FRAMATOME ANP

Proj. 693

February 22, 2001
GR01-046.doc

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555

Subject: Oxidation Criteria for LOCA Conditions

Gentlemen:

Enclosed is the information to be discussed with the NRC staff on February 23, 2001. Framatome ANP requests in accordance with 10CFR2.790 that this information be considered proprietary. An affidavit supporting this request is included as Attachment 1. Attachment 2 is the proprietary version of the material. Attachment 3 is the non-proprietary version.

Very truly yours,

T. A. Coleman

T. A. Coleman, Vice President
Government Relations

cc: S. N. Bailey, NRC
M. S. Chatterton, NRC
R. Caruso, NRC
S. L. Wu, NRC
J. S. Wermiel, NRC
M. A. Schoppman

3315 Old Forest Road P.O. Box 10935 Lynchburg, VA 24506-0935 Tel: 804-832-3000 www.framatech.com

bcc: T. A. Coleman
J. D. Gale
G. T. Urquhart
M. E. Aldrich
C. F. McPhatter
B. M. Dunn
G. E. Hanson
J. T. Willse
R. D. Williamson
S. de Perthuis
H. A. Hassan
S. T. Wilkerson
J. J. Cudlin

Attachment 1

Affidavit for Proprietary Classification of Material Presented to NRC on February 23, 2001

AFFIDAVIT OF THOMAS A. COLEMAN

A. My name is Thomas A. Coleman. I am Vice President of Government Relations for Framatome ANP. Therefore, I am authorized to execute this Affidavit.

B. I am familiar with the criteria applied by Framatome ANP to determine whether certain information of Framatome ANP is proprietary and I am familiar with the procedures established within Framatome ANP to ensure the proper application of these criteria.

C. In determining whether an Framatome ANP document is to be classified as proprietary information, an initial determination is made by the cognizant manager, who is responsible for originating the document, as to whether it falls within the criteria set forth in Paragraph D hereof. If the information falls within any one of these criteria, it is classified as proprietary by the originating cognizant manager. This initial determination is reviewed by the cognizant Section Manager. If the document is designated as proprietary, it is reviewed again by personnel and other management within Framatome ANP as designated by the Vice President of Government Relations to assure that the regulatory requirements of 10 CFR Section 2.790 are met.

D. The following information is provided to demonstrate that the provisions of 10 CFR Section 2.790 of the Commission's regulations have been considered:

(i) The information has been held in confidence by Framatome ANP. Copies of the document are clearly identified as proprietary. In addition, whenever Framatome-ANP transmits the information to a customer, customer's agent, potential customer or regulatory agency, the transmittal requests the recipient to hold the information as proprietary. Also, in order to strictly limit any potential or actual customer's use of proprietary information, the substance of the following provision is included in all agreements entered into by Framatome ANP, and an equivalent version of the proprietary provision is included in all of Framatome ANP's proposals:

"Any proprietary information concerning Company's or its Supplier's products or manufacturing processes which is so designated by Company or its Suppliers and disclosed to Purchaser incident to the performance of such contract shall remain the property of Company or its Suppliers and is disclosed in confidence, and Purchaser shall not publish or otherwise disclose it to others without the written approval of Company, and no rights, implied or otherwise, are granted to produce or have produced any products or to practice or cause to be practiced any manufacturing processes covered thereby.

Notwithstanding the above, Purchaser may provide the NRC or any other regulatory agency with any such proprietary information as the NRC or such other agency may require; provided, however, that Purchaser shall first give Company written notice of such proposed disclosure and Company shall have the right to amend such proprietary information so as to make it non-proprietary. In the event that Company cannot amend such proprietary information, Purchaser shall, prior to disclosing such information, use its best efforts to obtain a commitment from NRC or such other agency to have such information withheld from public inspection.

Company shall be given the right to participate in pursuit of such confidential treatment."

(ii) The following criteria are customarily applied by Framatome ANP in a rational decision process to determine whether the information should be classified as proprietary. Information may be classified as proprietary if one or more of the following criteria are met:

a. Information reveals cost or price information, commercial strategies, production capabilities, or budget levels of Framatome ANP, its customers or suppliers.

b. The information reveals data or material concerning Framatome ANP research or development plans or programs of present or potential competitive advantage to Framatome ANP.

c. The use of the information by a competitor would decrease his expenditures, in time or resources, in designing, producing or marketing a similar product.

d. The information consists of test data or other similar data concerning a process, method or component, the application of which results in a competitive advantage to Framatome ANP.

e. The information reveals special aspects of a process, method, component or the like, the exclusive use of which results in a competitive advantage to Framatome ANP.

f. The information contains ideas for which patent protection may be sought.

The document(s) listed on Exhibit "A", which is attached hereto and made a part hereof, has been evaluated in accordance with normal Framatome ANP procedures with respect to classification and has been found to contain information which falls within one or more of the criteria enumerated above. Exhibit "B", which is attached hereto and made a part hereof, specifically identifies the criteria applicable to the document(s) listed in Exhibit "A".

(iii) The document(s) listed in Exhibit "A", which has been made available to the United States Nuclear Regulatory Commission was made available in confidence with a request that the document(s) and the information contained therein be withheld from public disclosure.

(iv) The information is not available in the open literature and to the best of our knowledge is not known by Combustion Engineering, Siemens, General Electric, Westinghouse or other current or potential domestic or foreign competitors of Framatome ANP.

(v) Specific information with regard to whether public disclosure of the information is likely to cause harm to the competitive position of Framatome ANP, taking into account the value of the information to Framatome ANP; the amount of effort or money expended by Framatome ANP developing the information; and the ease or difficulty with which the information could be properly duplicated by others is given in Exhibit "B".

E. I have personally reviewed the document(s) listed on Exhibit "A" and have found that it is considered proprietary by Framatome ANP because it contains information which falls within one or more of the criteria enumerated in Paragraph D, and it is information which is customarily held in confidence and protected as proprietary information by Framatome ANP. This report comprises information utilized by Framatome ANP in its business which afford

Framatome ANP an opportunity to obtain a competitive advantage over those who may wish to know or use the information contained in the document(s).

THOMAS A. COLEMAN

State of Virginia)
) SS. Lynchburg
City of Lynchburg)

Thomas A. Coleman, being duly sworn, on his oath deposes and says that he is the person who subscribed his name to the foregoing statement, and that the matters and facts set forth in the statement are true.

THOMAS A. COLEMAN

Subscribed and sworn before me
this 22nd day of February 2001.

Notary Public in and for the City
of Lynchburg, State of Virginia.

My Commission Expires 8/31/01

EXHIBITS A & B

EXHIBIT A

Materials handed out at NRC/Framatome ANP
Meeting on February, 23,2000

EXHIBIT B

The above listed materials contain information which is considered Proprietary in accordance with Criteria b, c, and d of the attached affidavit.

Attachment 2

Attachment 3

ADAMS cpf

NRC - Framatome ANP, Inc. Meeting on M5^{TM} LOCA Performance

February 23, 2001

FRAMATOME ANP

Objective and Overview

Mike Aldrich, Fuel Development Manager

FRAMATOME ANP

Objective

➢ Demonstrate acceptable performance of M5™ advanced alloy cladding under LOCA and post-LOCA conditions

- Review M5™ in-reactor operating experience and future plans
- Provide an overview of Framatome ANP's tests of cladding performance that demonstrate acceptable M5™ performance
- Present detailed Framatome ANP proprietary information that confirm acceptable M5™ performance

Overview

- M5™ Update
  - Continued excellent in-reactor performance of M5™
  - Very low corrosion and very low hydrogen pickup
  - No acceleration of corrosion or hydrogen pickup at high burnup

- M5™ Testing
  - Demonstrates that M5™ performs equal to or better than Zr4 and significantly better than the Zr-1%Nb alloy tested by Böhmert
    - Oxidation Rate
    - Quench Embrittlement
    - Ring Compression
    - Bending
    - Impact

M5^{TM} Performance Review

An update on the in-reactor performance of M5 cladding

Garry Garner

M5™ Manufacturing Experience

- 62 industrial ingots since the beginning of the M5 program (1989)

