CRACK SHAPE AND SIZE FOR ASME CODE APPLICATIONS

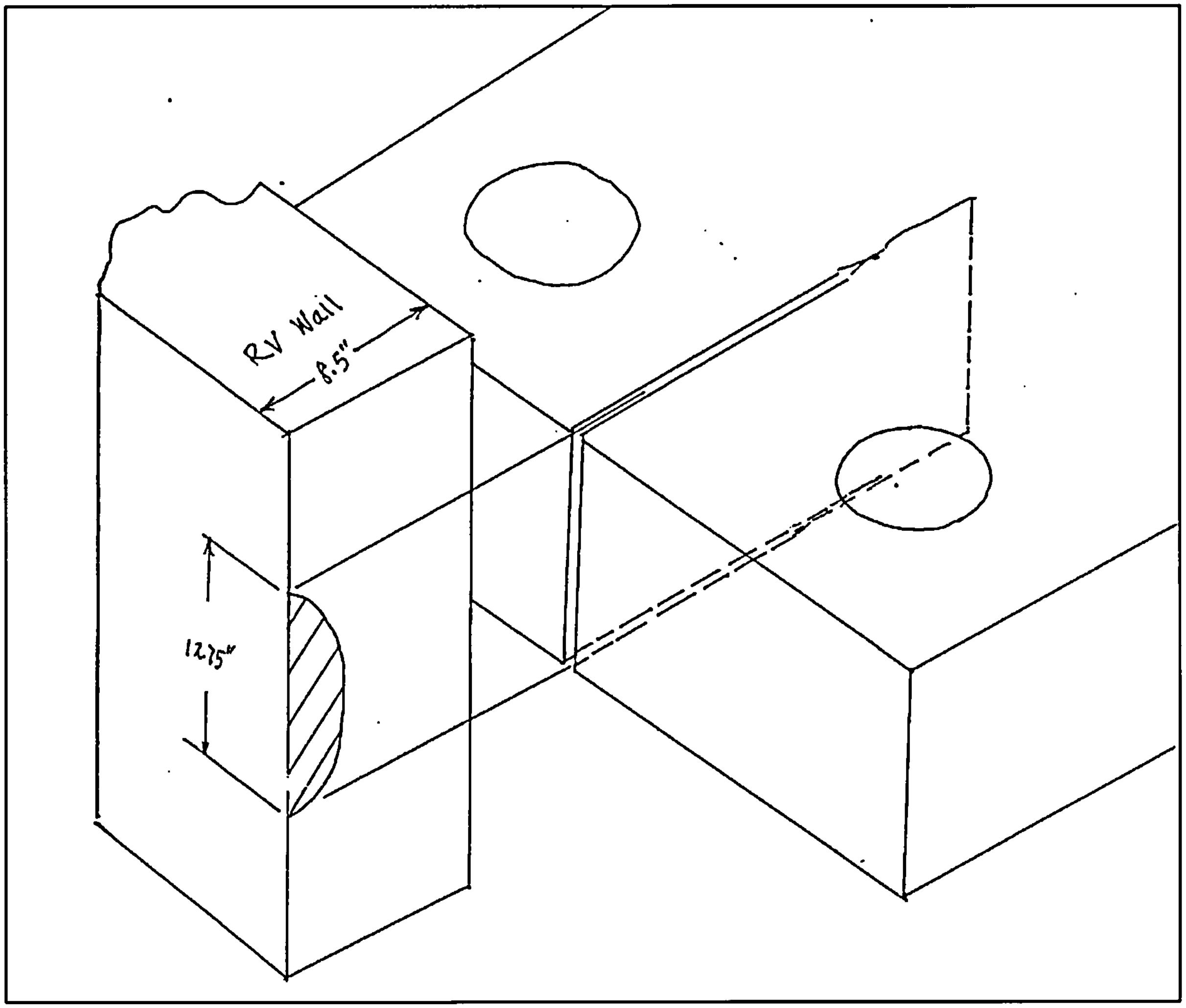
AREVA

CRACKS ANTICIPATED IN CODE APPLICATIONS

- ➔ NO LARGE SIZE CRACKS ARE ANTICIPATED
- ➔ SEMI-ELLIPCAL SURFACE FLAWS WITH IRREGULAR SHAPE WITH CONSTANT KI FIELD LESS THAN 1T LENGTH
- ➔ EMBEDDED FLAWS OF SMALL SIZES WITH IRREGULAR SHAPE
- ➔ POSTULATED QUARTER THICKNESS SEMI-ELLIPTICAL CRACK – CONSTANT KI FIELD LESS THAN 1T
- ➔ NOTHING LIKE 48 INCH LONG SURFACE CRACK

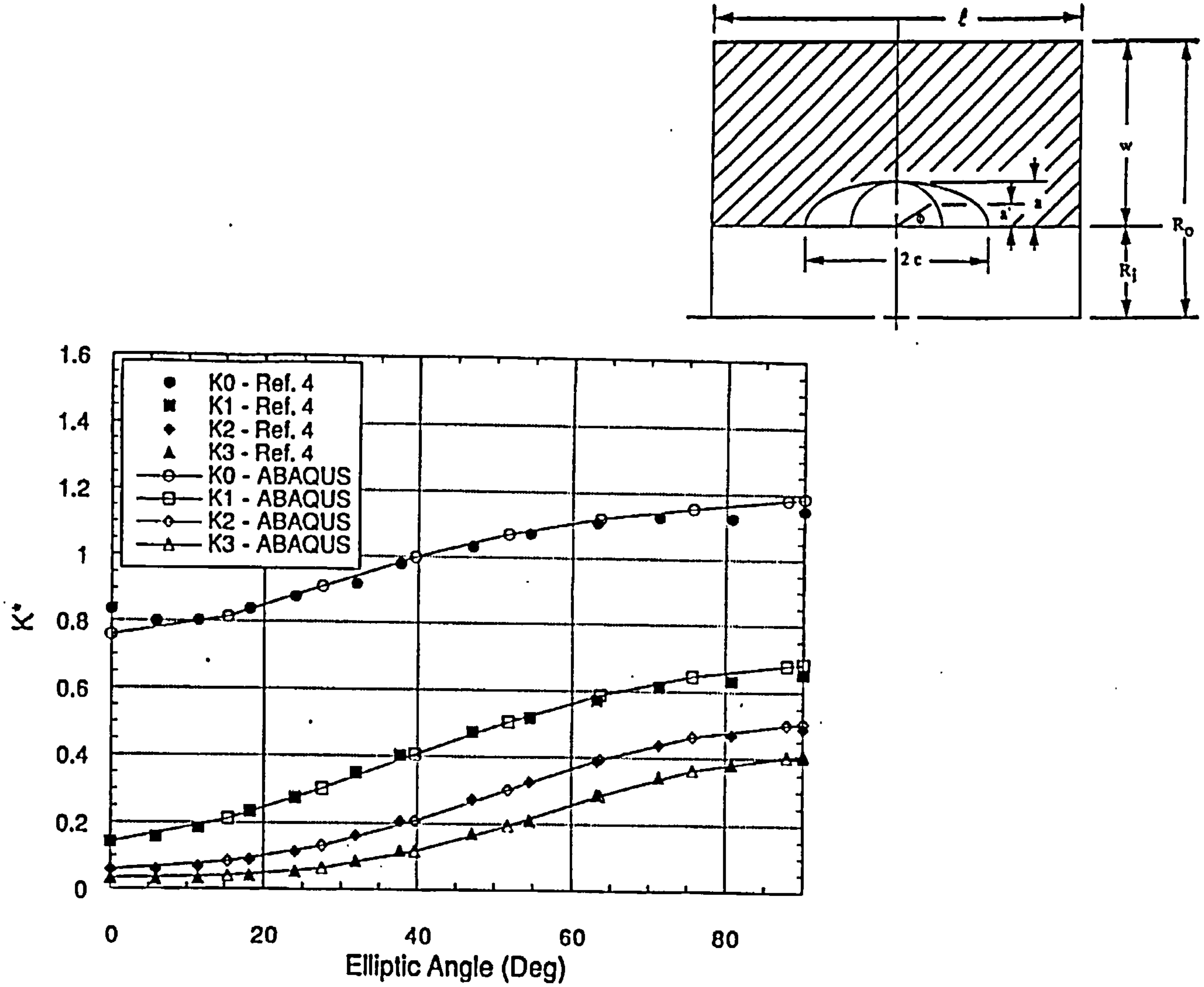
AREVA

CRACK LENGTH 1/4T FLAW
What is the crack front length?



