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MASTER

PRESSURIZED-THERMAL-SHOCK EXPERIMENTS*

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The reactor pressure vessel in a pressurized water reactor is normally subjected to temperatures and pressures that preclude propagation of sharp, crack-like defects that might exist in the wall of the vessel. However, there is a class of postulated accidents, referred to as overcooling accidents, that can subject the pressure vessel to severe thermal shock while the pressure is substantial. As a result of such accidents vessels containing high concentrations of copper and nickel, which enhance radiation embrittlement, may possess a potential for extensive propagation of preexistent inner-surface flaws prior to the vessel's normal end of life.

The primary objective of the ORNL pressurized-thermal-shock (PTS) experiments is to verify analytical methods that are used to predict the behavior of pressurized-water-reactor vessels under these accident conditions involving combined pressure and thermal loading. The criteria on which the experiments are based are:

(a) Scale large enough to attain effective flaw border triaxial restraint and a temperature range sufficiently broad to produce a progression from frangible to ductile behavior through the wall at a given time.

(b) Use of materials that can be completely characterized for analysis.

(c) Stress states comparable to the actual vessel in zones of potential flaw extension.

(d) Range of behavior to include cleavage initiation and arrest, cleavage initiation and arrest on the upper shelf, arrest in a high K_I gradient, warm prestressing, and entirely ductile behavior.

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(e) Long and short flaws with and without stainless steel cladding.

(f) Control of loads to prevent vessel burst, except as desired.

A PTS test facility is under construction which will enable the establishment and control of wall temperature, cooling rate, and pressure on an intermediate test vessel (ITV) in order to simulate stress states representative of an actual reactor pressure vessel. The facility, to be completed in June of 1983, will house an ITV in a heated shroud, which will also serve to establish sufficient flow of a precooled water-alcohol mixture to thermally shock the flawed ITV outer surface. The ITV will be pressurized internally during the test and will contain instrumentation to enable on-line data acquisition and control. Vessel wall temperatures, initiation and arrest fracture toughness, and stress intensity will be calculated and displayed during the tests.

Three experiments are presently planned. The first will address warm prestressing effectiveness and arrest on the ductile upper shelf. The second will examine arrest on a low-toughness ductile upper shelf, and the last will evaluate stainless steel cladding effectiveness in restricting small flaw growth. The test matrix and first two experiments are discussed in detail and the third experiment is summarized.

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PRESSURIZED–THERMAL–SHOCK EXPERIMENTS

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TENTH WATER REACTOR SAFETY RESEARCH
INFORMATION MEETING

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SUMMARY

- STATEMENT OF THE PROBLEM
- CRITERIA FOR PRESSURIZED–THERMAL–SHOCK EXPERIMENTS
- PRESSURIZED–THERMAL–SHOCK TEST FACILITY
- PLANNED PRESSURIZED–THERMAL–SHOCK EXPERIMENTS

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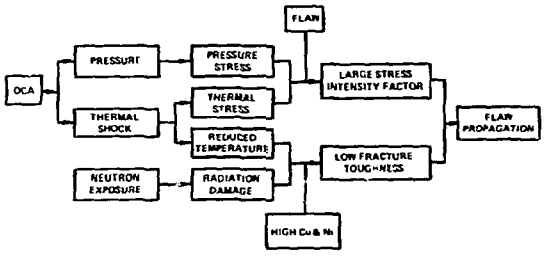
OCA'S REPRESENT A CHALLENGE TO THE INTEGRITY OF PWR PRESSURE VESSELS



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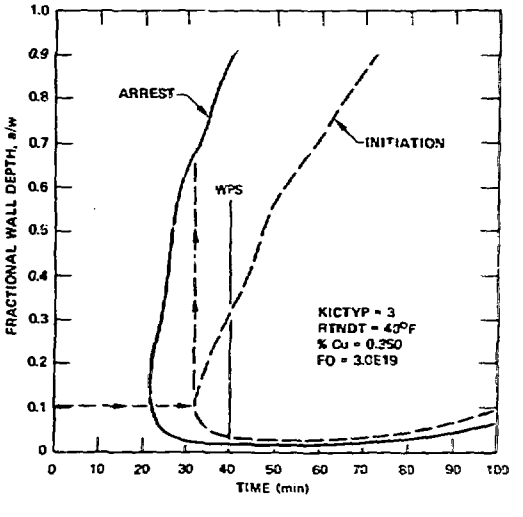
CRITICAL CRACK DEPTH CURVES FOR A REFERENCE PWR VESSEL INDICATE DEEP PENETRATION OF A FLAW UNDER SOME PRESSURIZED-THERMAL-SHOCK LOADINGS



CRITERIA FOR PRESSURIZED–THERMAL–SHOCK EXPERIMENT

- TEST TO VALIDATE METHODS OF ANALYSIS APPLICABLE TO FULL–SCALE PTS UNDER COMBINED LOADING
- SCALE LARGE ENOUGH TO ATTAIN EFFECTIVE FULL–SCALE RESTRAINT
- USE CHARACTERIZED MATERIAL IN FLAW REGION (INCLUDING CLADDING)
- TEST CONDITIONS AND MATERIALS PRODUCE
  - (1) REALISTIC (PWR) STRESS FIELDS AND GRADIENTS
  - (2) REALISTIC FRACTURE TOUGHNESS CONDITIONS IN ZONE OF ACTION

CRITERIA FOR PRESSURIZED–THERMAL–SHOCK EXPERIMENT (CONTINUED)