- 146,000 fuel rods loaded in 28 commercial reactors with 5 F/A designs (14x14 →18x18) since the beginning of the M5 program

- Chemical composition:
  - Sn: Impurity in M5™
  - Fe: target 250 - 500 ppm (improve corrosion)
  - O: target value 1250 - 1450 ppm (improve creep)

- Thermomechanical processing

M5^{TM} PWR Irradiation Experience

- 6 full batches loaded in 1999
  - Nogent 2
  - Tihange 1
  - Ringhals 3, 4
  - KKP 2 and GKN

- 8 full batches loaded in 2000
  - Nogent 2
  - Tihange 1, 3
  - Ringhals 3, 4
  - GKN 2
  - Davis Besse
  - Oconee 1

- 12 reloads planned for 2001
  - TMI 1
  - Oconee 2, 3
  - Sequoyah 1
  - Ringhals 3, 4
  - GKN 2
  - KKG
  - KKP
  - KKU
  - Tihange 1 and 3

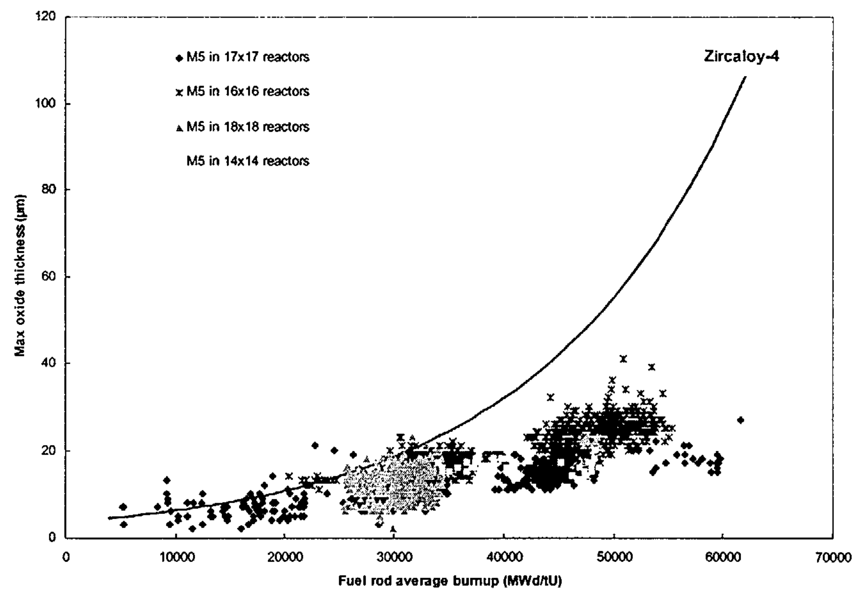
M5™ Fuel Rod PWR Irradiation Experience

- Maximum Burnup Achieved $\rightarrow$ 63 GWd/tU
- Maximum Heat Flux $\rightarrow$ 78 - 91 W/cm^2
- Average Core Linear Power $\rightarrow$ 165-238 W/cm
- Outlet Temperature $\rightarrow$ 315 - 330°C

M5™ PWR Corrosion Performance

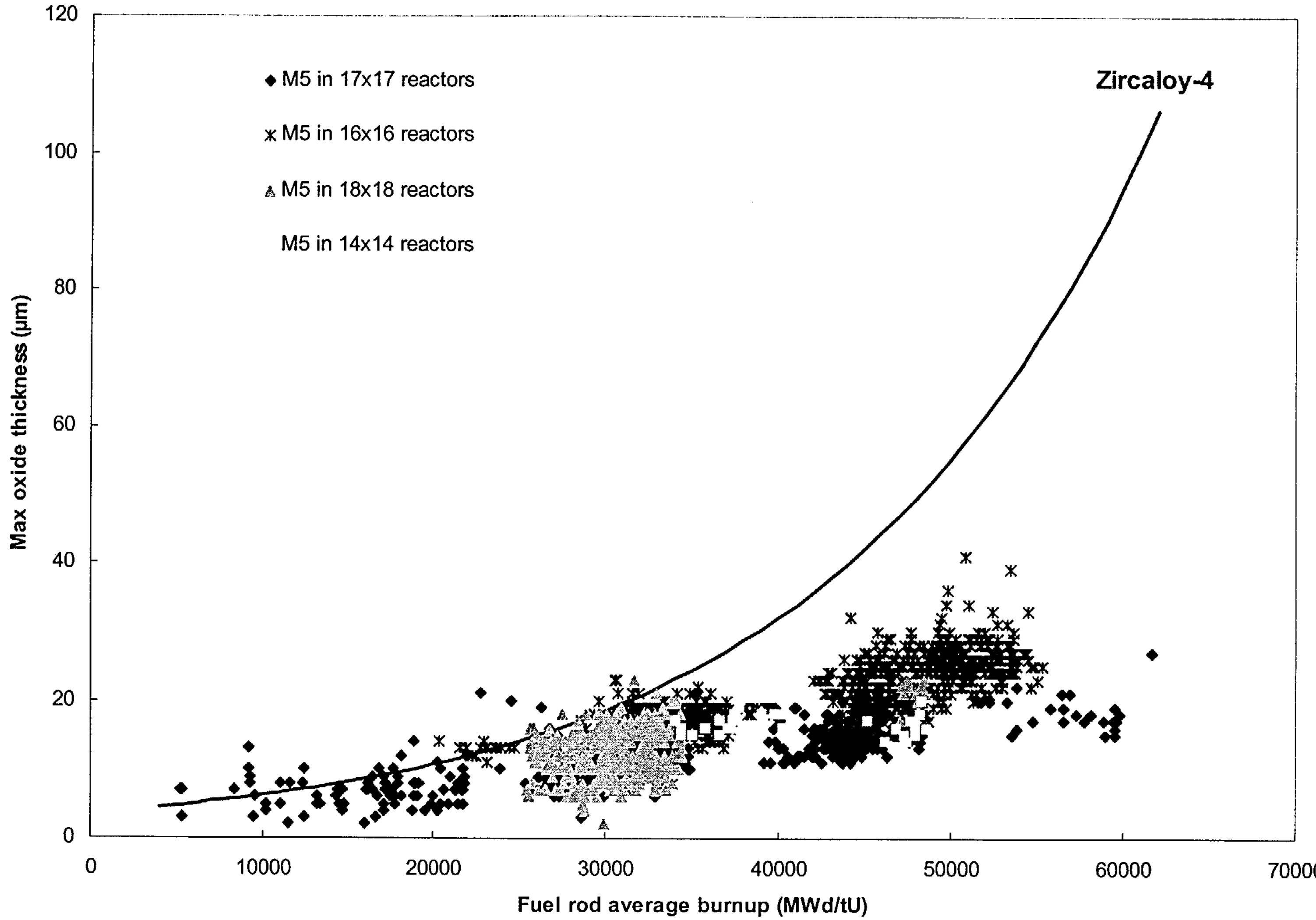
- Additional data in BU range 50-60 GWd/tU
- Excellent corrosion behavior of M5™
  - for all designs and for all operating conditions
- Thickness < 40 μm for BU up to 63 GWd/mtU
- Additional data to > 70 GWd/mtU planned