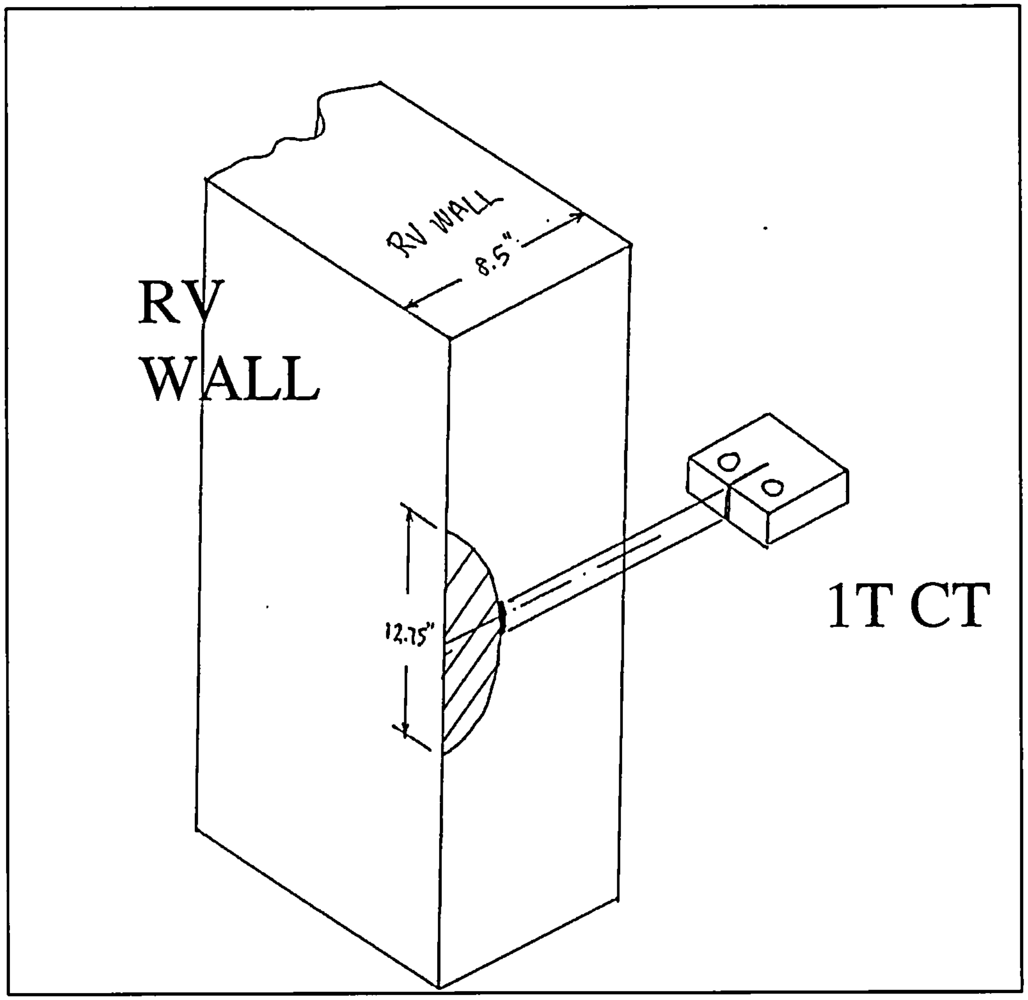
AREVA

KI FOR A SEMI-ELLIPTICAL FLAW



AREVA

CRACK LENGTH 1/4T FLAW



CRACK LENGTH FOR ASME CODE APPLICATIONS

- ➔ 1T EQUIVALENT TOUGHNESS IS ADEQUATE FOR MOST ASME CODE APPLICATIONS
- ➔ 48T CRACK LENGTH OF TSE SPECIMEN IS MUCH TOO LARGE
- ➔ THEREFORE, SIZE UNADJUSTED TSE DATA PLOT IS INAPPROPRIATE FOR ASME CODE APPLICATIONS

COMPARISON WITH PTSE DATA

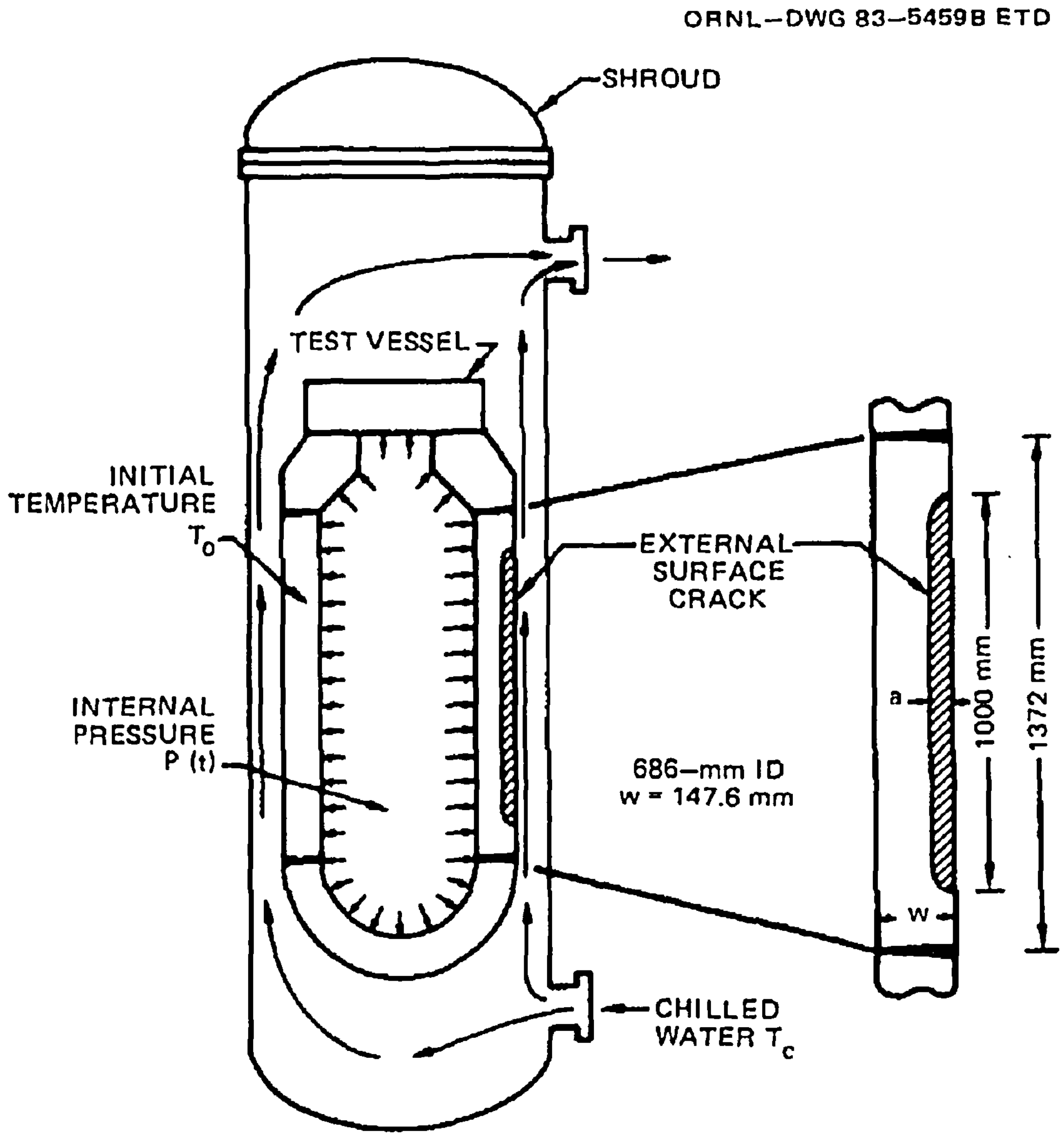
PRESSURIZED THERMAL SHOCK EXPERIMENT

- ➔ PRESSURE AND THERMAL LOADING
- ➔ VESSELS WITH END CAPS
- ➔ TYPICAL STRUCTURE FOR NUCLEAR APPLICATIONS
- ➔ TEST TEMPERATURE WAS INTERMEDIATE
- ➔ FAIR AMOUNT OF PLASTIC ZONE
- ➔ MORE CREDIBLE TEST DATA FOR THE INDUSTRY
- ➔ STILL UNREALISTIC CRACK SIZE (LENGTH)

