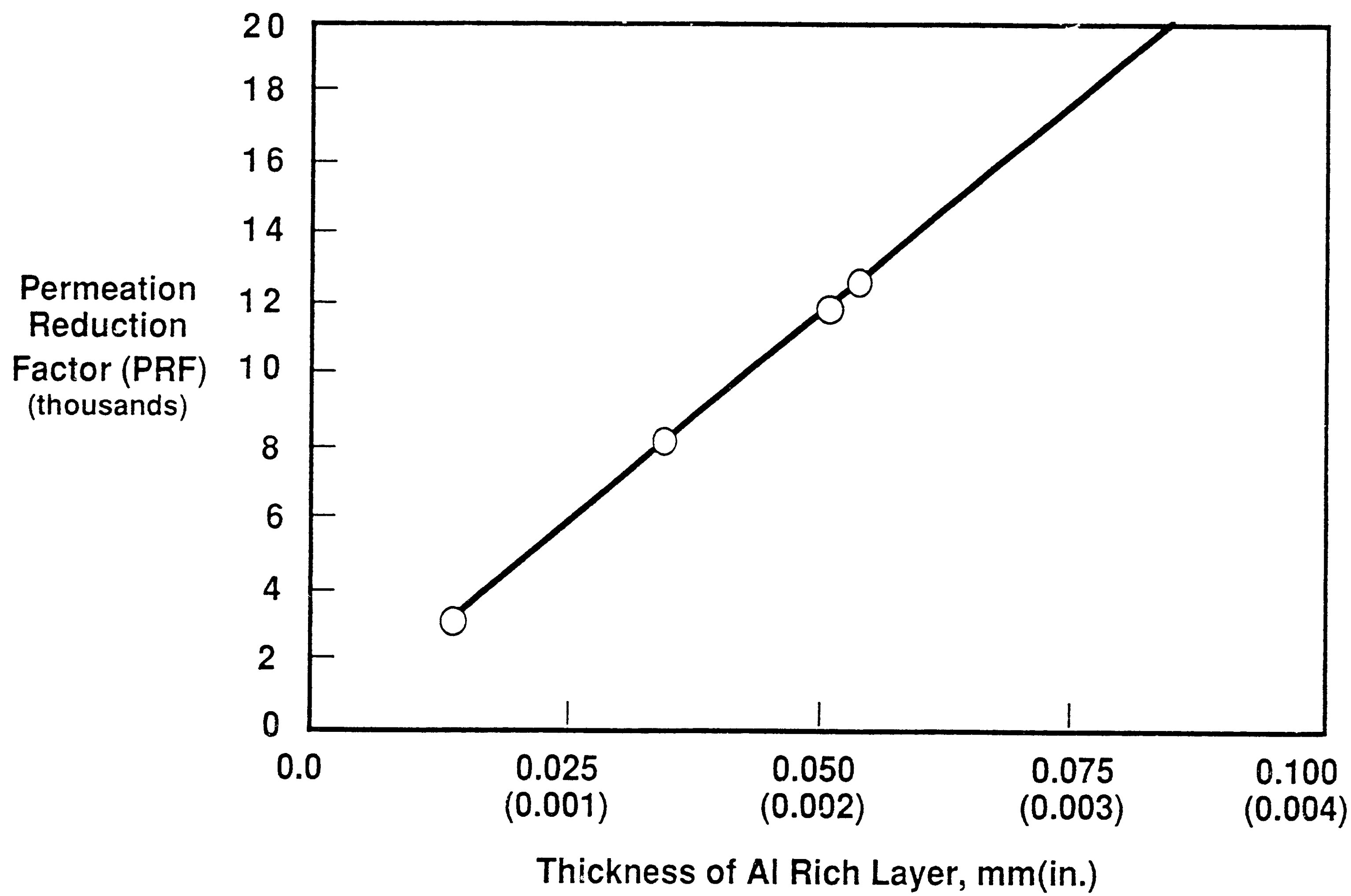
Aluminide Barrier – Destructive Evaluation (Electron Microprobe)