Corrosion behavior of Zirconium alloy claddings



FRAMATOME ANP

In-Reactor Oxidation Performance

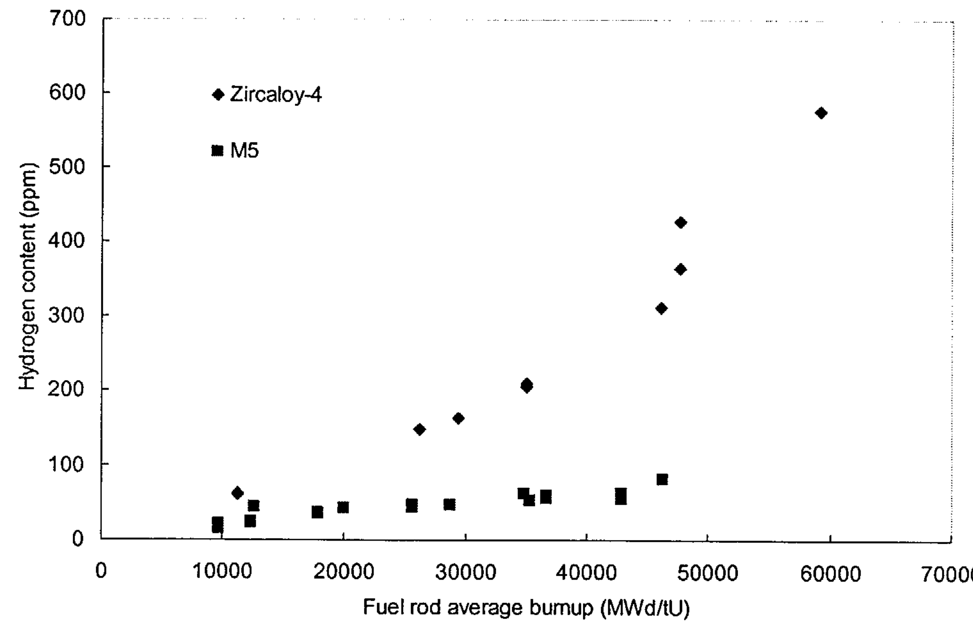


FRAMATOME ANP

PWR Hydrogen Performance Of M5™

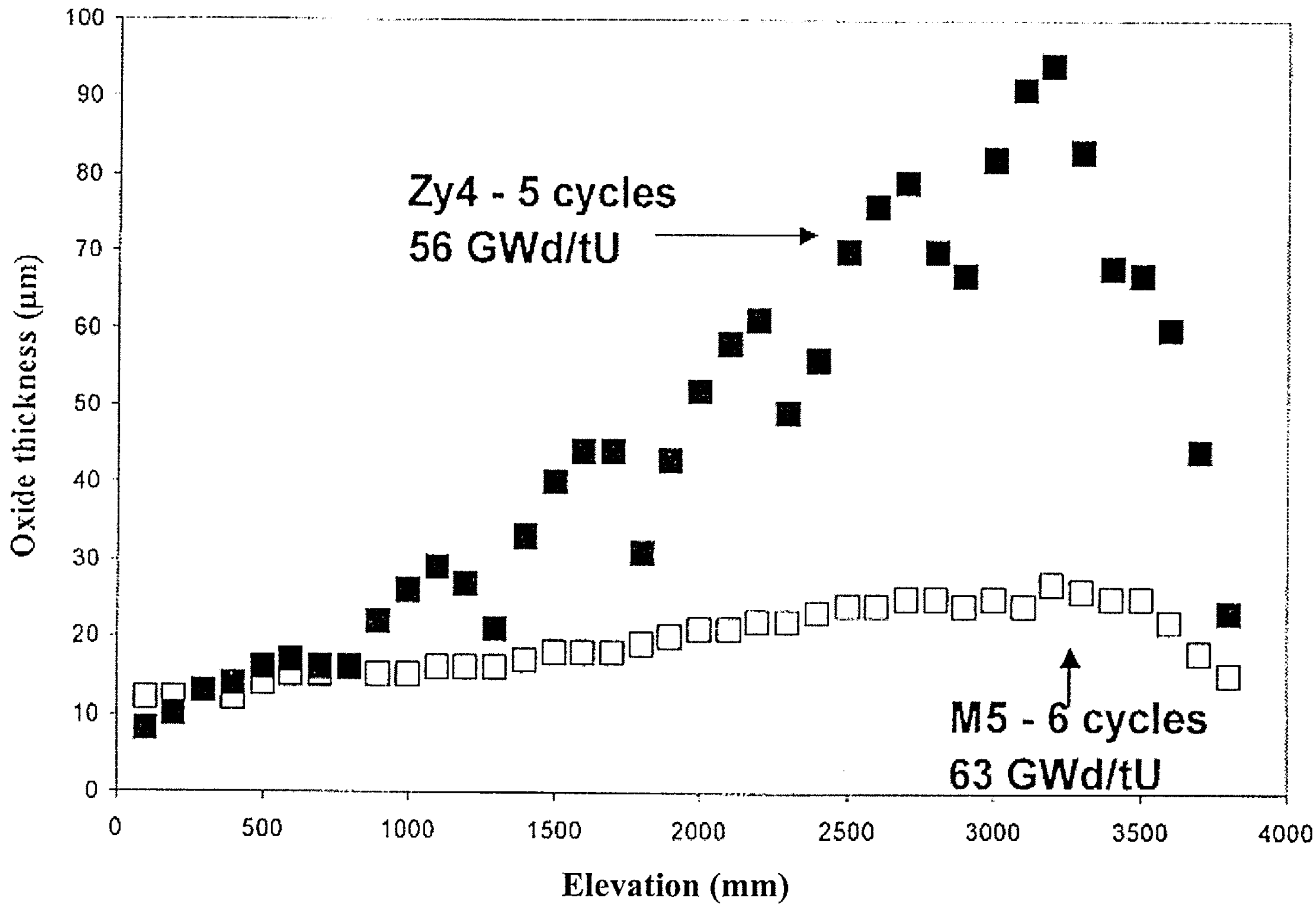
- Significant reduction of clad hydrogen content

- Additional M5™ data at high burnup planned in 2001



FRAMATOME ANP

M5™ and Zr-4 Corrosion vs. Temperature



Summary: M5™ Corrosion Performance

- Low oxidation rate
- No increase in rate to burnups of 63 GWd/mtU
- Lower sensitivity to temperature and rod power than Zr-4 (reactor duty)
- **Low oxidation rate + low hydrogen absorption = low hydrogen content at high burnup**

Summary: M5™ PWR Experience

- High stability of the M5™ microstructure under irradiation
  - Second phase particles remain fully crystalline and unchanged in composition
  - Low density of $\vec{c}$ loops and low activation energy of the corrosion process

Review of Framatome ANP Test Programs

Garry Garner

FRAMATOME ANP

Review of Oxidation and Quench Test Programs

➢ Oxidation Rate Testing

- Performed by FRA-ANP and an independent, private Japanese firm
- Both sets of testing confirm that M5™ oxidizes at rates equal to or slower than Zr4 at LOCA and post-LOCA temperatures
- The amount of M5™ cladding reacted will be less than or equal to Zr4 for events of equal time and temperature

➢ Quench Testing

- M5™ cladding performs equal to or better than Zr4
- The time to failure for M5™ cladding is equal to or greater than Zr4
- M5™ cladding will survive as long or longer than Zr4 at equal temperatures