PRESSURIZED THERMAL SHOCK EXPERIMENT – PTSE 1986

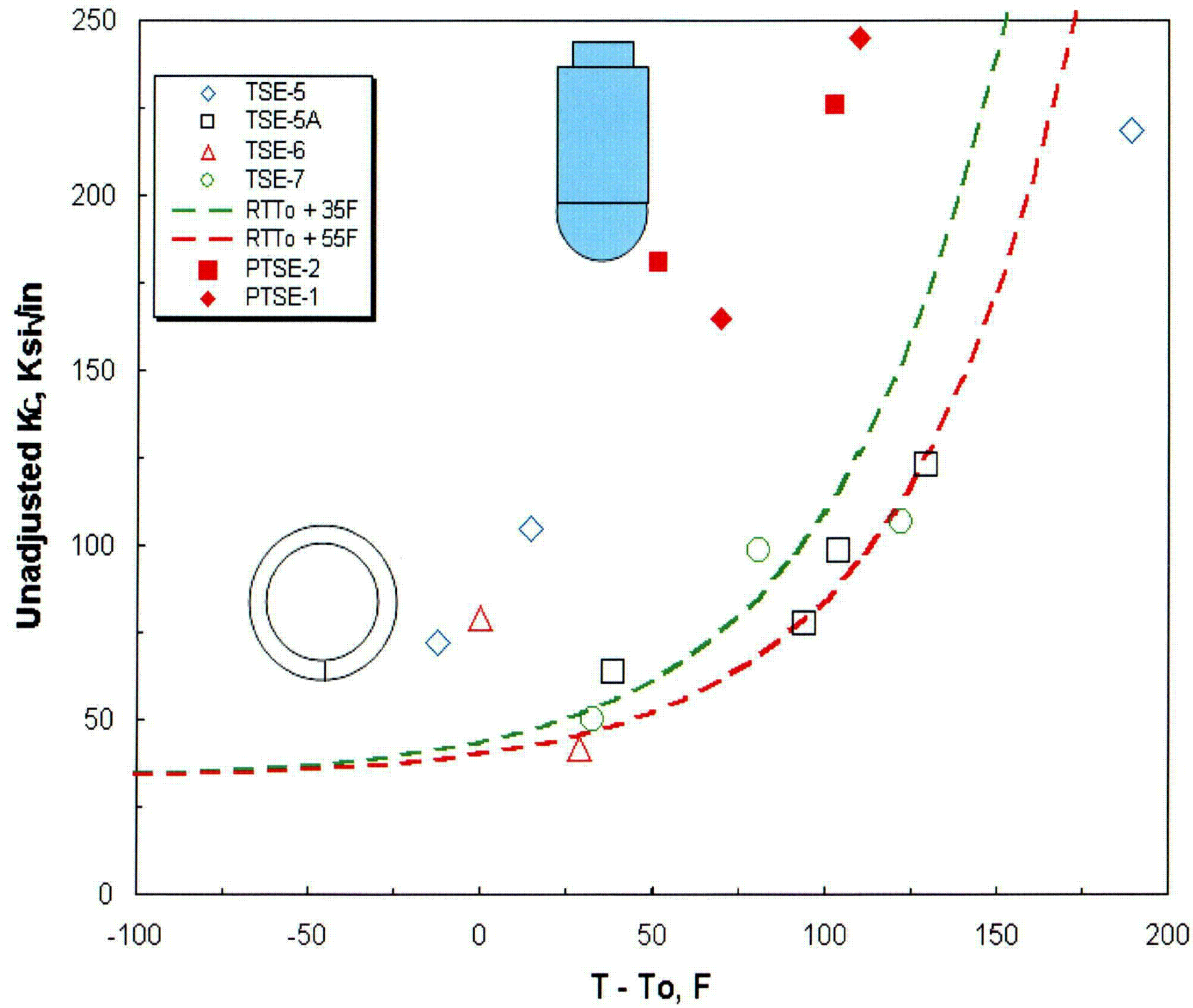
- ➔ THERMAL SHOCK AND PRESSURE LOADING
- ➔ TEST TEMPERATURE – APPLICATION RANGE
- ➔ MATERIAL A 387, GR 22, CL 2 (2 ¼ Cr 1Mo Steel)
- ➔ RT_{NDT} = 49°C (120°F) FAIRLY HIGH FOR UNIRRADIATED MATERIAL S255 MPA
- ➔ A PRESSURE VESSEL GEOMETRY – TYPICAL APPLICATIONS
- ➔ UNCERTAINTY ON WARM PRESTRESSING
- ➔ EXTERNAL FLAW LOCATION

ɔ


ORNL–DWG 83–5459B ETD
SHROUD
TEST VESSEL
INITIAL TEMPERATURE T_0
INTERNAL PRESSURE P (t)
EXTERNAL SURFACE CRACK
686–mm ID
w = 147.6 mm
a
w
1000 mm
1372 mm
CHILLED WATER T_c

AREVA

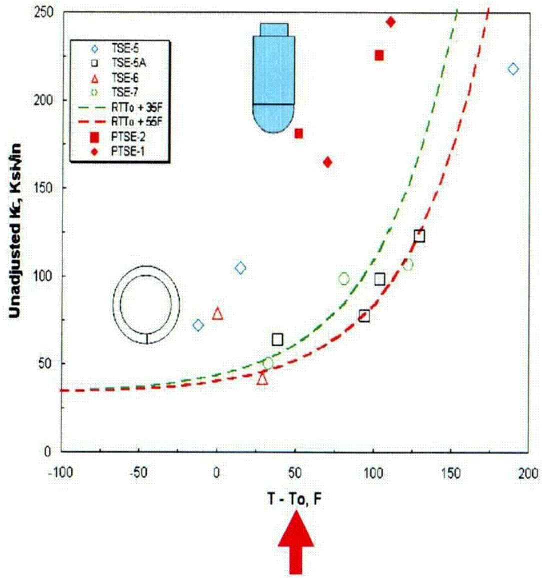
TSE AND PTSE TEST DATA



AREVA

C09

SUMMARY OF TSE DATA PLOT



- ➔ **LACK OF TSE SPECIFIC T_0**
  - **T_0 BASED ON TSE DATA CONVERTED 1T EQUIVALENT K_{IC}**
- ➔ **T_0 USED TO PLOT TSE DATA MAY BE OFF BY CONSIDERABLE AMOUNT DUE TO T_0 VARIABILITY**

AREVA

C10

SUMMARY OF TSE DATA PLOT

REASONS FOR T_0 VARIABILITY:

1. CRACK TIP MATERIAL
2. SPECIMEN SIZE EFFECT
3. FRACTURE SPECIMEN TYPE
4. SPECIMEN LOADING
5. THROUGH-WALL VARIATION OF TOUGHNESS
6. TEST CONDITION TSE VS. PTSE

SUMMARY OF TSE DATA PLOT

- ➔ SO MANY UNANSWERED QUESTIONS EXIST FOR TSE DATA
- ➔ CRACK SIZE IS TOO LARGE FOR TYPICAL ASME CODE APPLICATIONS
- ➔ PREMATURE TO PLOT TSE DATA AGAINST T_0 FROM SMALL SPECIMEN TESTS
- ➔ SEEM MORE APPROPRIATE TO COMPARE PTSE DATA INSTEAD OF TSE BECAUSE OF SPECIMEN GEOMETRY AND TEST TEMPERATURE