Aluminide Barrier – Destructive Evaluation (Electron Microprobe)



Aluminide Barrier – Preliminary Correlation



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Aluminide Barrier – Preliminary Conclusions

- Adequate permeation barrier (>1000 PRF) can be placed on target rod cladding I.D.
- Barrier coating process can be scaled to full production of full length cladding
- Homogeneous microstructure is preferable (performance, NDE, process)
- Commercially applied
- Good adherence, abrasion resistance and ductility

NDE Objectives – Aluminide Barrier

- Measure barrier characteristics and determine/develop performance (permeation) related correlations
- Measure dimensional characteristics
- Sensitive to localized changes in barrier quality
- Provide adequate precision and accuracy of measurement
- Capable of production scale application
- Applicable by a barrier coating fabricator

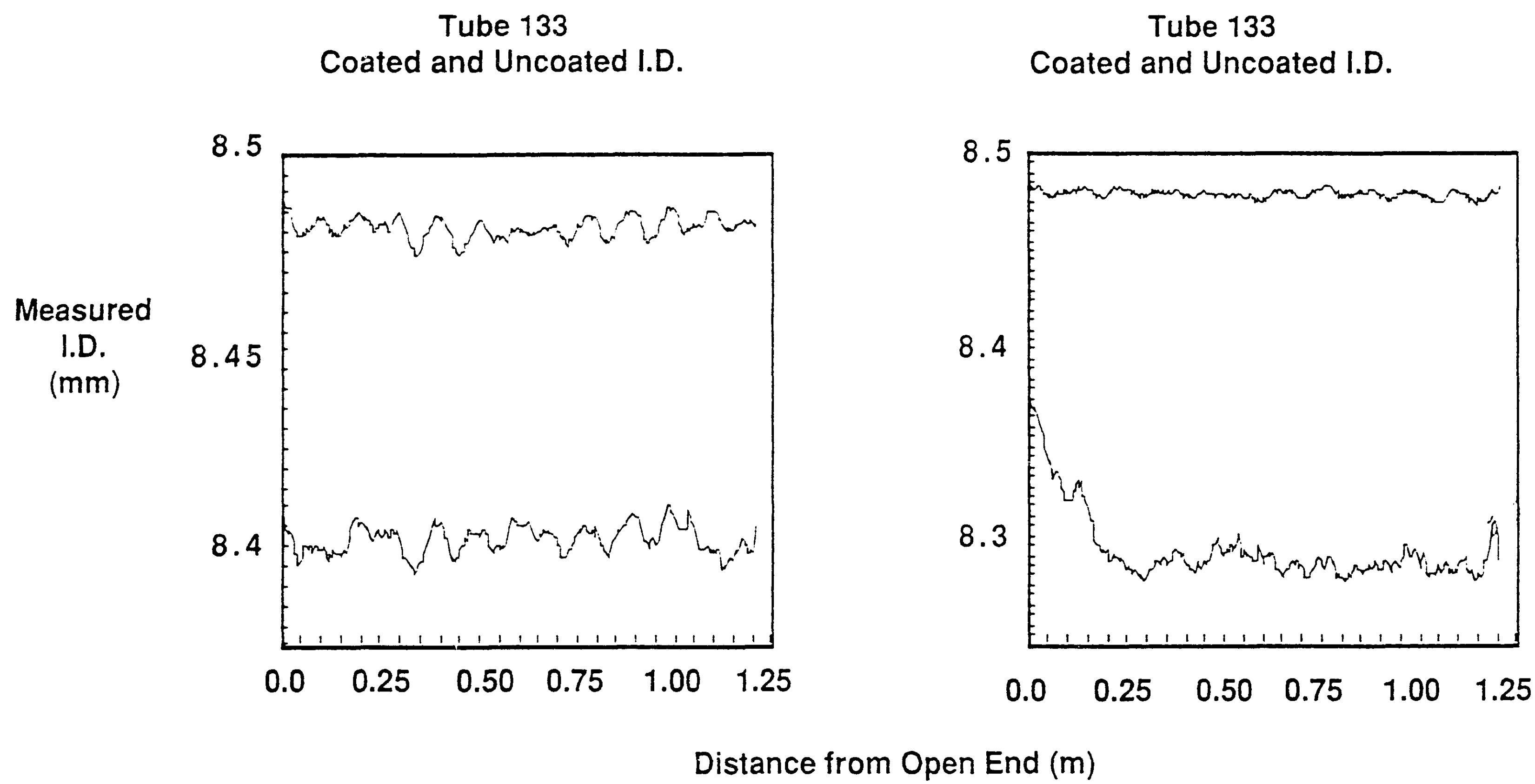
NDE Techniques – Aluminide Barrier

- Deuterium permeation
  - Integrated barrier value (PRF)
  - Temperature/pressure effects
  - Time consuming – days

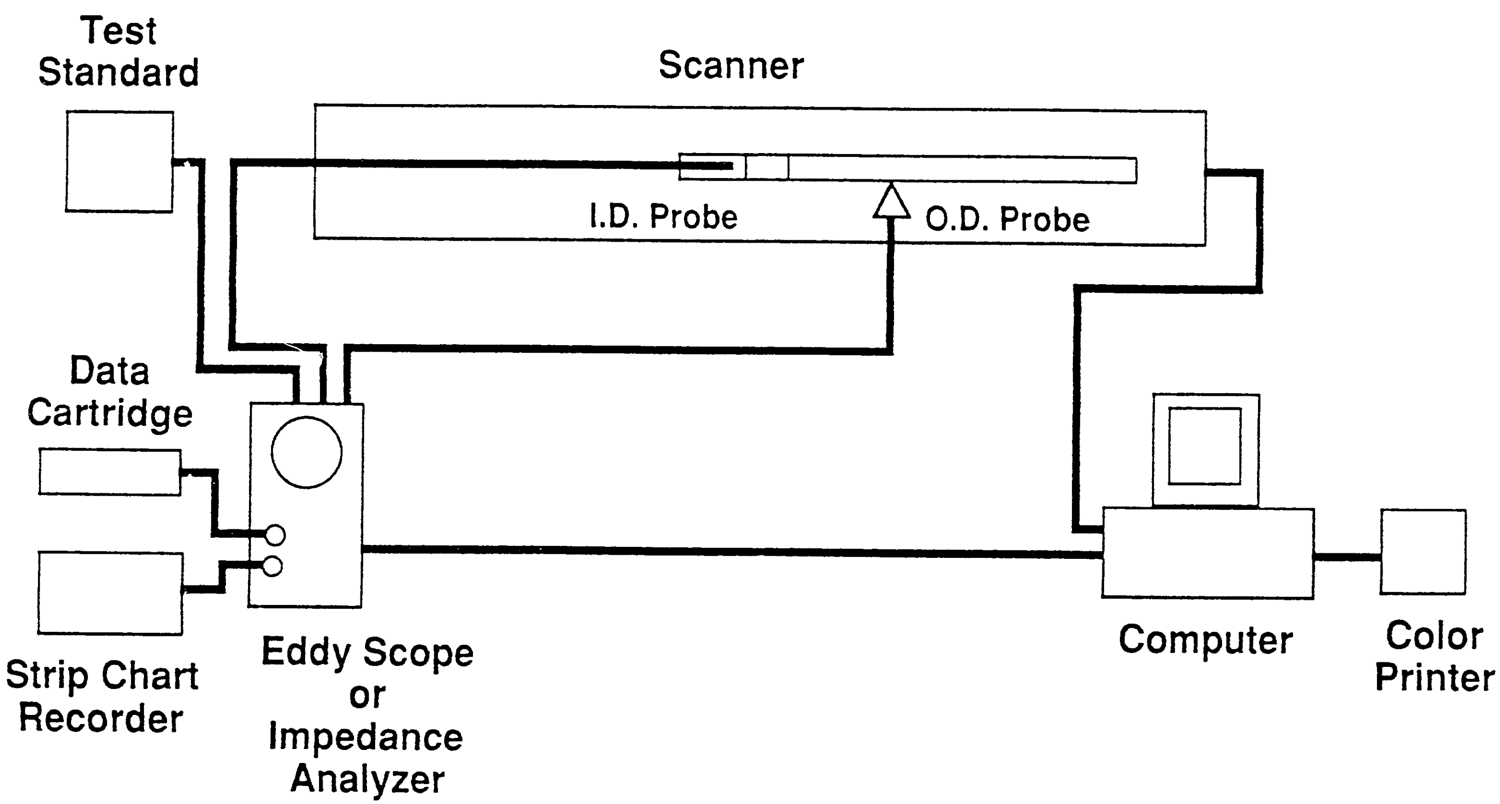
- Air gauge
  - Dimensional acceptability
  - Fast and precise (15-30 min.)