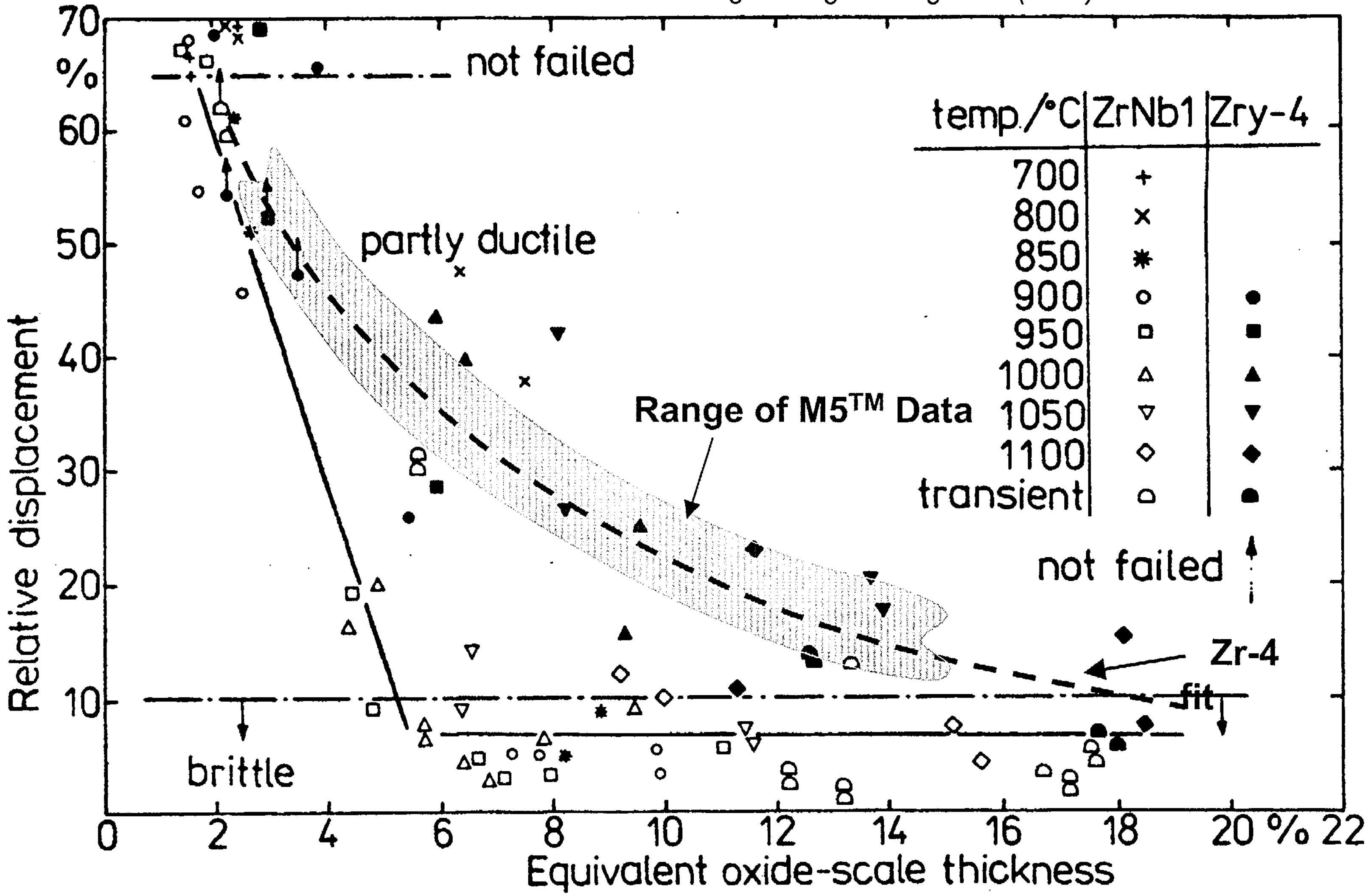
Review of Mechanical Test Programs

➢ M5™ and Zr-4 Behave Similarly

- Ring Compression Testing
  - M5™ performs significantly better than the Zr-1%Nb alloy test results presented in the 1992 Böhmert paper
- Bend Testing
  - M5™ survives bending displacements as well as Zr4
- Impact Testing
  - M5™ resists impact failure as well as Zr4

J. Böhmert et al. / High-temperature corrosion of ZrNb1 and Zircaloy-4

Nuclear Engineering & Design 147 (1993)



Summary

- M5™ in-reactor operating performance is superior to Zr4

- M5™ LOCA and post-LOCA oxidation rates are equal to or slower than Zr4

- M5™ LOCA and post-LOCA mechanical performance is equivalent to Zr4

- M5™ LOCA and post-LOCA performance is acceptable and is equal to or better than Zr4 in events of equal duration

- M5™ LOCA and post-LOCA mechanical performance is superior to the Zr-1%Nb alloy tested by Böhmert

M5^{TM} Oxidation and Quench Tests

Bert Dunn

FRAMATOME ANP

M5 Test Program Results

- M5™ High Temperature Oxidation Rates Are Equal To or Less Than Zr-4

- M5™ Hydrogen Uptake is Low (Both Operationally and During Transient)

- M5™ Accident Survival is Superior to Zr-4
  - T > 1100 C M5 and Zr-4 Have Similar Survival Ability
  - T < 1100 C M5 Survives up to 2 Times Longer than Zr-4

- M5™ has Similar or Better Properties than Zr-4 After Oxidation
  - No Delamination
  - Similar Bend Test Results
  - Slightly Better Impact Resistance
  - Slightly Better than Zr-4 & Much Better than E110 in Ring Compression Tests

M5 Test Program Results

- Testing Is Sufficient To Validate Current 50.46 Criteria as Applicable to M5™
- Using Baker/Just to Establish ECR M5™ Always Meets the 17 % Criterion
- At Moderate Temperatures (1100 C > T > 900 C) M5 Requires Excessive Oxidation Times to Achieve ECRs near 17 %
- Because M5™ Actually Performs Better During an Accident, The LOCA Criterion Should Remain 17 % Local Oxidation as Calculated by Baker/Just