CONCLUSION

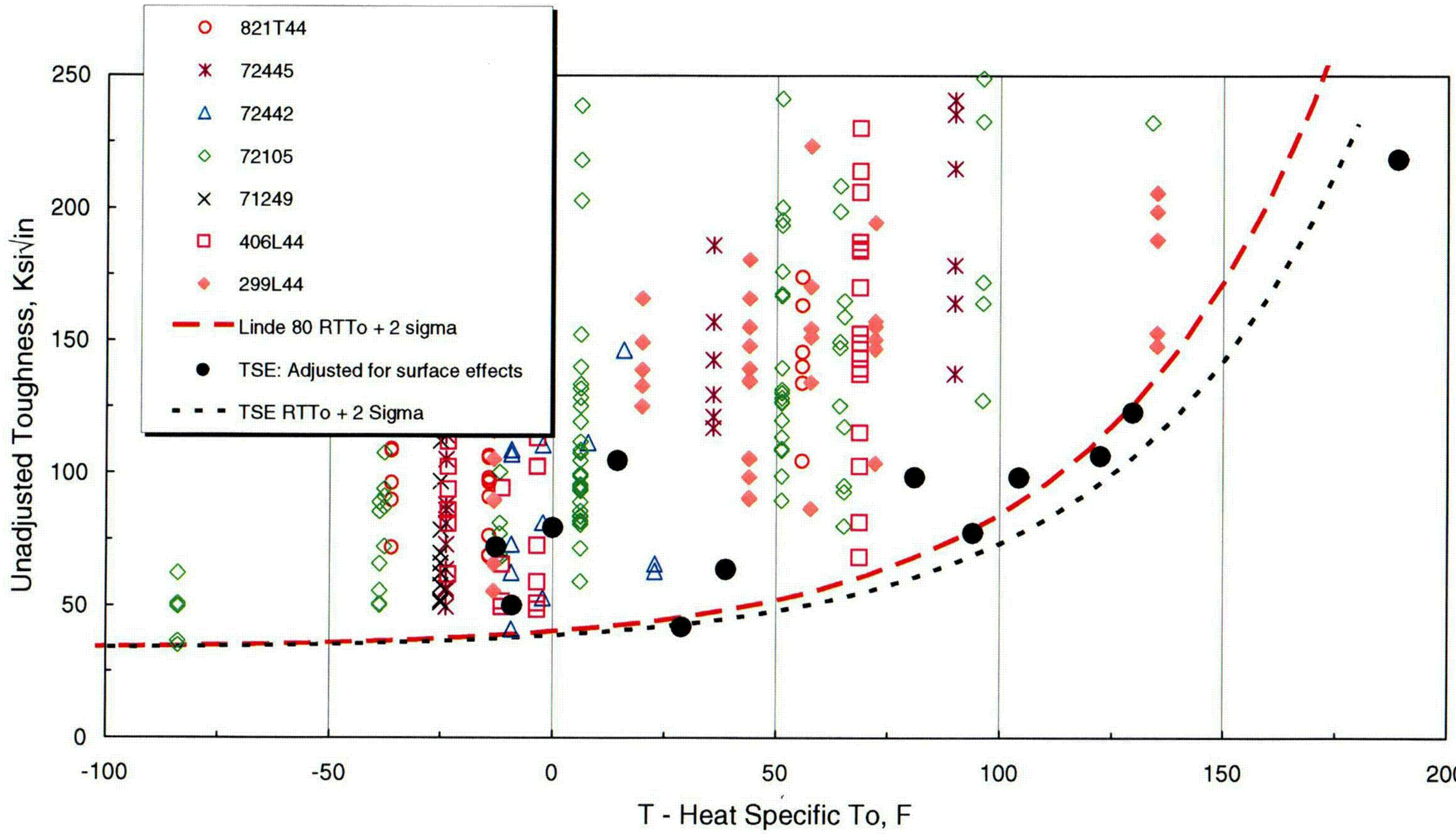
- ➔ TSE DATA INDEXED BY T_0 FROM SMALL SPECIMEN DATA ARE INAPPROPRIATE FOR USE AS TYPICAL RPV APPLICATIONS
  - ❑ DUE TO T_0 VARIABILITY
  - ❑ DUE TO PECULIAR SPECIMEN TYPE AND LODING
  - ❑ DUE TO LONG CRACK FOR A TYPICAL ASME CODE APPLICATION
- ➔ PTSE DATA APPEAR TO BE MORE TYPICAL FOR NUCLEAR APPLICATIONS – BUT CRACK SIZE IS STILL LARGE
- ➔ PTSE DATA SHOW ADEQUACY OF CODE CASES

TOPICAL REPORT BAW-2308

- ➔ *THE LATEST RAI IS ADDRESSED BY SHOWING THE TSE DATA PLOT IS NOT SO CREDIBLE*
- ➔ *NOTE THAT FINAL APPLICATION IS SUBJECT TO ADDITIONAL INITIAL MARGIN THROUGH TWO STANDARD DEVIATIONS*
- ➔ *THIS MARGIN TERM AMPLY COVERS ANY FURTHER CONCERN*
- ➔ *REQUEST THAT BAW-2308 REVIEW BE COMPLETED AS SOON AS POSSIBLE*
- ➔ *THIS HAS DIRECT BEARING ON POINT BEACH SUBMITTAL*

AREVA

Linde 80 and TSE Data with N-629 Curve with BAW-2308 Approach of Adding Initial Margin



C11

RAI

In the light of this new information, the NRC staff has concluded that the technical basis for Master Curve application contained in topical report BAW-2308, Revision 1 needs to address the issues raised by Dr. Merkle and assess the impact if any, on the conclusions in the report. In addition, this same consideration applies to the September 2003 Nuclear Management Company (NMC) submittal which proposed to apply the methodology of BAW-2308, Revision 1 to the evaluation of RPV integrity issues for Point Beach Units 1 and 2. The NRC staff considers approval of the NMC submittal for the Point Beach units to be contingent upon the completion of our review and approval of BAW-2308, Revision 1.

AREVA

RESPONSE TO THE RAI

It is our opinion that the TSE data used to raise the concern are inappropriate to assess the adequacy of Code Cases N-629 and N-631, based on the number of uncertainties listed in the attached presentations.

Attachments:

1. Merkle's RT_{T0} concern by K. K. Yoon
2. ORNL Experiments by J. B. Hall
3. A Critical Review of the Technical Basis of the ORNL Report 01/08 by Kim Wallin

ORNL
Thermal Shock Experiment Uncertainties

J. Brian Hall

AREVA

ORNL HSST Vessel Experiments

- Intermediate Test Vessel (ITV)
  - 1973-1979
  - 10 tests
- Thermal Shock Experiments (TSE)
  - TSE 1-4
    - 1975-1977
  - TSE 5, 5A, 6, 7
    - 1979-1983
- Pressurized TSE (PTSE)
  - 1984-1986
  - Warm Prestressing
  - 3 tests

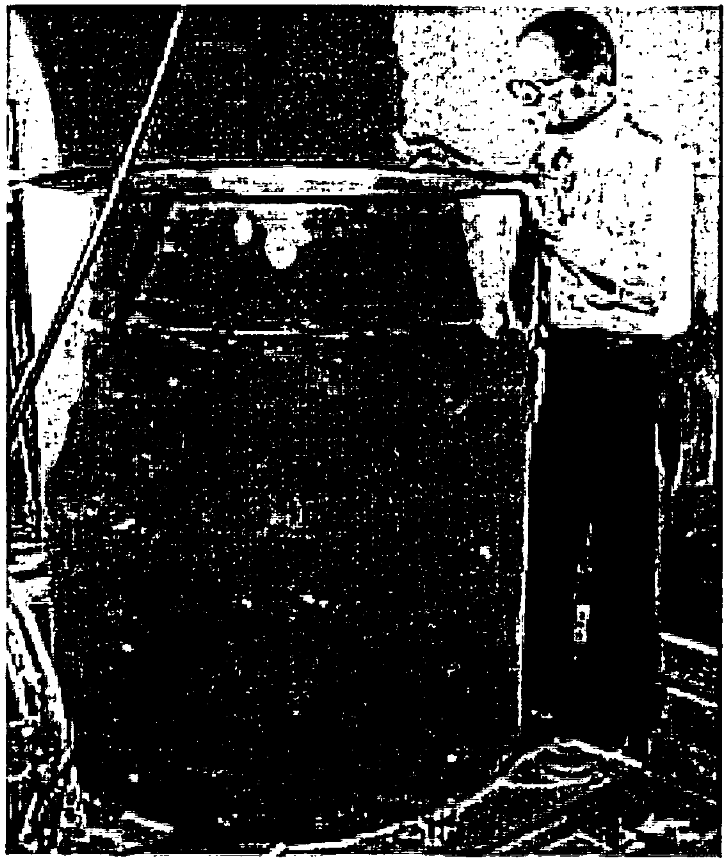
Early ORNL Vessel Experiments

➔ *Intermediate Test Vessel (ITV)*
- ❑ *Mostly conducted on upper shelf – not applicable*