- Eddy current
  - Barrier thickness
  - Microstructure (homogeneity)
  - Fast and precise (15-30 min.)

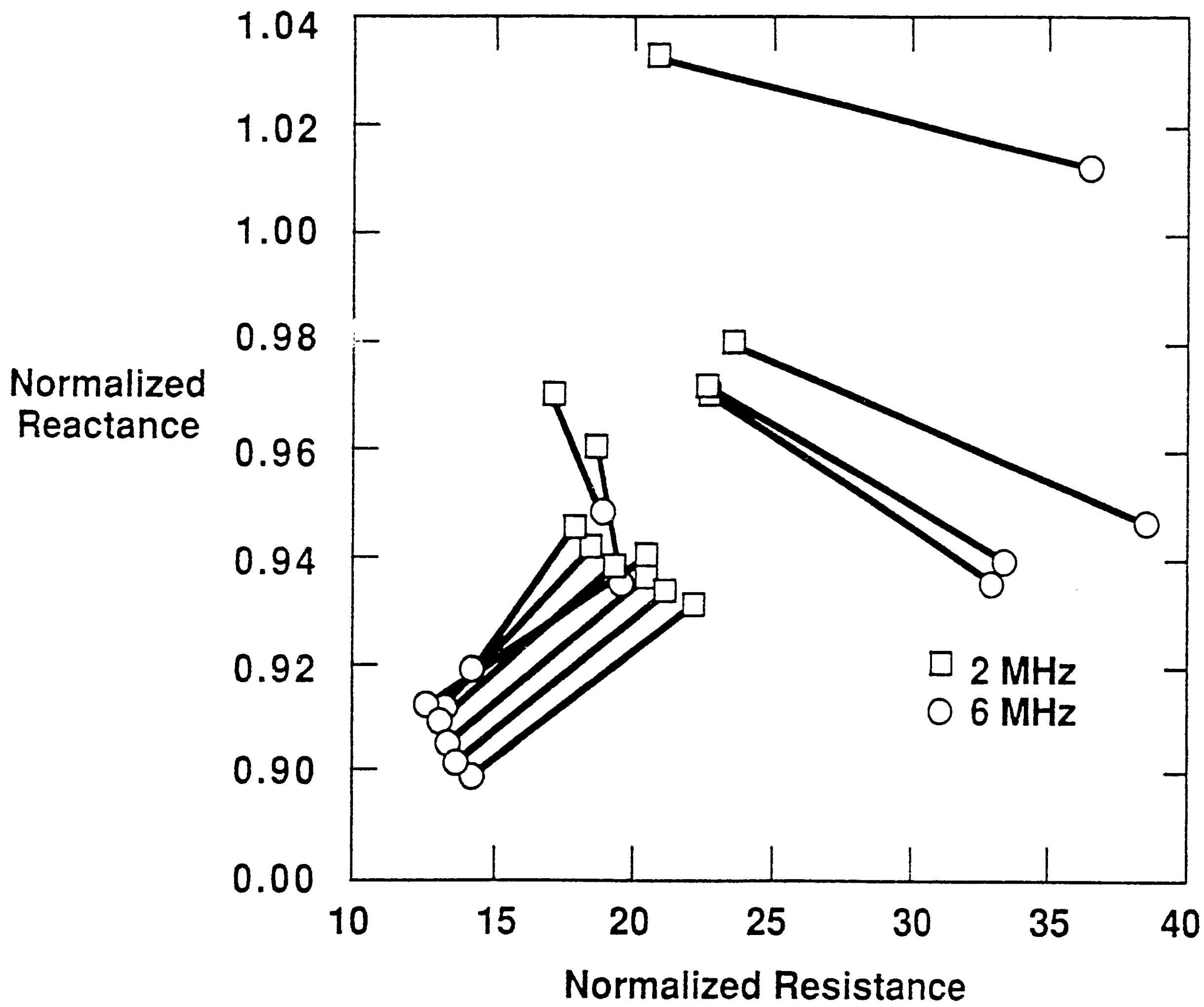
NDE Techniques – Air Gauge



NDE Techniques – Eddy Current System Block Diagram



Eddy Current – Dual Frequency Impedance Plot



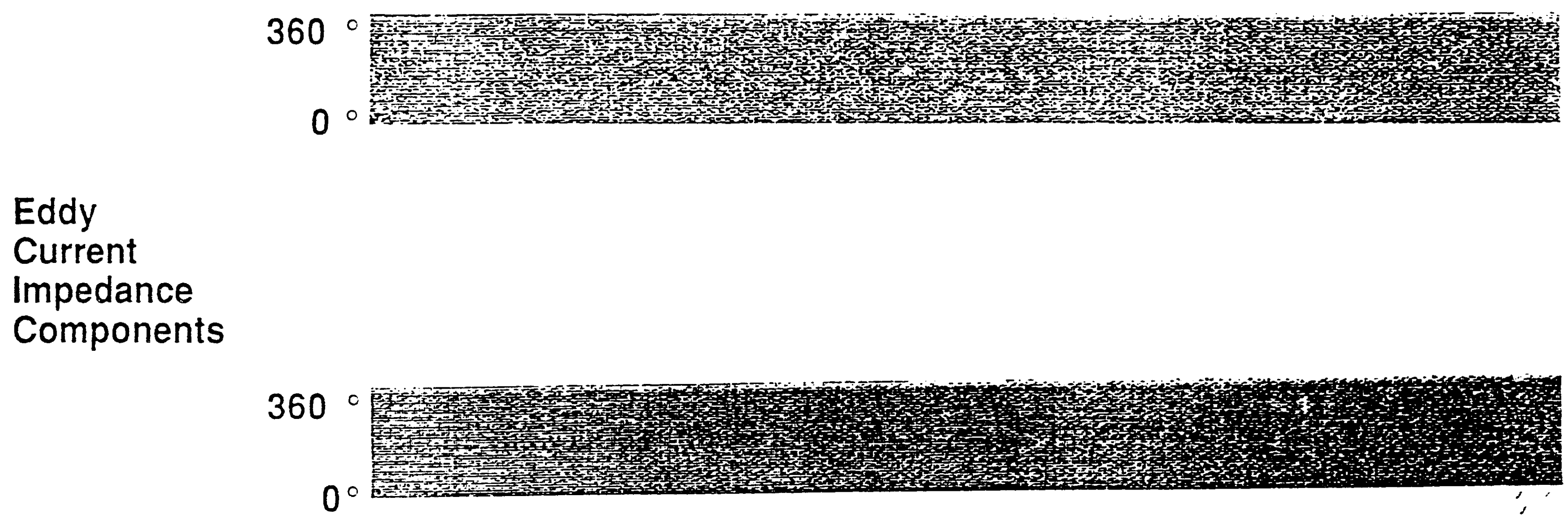
Nondestructive Examination Technique