M5 Embrittlement Discussion Organization

- Discussion of ECCS Criterion - Mission and Bases

- M5^{TM} Oxidation Rate Testing

- M5^{TM} Thermal Shock Testing - Transient Hydrogen Absorption

- M5^{TM} Mechanical Testing

    3 Point Bend Tests
    Impact Tests
    Ring Compression Tests

- Summary and Application of Results

CINOG Oxidation and Embrittlement Tests

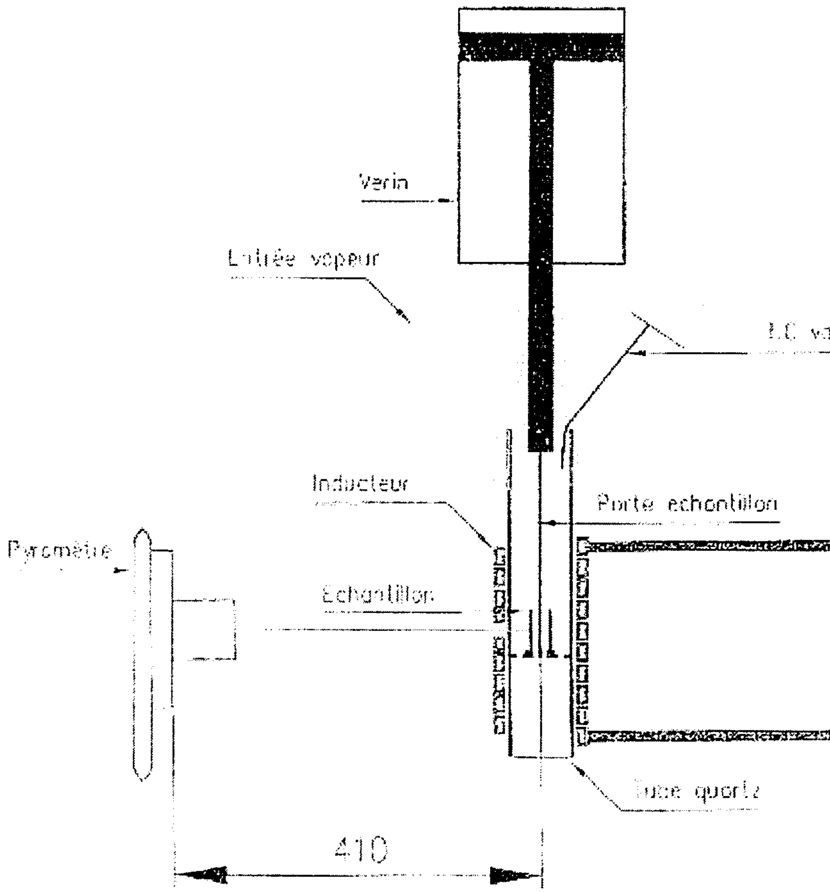
- Oxidation Kinetics

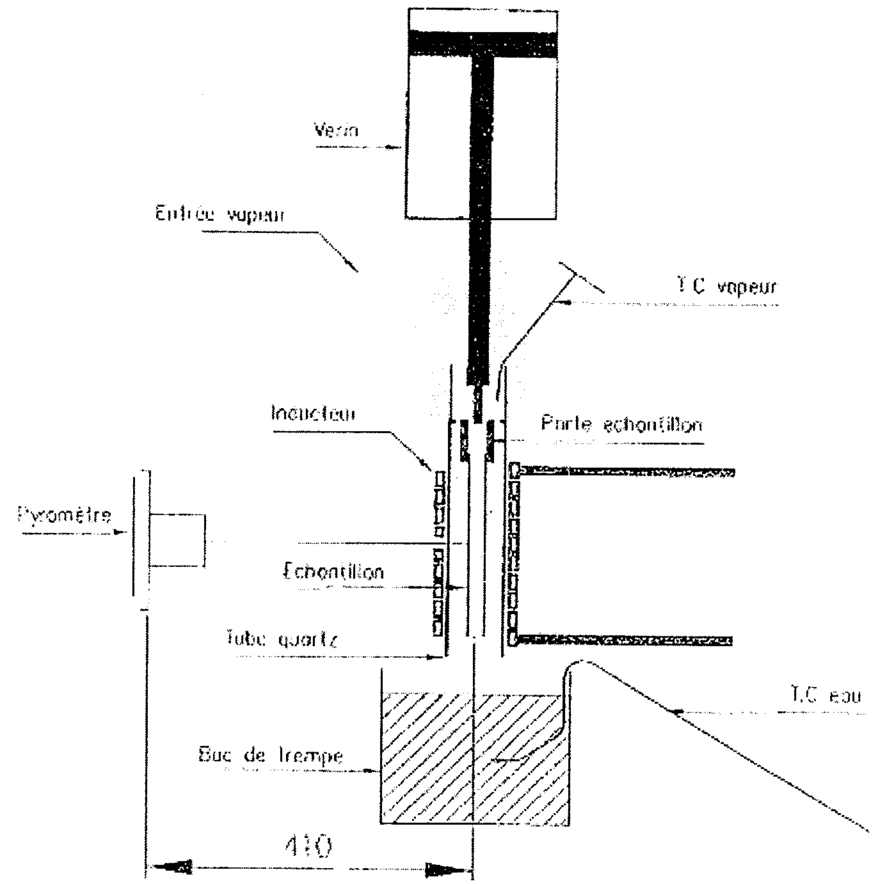
- Thermal Shock Survival

- Facility and Test Matrix Developed to be Compatible with Previous French Programs

  TAGCIS
  TAGCIR
  HYDRAZIR

OXIDATION AND QUENCH EMBRITTLEMENT CINOG TEST FACILITY





Oxidation and Quench Embrittlement CINOG Test Matrix

- Oxidation Tests (M5™ and Zr-4)
  -

- Quench Embrittlement Tests (M5™ and Zr-4)
  -

- Post-Test Metallography and Hydrogen Analysis

NFI - TEST APPARATUS

High - Temperature Oxidation
NFI - Test Matrix

OXIDATION °C - CINOG

Zr-4 and M5™

Weight gain, mg/cm²

Oxidation Time, $s^{-1/2}$

- M5™ Oxidation Less Than Zr-4 From C

°C OXIDATION - CINOG
EFFECT OF PREHYDRIDING (ppm)

→ Slight effect of hydrogen content ≈ %

OXIDATION KINETICS -
Effect of hydrogen content

→ M5™ behaves better than Zy4 at °C
→ B-J correlation can be applied conservatively to M5™ cladding
→ Slight hydrogen effect up to ppm on oxidation kinetics

OXIDATION KINETICS - CINOG
Comparison with the results in the literature

CINOG Embrittlement Tests

Zy4 METALLOGRAPHIC OBSERVATIONS AFTER OXIDATION SECONDS

Outer layer

Outer layer

Inner layer

→ Trace of in inner and outer zirconia layers

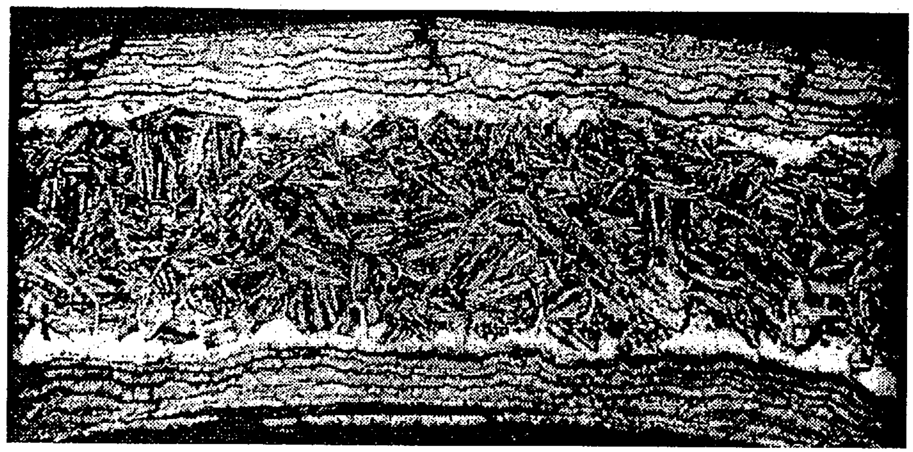
M5™ METALLOGRAPHIC OBSERVATIONS AFTER OXIDATION SECONDS

Outer layer

Inner layer

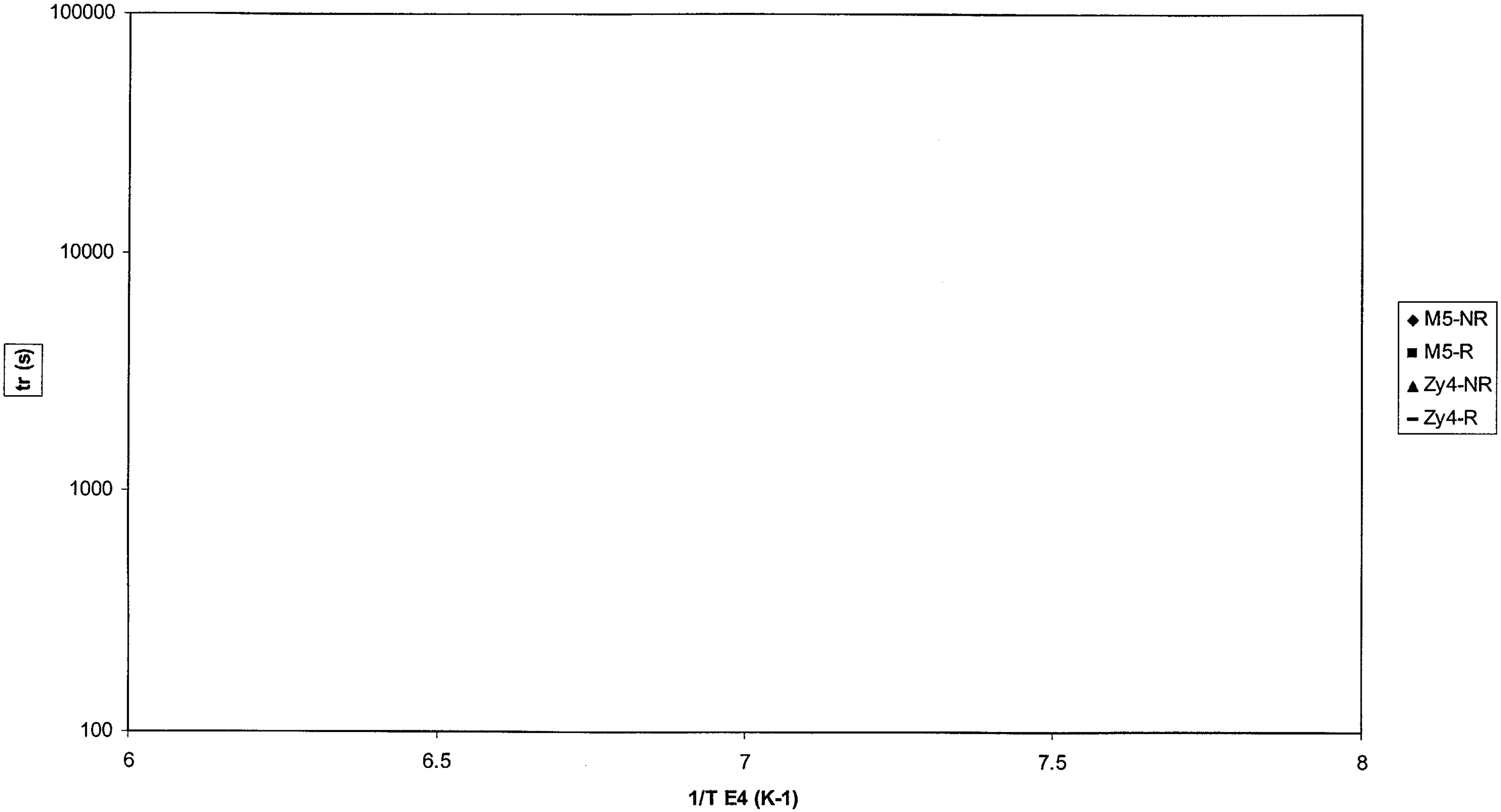
- The inner and outer zirconia layers are homogeneous
- No trace of delamination