➔ *TSE 1-4*
- ❑ *Trepanned forgings*
- ❑ *21"OD; 9.5" ID*
- ❑ *TS achieved cracking*
- ❑ *Little crack extension due to constraint*

ORNL TSE 5-7

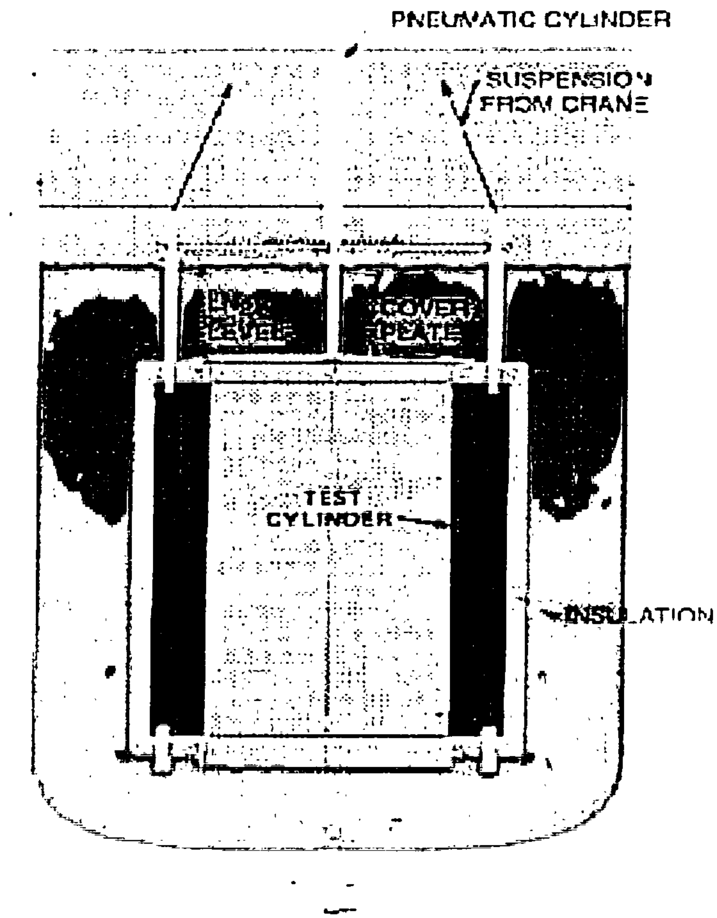
- ➔ *SA-508 Class 2 forging*
  - ❑ *Tempered to simulate brittle material*
- ➔ *0.99 m diameter (39 in.)*
- ➔ *1.22 m long (48 in.)*
- ➔ *0.15 or .076 m thick (6, 3 in.)*
- ➔ *Initial ID flaw*
  - ❑ *Electron Beam Weld: brittle recast zone*
  - ❑ *Hydrogen charging causes cracking*
  - ❑ *7-16mm deep: full length or semi-elliptical (0.27-0.63 in.)*



AREVA

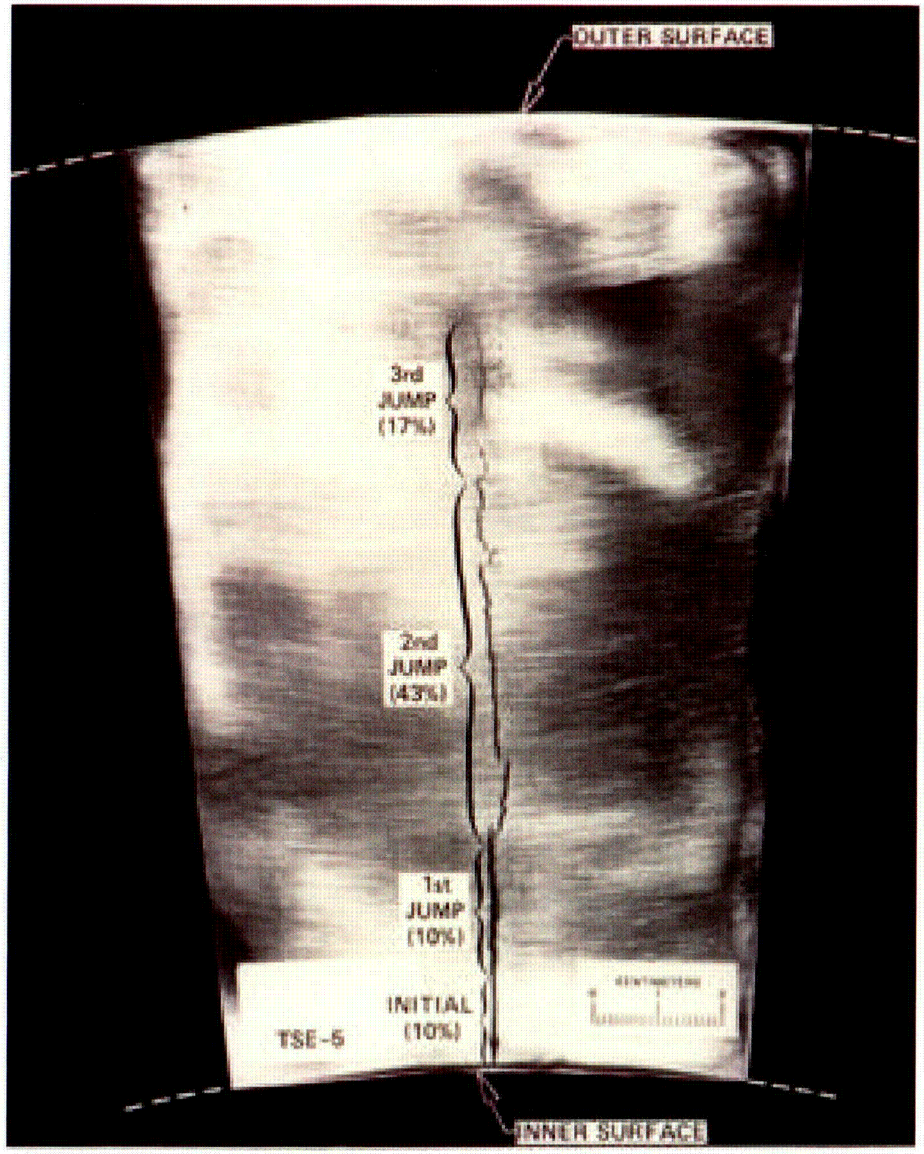
Thermal Shock

- OD insulated
- ID polymer coated
- Heated cylinder submerged into liquid N_2
- Temperature
  - Initial 96C
  - Final -196C
- Test lasted a few minutes
- Temperature measured at various depths
- Strain measured



AREVA

Up to 4 initiation-arrest events



AREVA

C12

Variables that Determine Position of TSE data Relative to ASME N-629 Curve

- T_0
  - ORNL small specimen T_0 data shows through thickness variation
  - Affects toughness at crack tip (a/W = 0.07 to 0.11)
  - Bulk material T_0 does not reflect crack tip toughness
- Test Temperature
  - Large temperature gradient at first initiation (5 C/mm)
  - Was initiation point at idealized location?
- K_{IC}
  - Reasonable agreement between 2D and 3D solutions
  - Actual flaw is different from idealized case
  - Did H_2 affect toughness at crack tip?
  - Was entire initial crack in base metal?
  - Unbroken ligaments in later events
  - Size Effect - Yoon