Unacceptable Target Rod Cladding

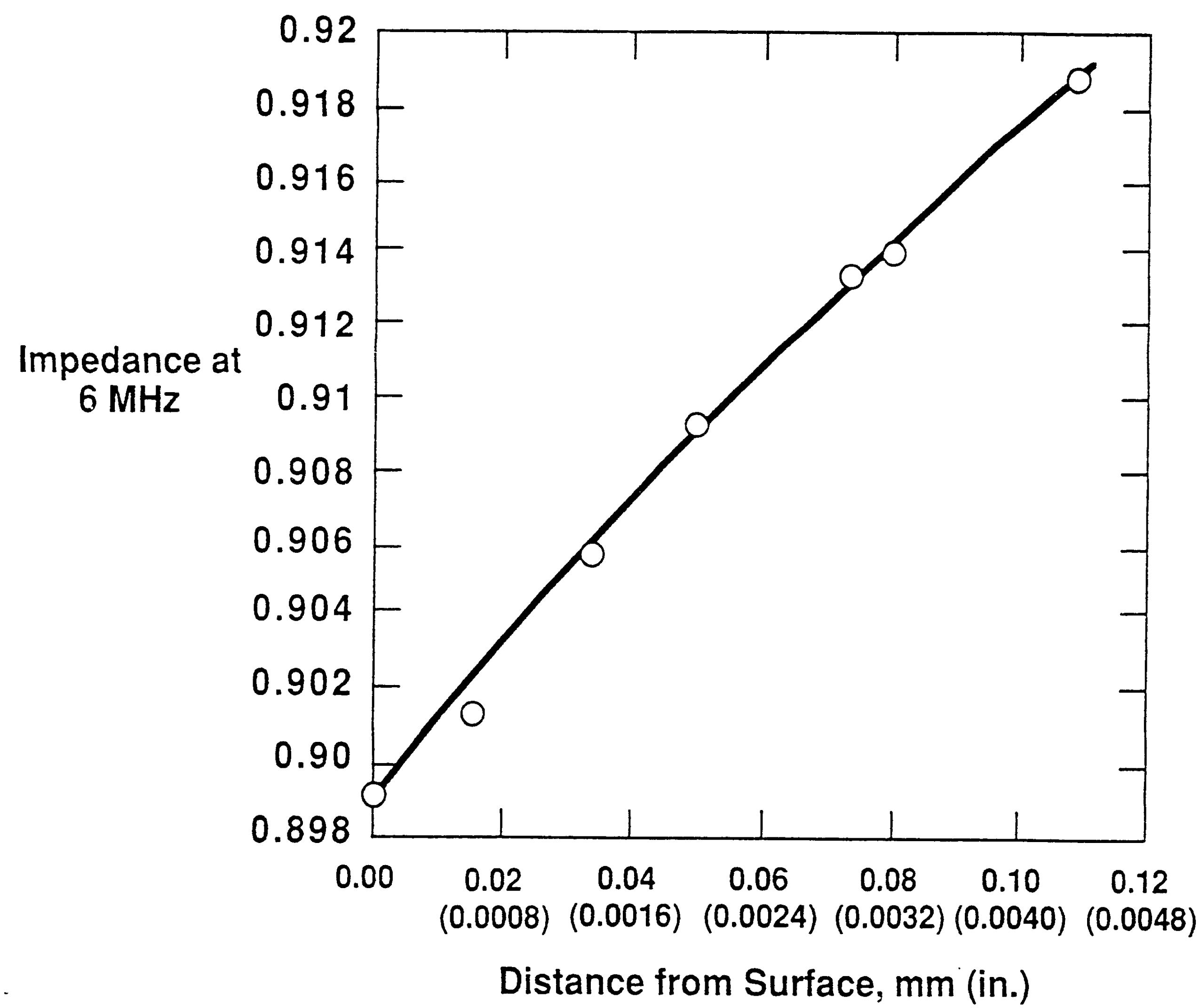
Eddy Current Trace

Metallography at 1500X

Eddy Current – Acceptable Barrier Trace Tube 128



Eddy Current – Barrier Thickness



NDE – Preliminary Conclusions

- Deuterium permeation
  - Good test technique – useful for coating process sampling overcheck and development of performance correlations with other NDE techniques
- Air gauge
  - Fast, precise dimensional characterization to assure target rod assembly
- Eddy current
  - Fast, precise characterization of barrier thickness
  - Able to discriminate between homogeneous and heterogeneous barrier microstructures
  - Potential for performance prediction

END

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