High - Temperature Oxidation Russian Alloy E-110 Cladding

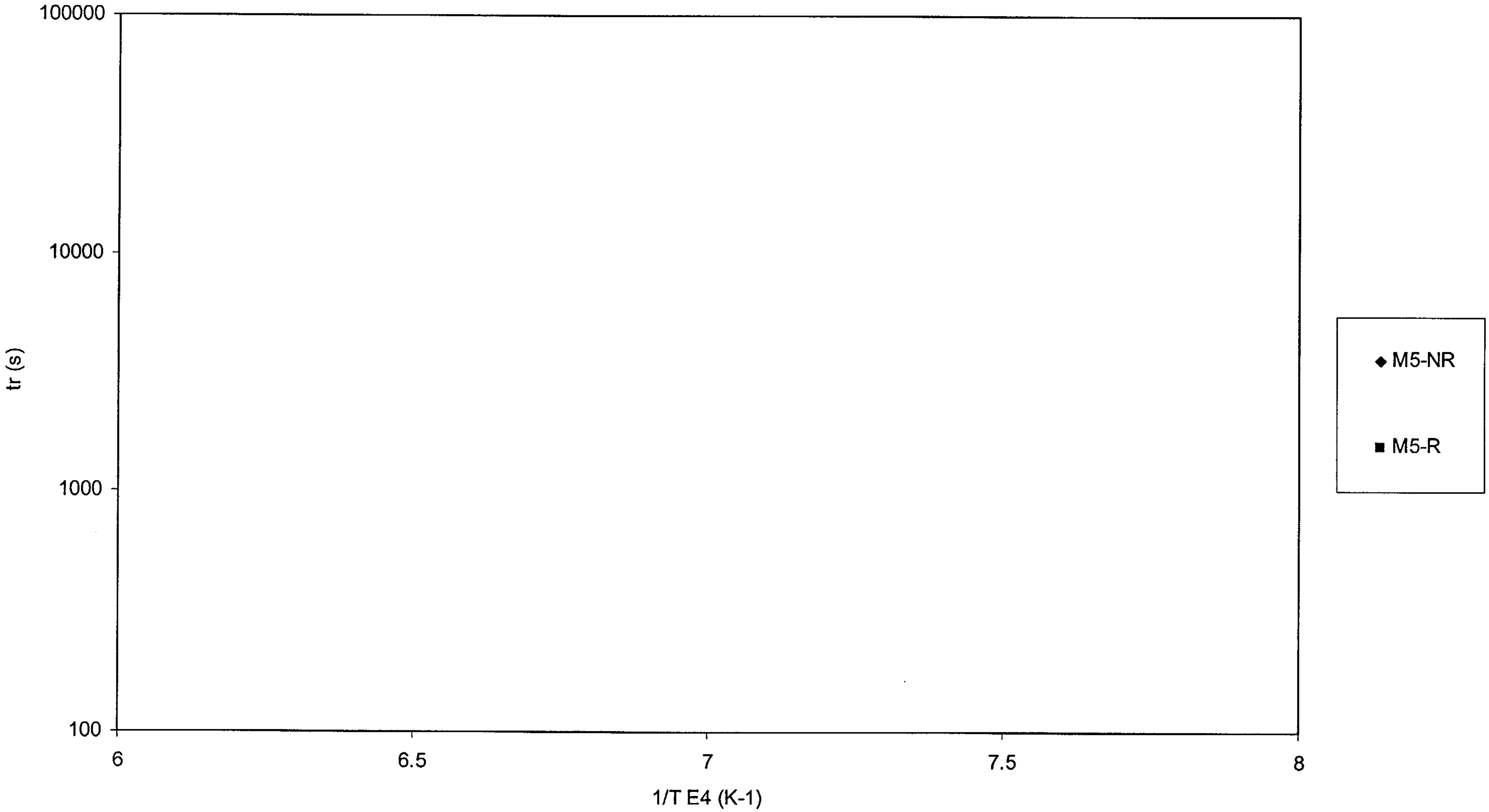


Stratified zirconia layer

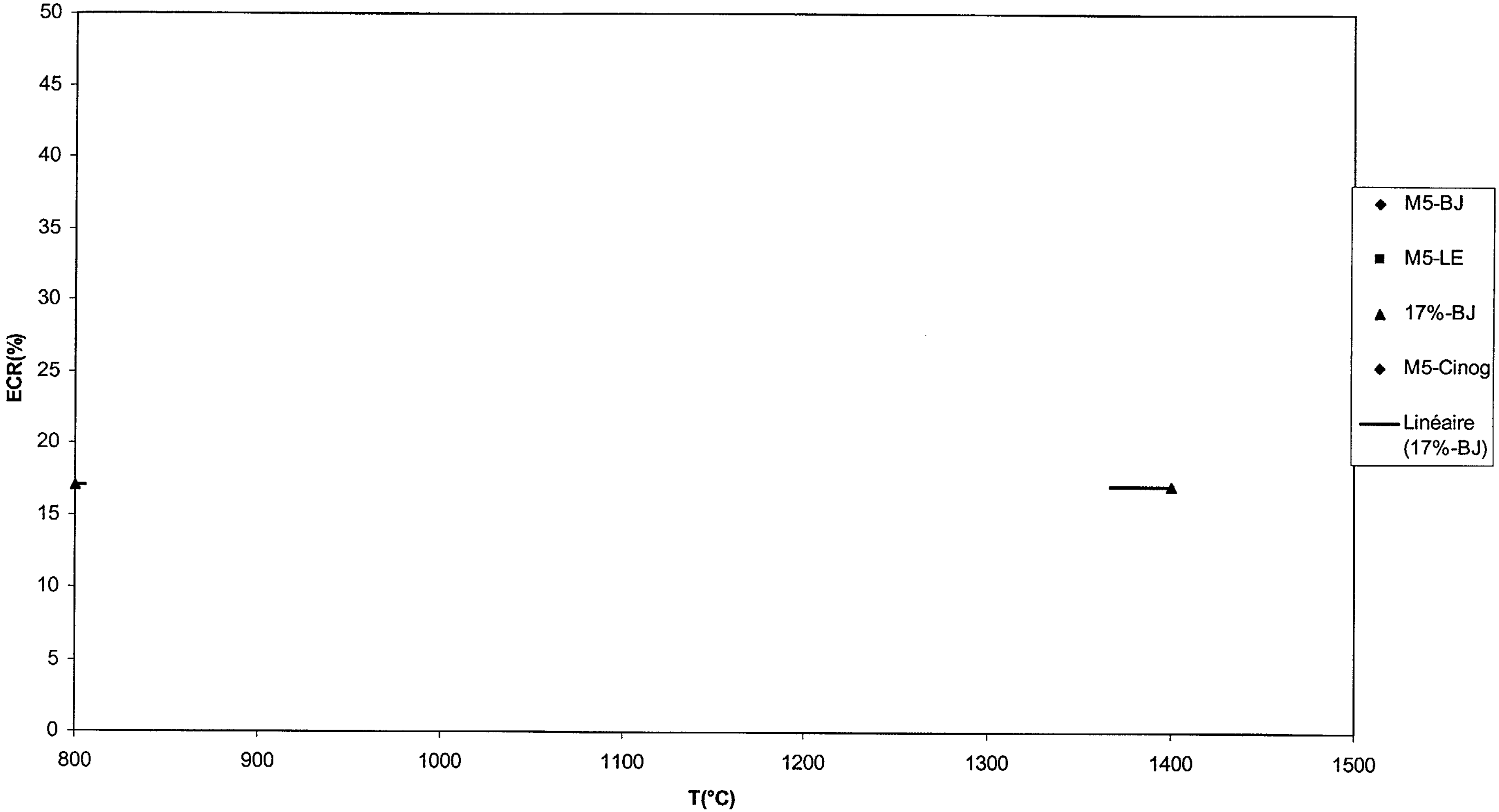
QUENCH EMBRITTLEMENT - CINOG
Time to rupture versus 1/T