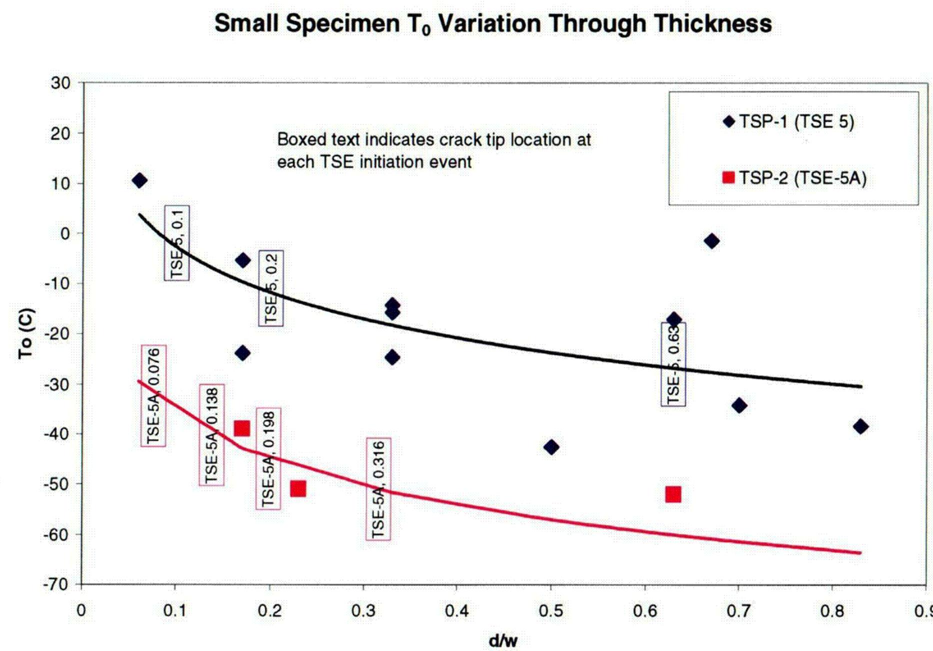
T_0 Uncertainty

- ➔ **TSE-6 and TSE-7 Materials**
  - ❑ Reasonably consistent through thickness
  - ❑ No adjustment needed
- ➔ **TSE-5 and TSE-5A Materials**
  - ❑ Through thickness variation in T_0
  - ❑ Sufficient small specimen data to estimate T_0 at each crack tip depth
- ➔ **Normal T_0 Uncertainty**
  - ❑ Specimen population
  - ❑ Material variability (Monte Carlo Analysis)

AREVA

T_0 Variation Through Thickness

- **Over 170 small specimen toughness tests**
- **Sufficient data to establish through thickness trend**
- **Atypical reduction of toughness near ID surface**



Trend lines represent data trend established in TSP-1 fit to the available data for TSE-5A. Boxed text identifies the location of the TSE crack tip. The likely T0 at that location can then be deduced

AREVA

C13

Test Temperature Uncertainty

- ➔ *Large temperature gradient at first initiation (5 C/mm)*
- ➔ *Significant error is introduced if initiation point is not at idealized (assumed) location*

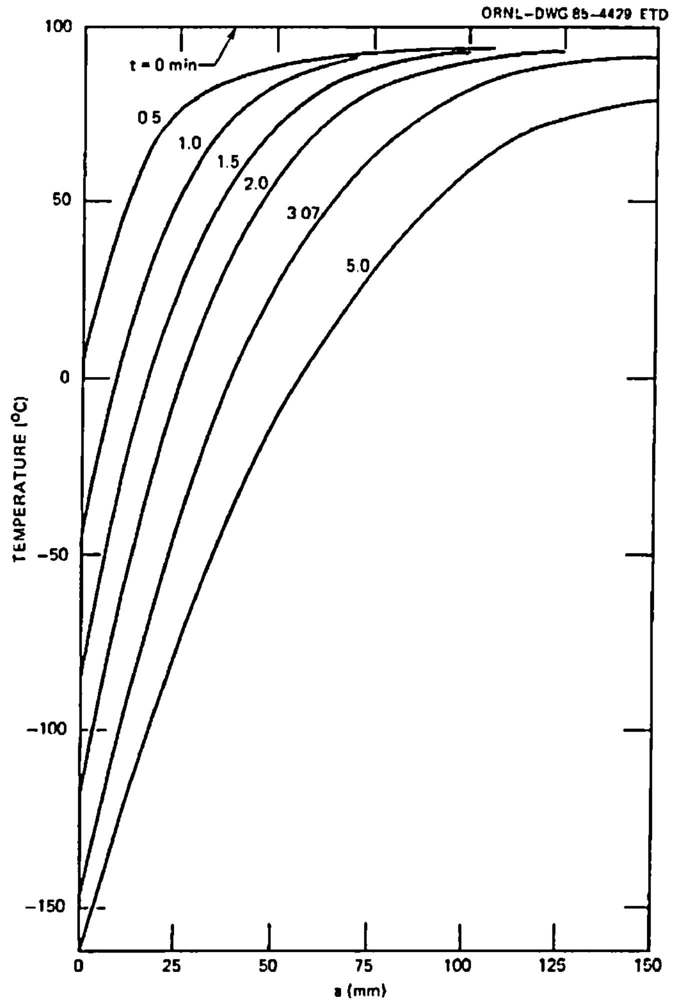


Fig. 9.6. Temperature vs a/w for several times during the TSE-5A transient.

AREVA

K_I Uncertainty

- ➔ Did H_2 affect toughness at crack tip?
  - ❑ Not addressed here
- ➔ Actual flaw is different from idealized case
- ➔ Was entire initial crack in base metal?
- ➔ Unbroken ligaments in later events

AREVA

TSE-7 Initial Flaw

- ➔ ***Which is it?***
- ➔ ***Different from idealized semi-elliptical surface flaw***