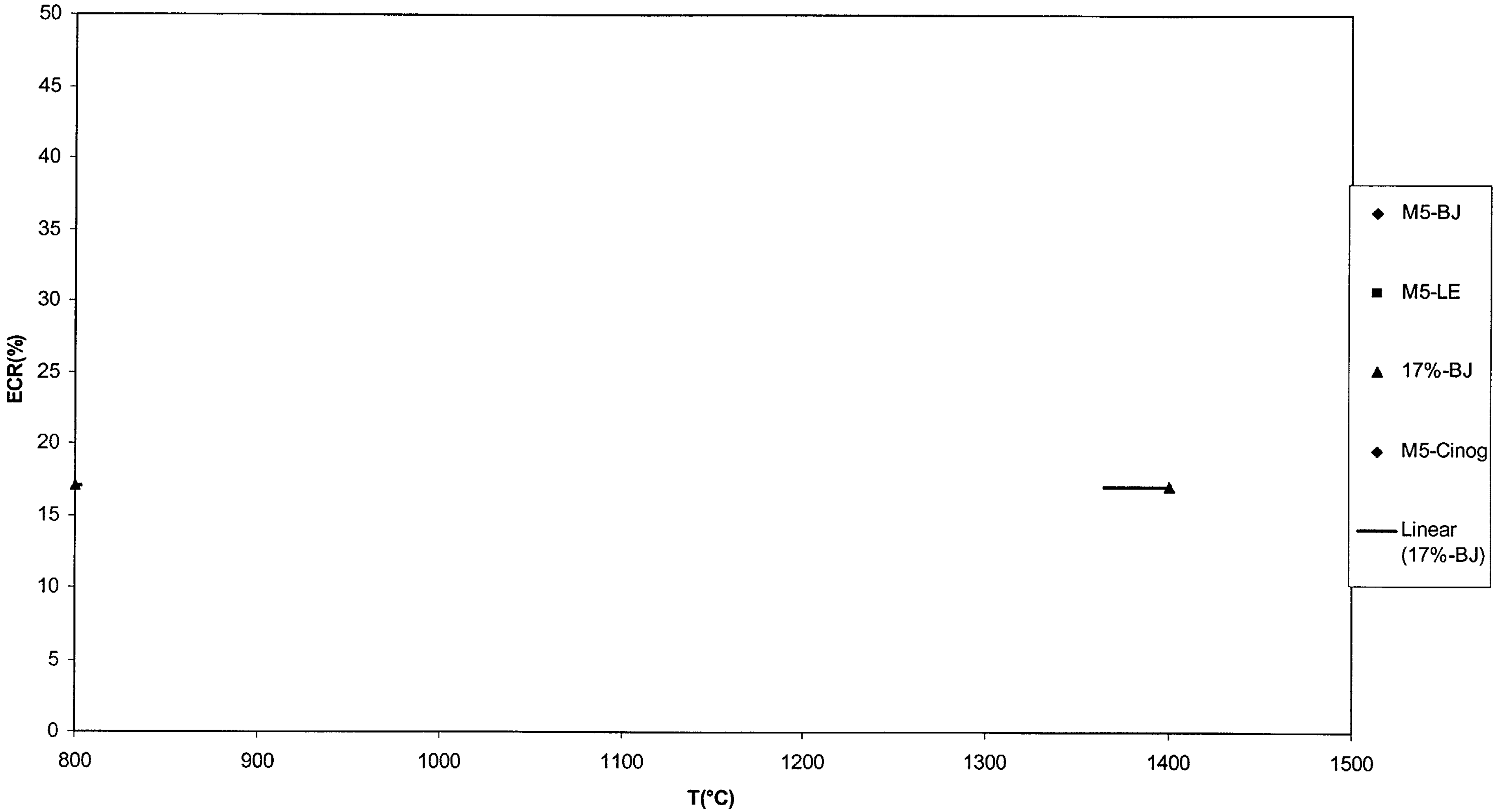
QUENCH EMBRITTLEMENT - CINOG
Time to rupture versus 1/T



QUENCH EMBRITTLEMENT - CINOG
ECR versus temperature 3/4



QUENCH EMBRITTLEMENT - CINOG
ECR versus temperature 4/4



FRAMATOME ANP

QUENCH EMBRITTLEMENT TESTS HYDROGEN CONTENT IN Zy4 AND M5™ AFTER QUENCH TESTS - CINOG

➡ Maximum oxidation duration before embrittlement similar or higher for M5™

➡ Slight hydrogen pickup, practically temperature-independent

CINOG Test Results Summary

- High Temperature Oxidation Performance of M5™ is Equivalent or Superior to Zr-4

- M5™ Hydrogen Uptake is Low

- M5™ Accident Survival is Superior to Zr-4

  T > 1100 C M5™ and Zr-4 Have Similar Survival Ability
  T < 1100 C M5™ Survives up to 2 Times Longer than Zr-4

- M5™ Does Not Suffer Delamination

- Using Baker/Just to Establish ECR M5™ Always Meets the 17 % Criterion

- At Moderate Temperatures (1100 C > T > 900 C) M5™ Requires Excessive Oxidation Times to Achieve ECRs near 17 %

- Because M5™ Actually Performs Better During an Accident, The LOCA Criterion Should Remain 17 % Local Oxidation as Calculated by Baker/Just

Post-Quench Mechanical Test Results

Garry Garner

FRAMATOME ANP

Post-Quench Mechanical Tests
Test Matrix

- **Oxidation**

- **Water Quench**

- **Mechanical tests**
  - Three point bend
  - Impact
  - Ring compression

OXIDATION °C
ZIRCALOY-4 and M5™

Weight gain, mg/cm²

Oxidation Time, s$^{-1/2}$

- M5™ behaves better than Zr-4 at °C
- Zr-4 values are consistent with literature
- M5™ values are consistent with independent Japanese tests

Post-Quench Mechanical Test
Oxidation - Device

Post-Quench Mechanical Test
Oxidation - Weight Gain vs. Exposure Time
C

Oxide Thickness (µm)

Time (s)

- Similar evolution of Oxide thickness with time for Zr-4 and M5™

Post-Quench Mechanical Test
Percent of spalled oxide after oxidation at and quench for the longest exposure time

Metallographic Observations Of Low-Tin Zr-4 After Oxidation At

t = and Quenched

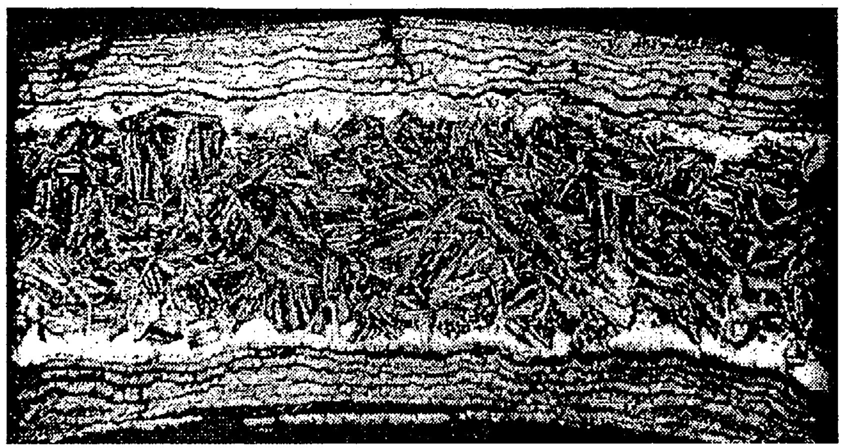
- α-Zr(0) layer: large α-grains
- α-Zr(0) layer: cracks

Metallographic Observations Of M5™ After Oxidation At °C t = s and Quenched

- ➢ α Zr (O) layer :
- ➢ α Zr (O) layer :

High - Temperature Oxidation 925 °C, 9341 s, 24 mg/cm²

Russian Alloy E-110 Cladding



- Stratified and cracked oxide layer
- Different morphology than M5™

"... at an early stage, multilayer oxide scales are formed which tend to flake."

Böhmert et al. on Russian alloy E110

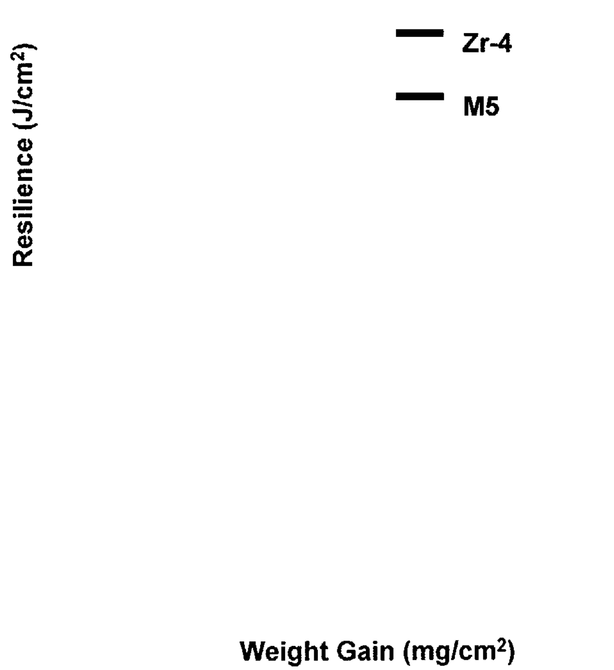
- M5™ has not exhibited multilayered oxide scale
- M5™ didn't flake in quench tests

Post-Quench Mechanical Test
3 Point Bend Test Apparatus

Post-Quench Mechanical Test
3 Point Bend Test Results

- M5™ and Zy4 behave similarly

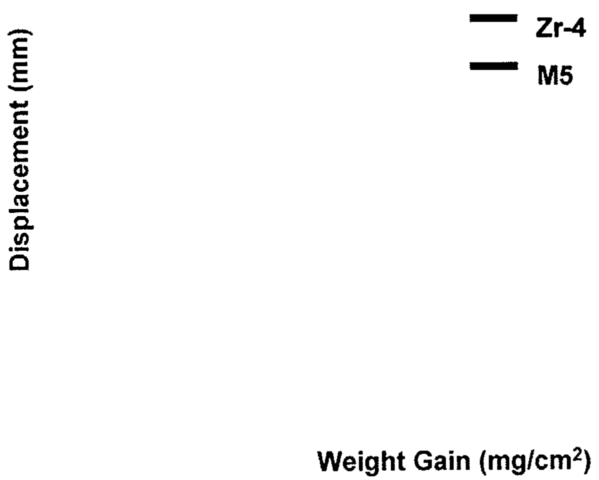
Post-Quench Mechanical Test
Impact Test Results



- M5™ behaves slightly better than Zr-4

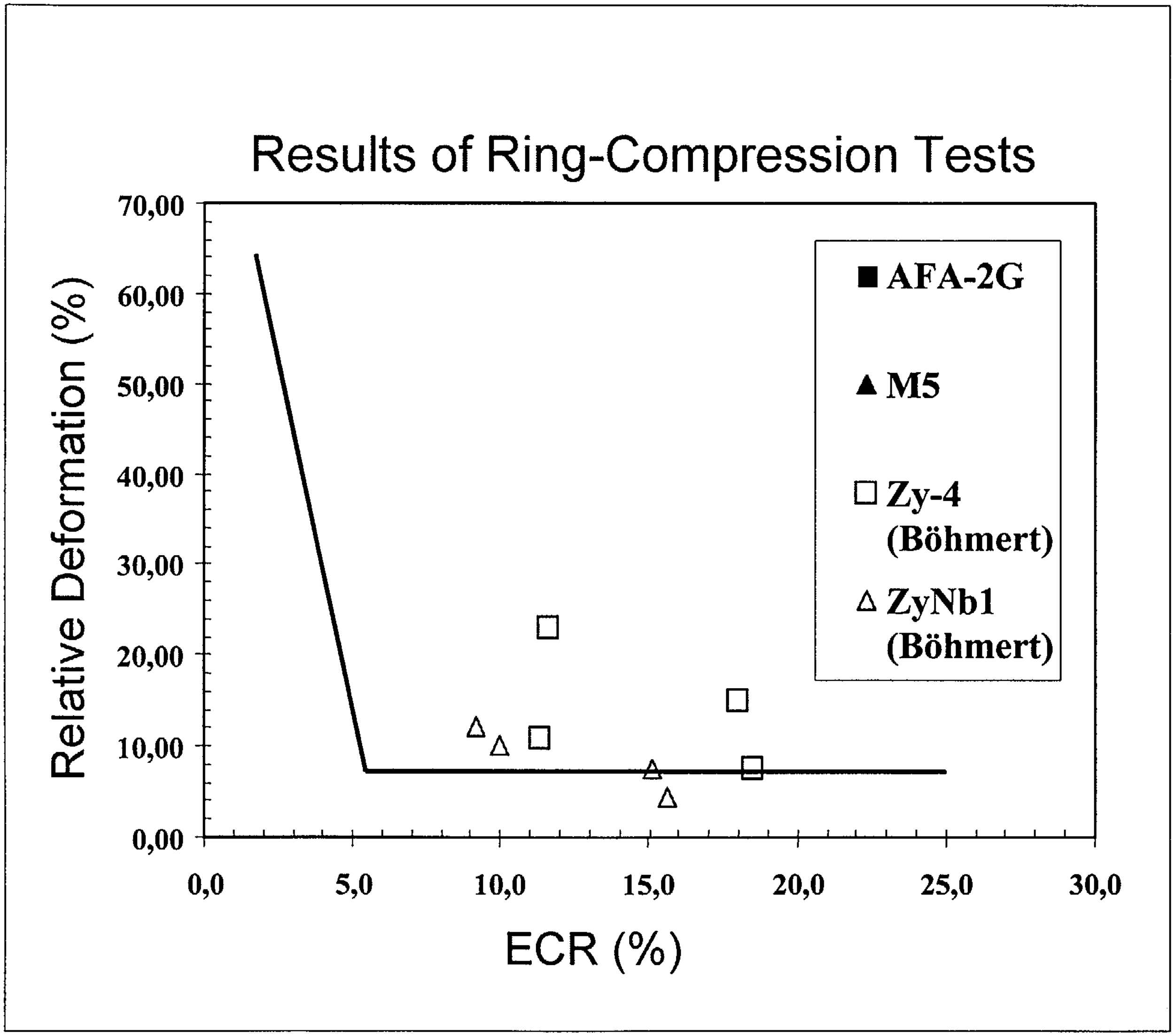
Post-Quench Mechanical Test
Ring Compression Test

Post-Quench Mechanical Test
Ring Compression Test Results



- M5™ behaves slightly better than Zr-4

Comparison With Böhmert's Results at C



FRAMATOME ANP

Conclusions
Post-Quench Mechanical Tests

- M5™ Tested in the Böhmert range with results different than E110
  - Order of magnitude less hydrogen uptake
  - Completely different oxide morphology

- M5™ Performed better than or similar to Zr-4
  - No delamination
  - Similar bend test results
  - Slightly better impact test results
  - Slightly better than Zr-4 and much better than E110 in ring compression tests

- Böhmert's conclusions regarding Zr-1Nb alloy performance may be valid for Russian alloy E110 tested in 1992, but are not valid for M5™
  - Significantly different composition and processing parameters

Conclusions
M5™ Test Program

- High temperature oxidation performance of M5™ is equivalent or superior to Zr-4

- M5™ accident survival is superior to Zr-4
  - T>1100 °C M5™ and Zr-4 have similar survival ability
  - T<1100 °C M5™ survives up to 2 times longer than Zr-4

- Using Baker/Just to establish ECR, M5™ always meets the 17% criteria

- At temperatures between 900 and 1100 °C, M5™ requires excessive oxidation times to achieve ECR's near 17%

Conclusions
M5™ Test Program

- Framatome ANP testing has sufficiently validated the current 50.46 criteria as applicable to alloy M5™

- The superior performance of M5™ in accident conditions allows for the retention of the Baker/Just 17% local oxidation LOCA criterion