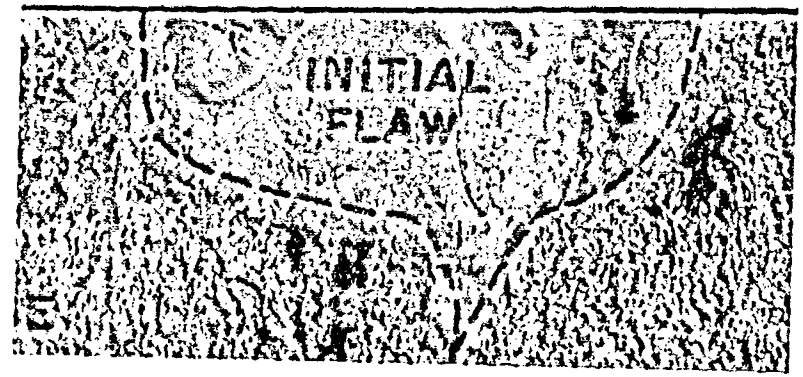
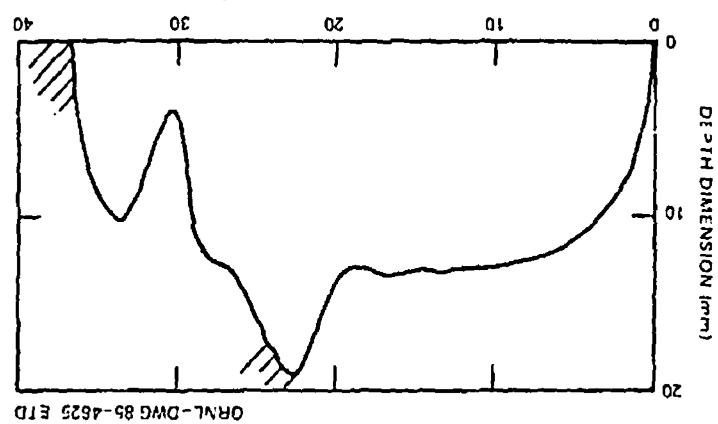
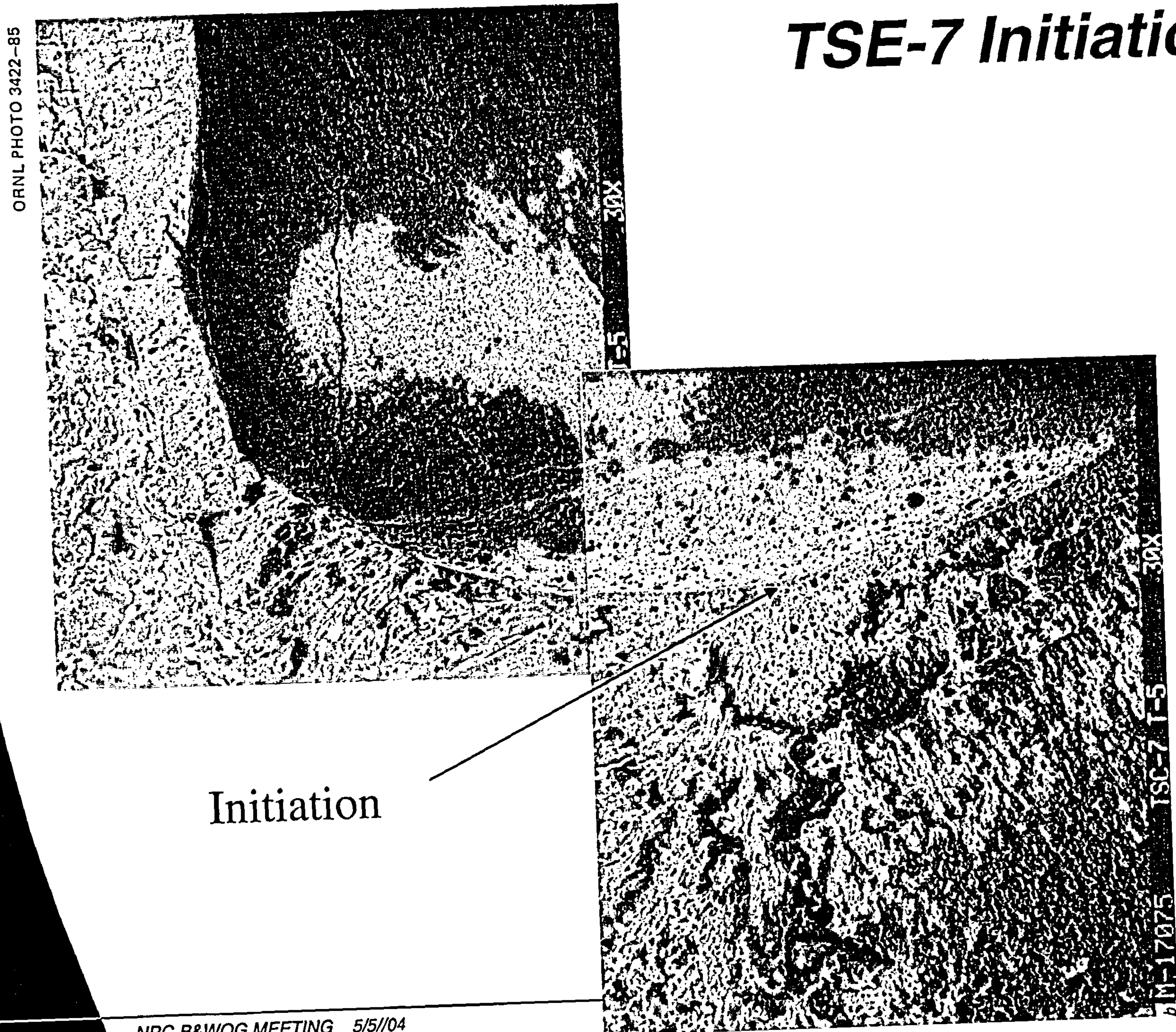


Fig. 8.11. Actual configuration of initial flaw for TSE-7.

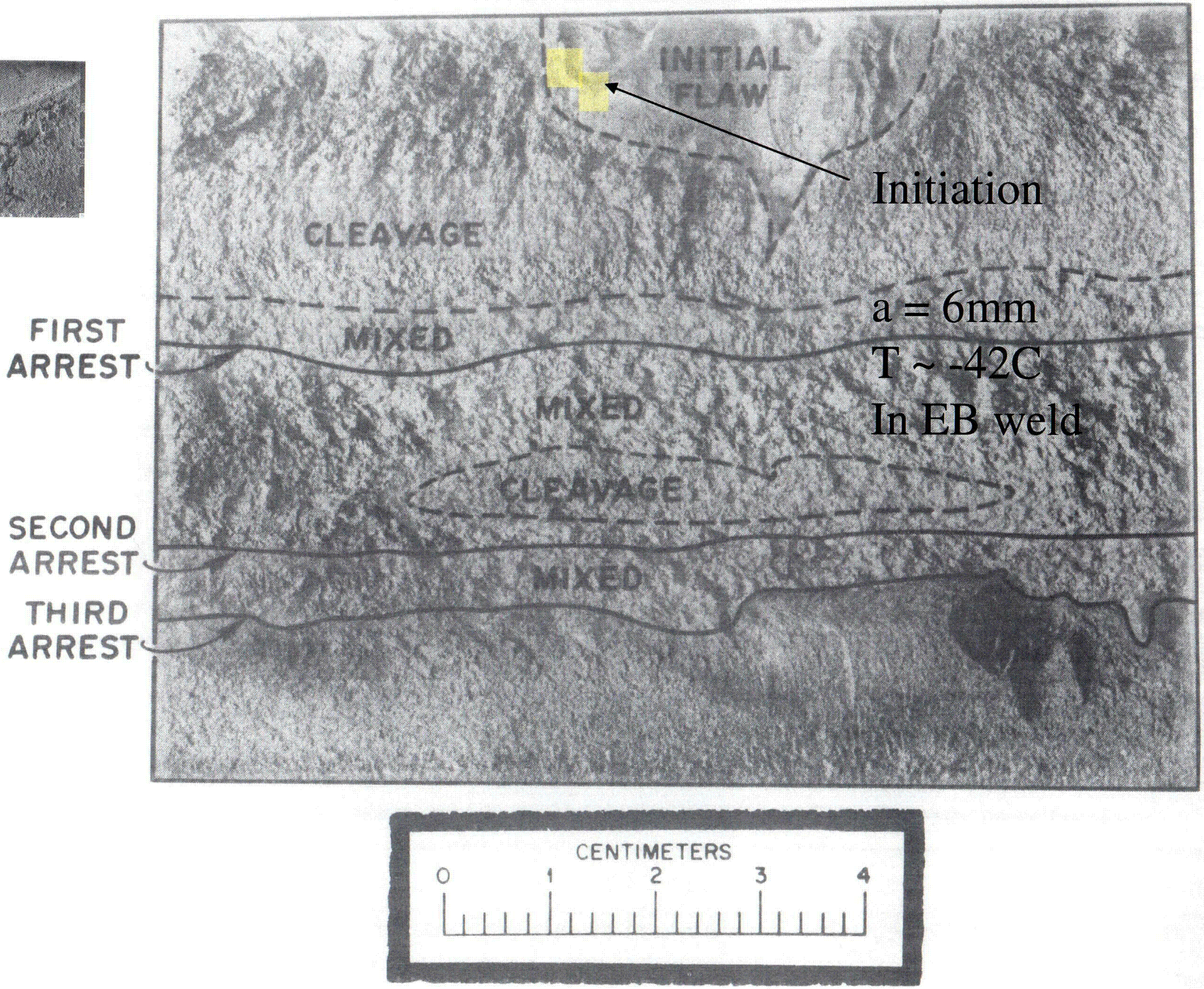


AREVA

TSE-7 Initiation



ORNL PHOTO 3497–85



C14

Two Possibilities

- ➔ ***Fig. 8.19.b is misidentified***
  - ❑ *Initiation site of initial crack creation, not first TSE event*

Or

- ➔ ***Initiation site is at the location shown***
  - ❑ *6mm depth*
  - ❑ *Temperature here is ~ -42C, not -19C*
  - ❑ *Recrystalized EB weld or HAZ material*
    - *T. Mager showed that cracks initiating in EB weld have ~ 50% lower toughness (WCAP-7579)*

- ➔ ***Wallin to discuss other initiation sites***

Initiation Point(s)?

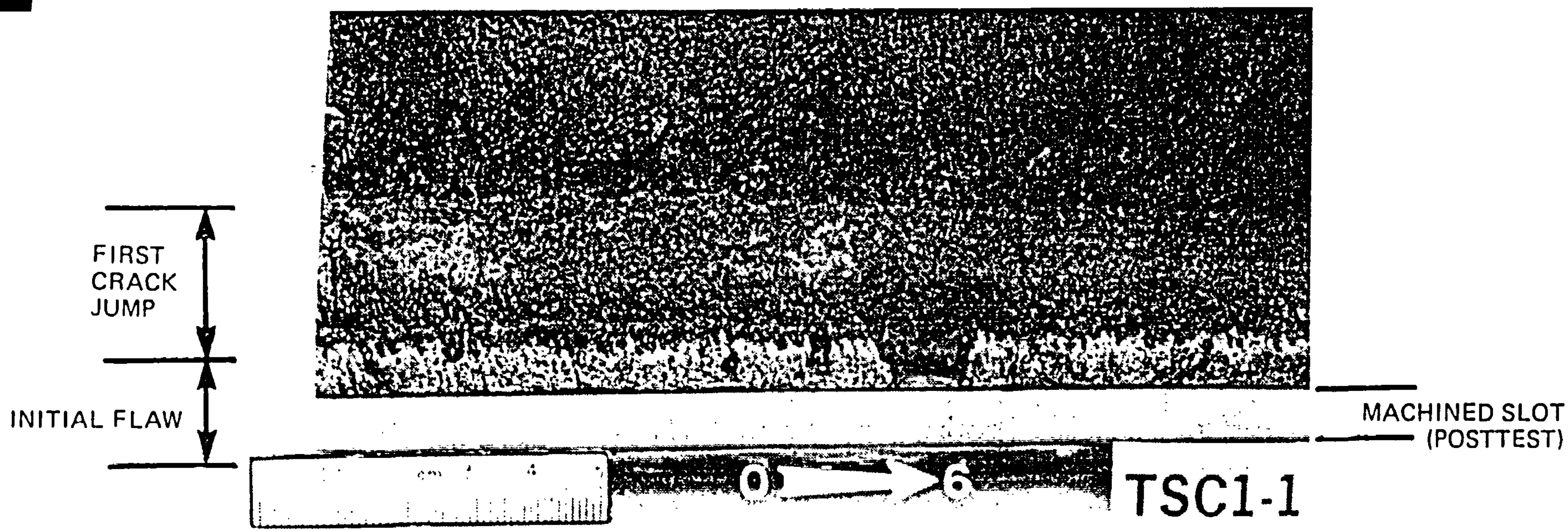


Fig. 8.11. Fracture surface (near midlength of test cylinder) of TSE-5 final long axial flaw.

>No attempt was made (that was reported) to verify entire initial crack was in base metal

>At what depth is actual initiation site?

Unbroken Ligaments

What is the effect of unbroken ligaments on initiation and arrest events?

The K_I seen would not be the same as calculated for idealized 2D or 3D flaw.

M&C PHOTO Y175292A

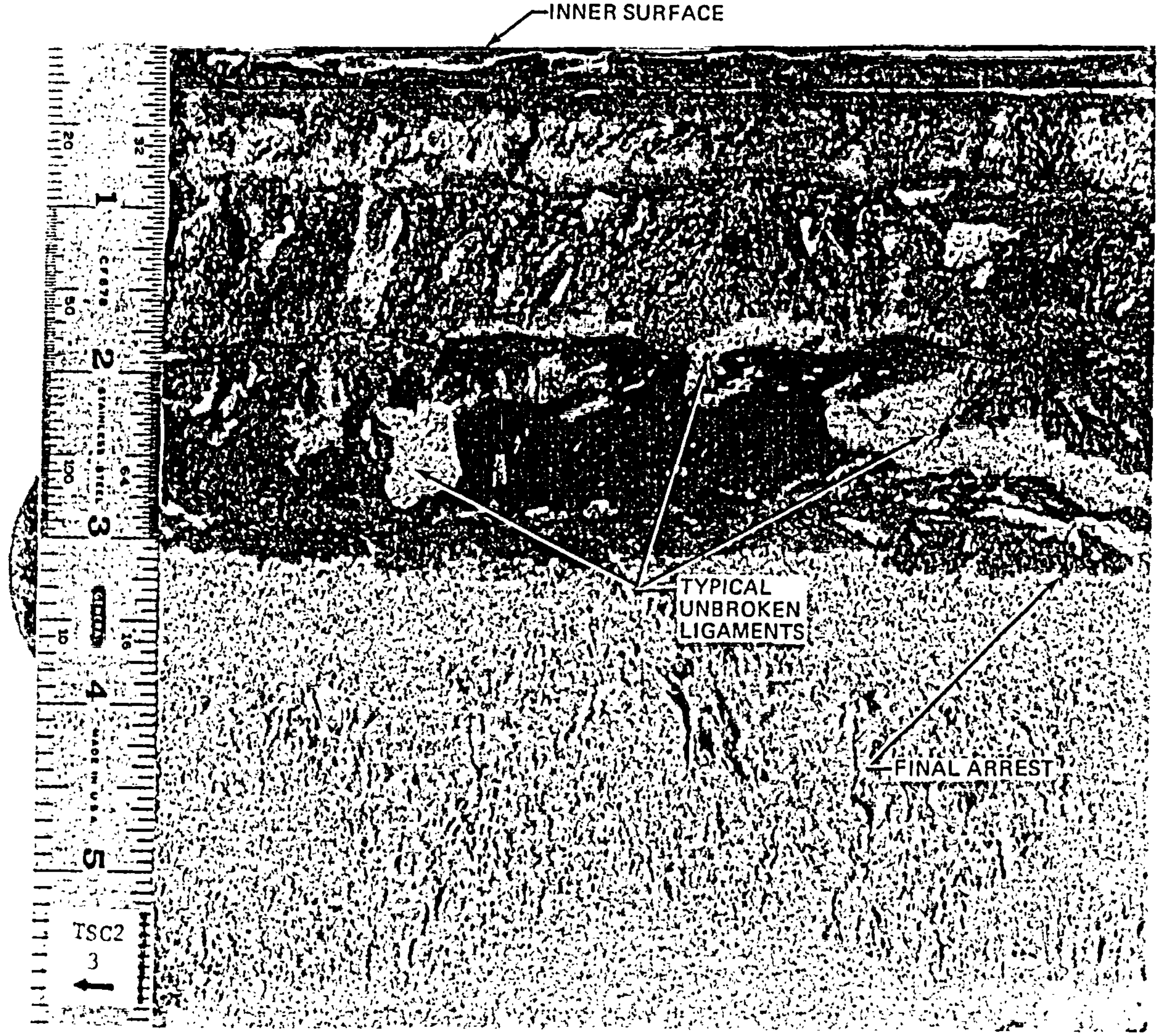


Fig. 11.4. Examples of unbroken ligaments (TSE-5A).

TSE Data Uncertainties

- ➔ K_{IC}
  - ❑ Actual flaw is different from idealized case
  - ❑ H_2 affect on toughness at crack tip not evaluated
  - ❑ Entire initial crack not proven to be in base metal
  - ❑ Unbroken ligaments in later events
- ➔ Test Temperature
  - ❑ Large temperature gradient at first initiation (5 C/mm)
  - ❑ Initiation point not likely at idealized location
- ➔ T_0
  - ❑ Small specimen T_0 through thickness variation
  - ❑ Normal measurement and variability

AREVA

Conclusion

- ➔ *Uncertainties are substantial for these four TSE tests*

- ➔ *These four tests should not be used to call into question the credibility of the 1500+ well characterized tests which are the basis for Code Cases N-629 and N-631!*