- TEST CONDITIONS ARE CAPABLE OF PRODUCING
  - (1) CLEAVAGE INITIATION (SMALL AND LONG FLAWS)
  - (2) CLEAVAGE INITIATION AND ARREST BELOW UPPER SHELF
  - (3) CLEAVAGE INITIATION WITH ARREST ON UPPER SHELF
  - (4) ARREST IN HIGH K GRADIENT
  - (5) WPS STATES, MARGINAL, RELIEF WITH LOW AND HIGH K_I, SECONDARY WPS
- LOADING CONDITIONS AND CONTROLS ARE CAPABLE OF PREVENTING VESSEL BURST (EXCEPT WHEN DESIRED)

PRESSURIZED–THERMAL–SHOCK ISSUES WHICH THE PRESSURIZED–THERMAL–SHOCK TEST FACILITY CAN ADDRESS INCLUDE

- INTERVENTION OF DUCTILE UPPER SHELF IN CRACK ARREST
- EFFECTIVENESS OF WARM PRESTRESSING
- ARREST IN A RAPIDLY RISING K_I FIELD
- BEHAVIOR OF SMALL FLAWS WITH AND WITHOUT SS CLADDING

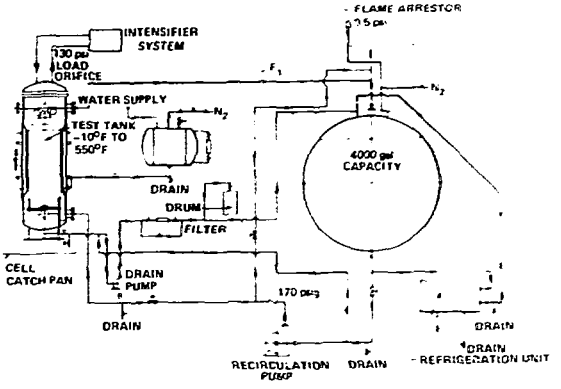
THE FUNCTION OF THE PTSTF IS TO ESTABLISH AND CONTROL

- MAXIMUM TEMPERATURE – T_{max}
- SINK TEMPERATURE – T_{sink}
- HEAT TRANSFER COEFFICIENT – h
- PRESSURE – p

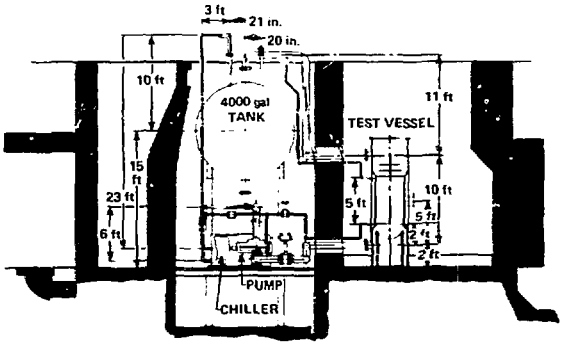
THE METHOD OF TESTING INCLUDES

- USING EXISTING HSST INTERMEDIATE TEST VESSELS (ITV'S)
- EXTERNAL FLAW, EXTERNAL COOLING, INTERNAL PRESSURE
- COMPLETE PRETEST MATERIALS CHARACTERIZATION
- PRETEST ANALYSIS AND PREDICTION
- HIGHLY INSTRUMENTED ITV
- ON-LINE CONTROL AND MONITORING
- POSTTEST FAILURE ANALYSIS

PRESSURIZED–THERMAL–SHOCK TEST FACILITY



SECTION ELEVATION OF HSST PROGRAM PRESSURIZED–THERMAL–SHOCK FACILITY



THE MAJOR OBJECTIVES OF A PRESSURIZED–THERMAL–SHOCK EXPERIMENT ARE

- SIMULATION OF CONDITIONS OF MATERIAL TOUGHNESS AND STRESS STATE REPRESENTING A COMBINATION OF PRESSURE AND THERMAL LOADINGS IN A REACTOR VESSEL
- DEVELOPMENT OF DATA FOR VALIDATION OF ANALYTICAL MODELS OF FLAW BEHAVIOR FOR THE CONDITIONS OF INTEREST

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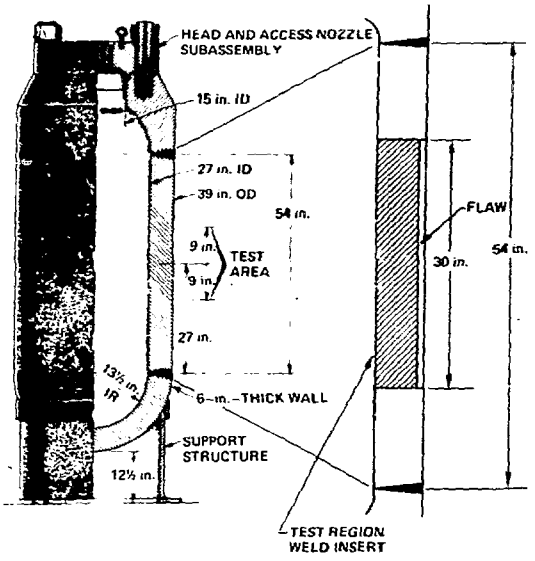
LONG FLAW CONFIGURATION FOR PRESSURIZED–THERMAL–SHOCK EXPERIMENTS



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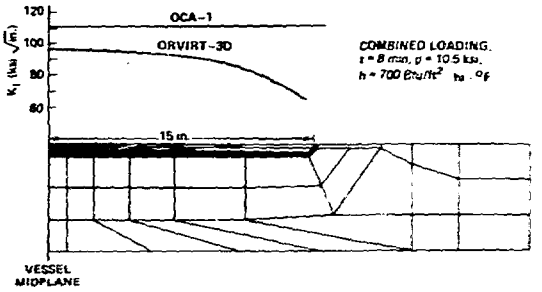
3D ANALYSIS SHOWS THE MIDSECTION OF THE FLAW HAS UNIFORM STRESS INTENSITY



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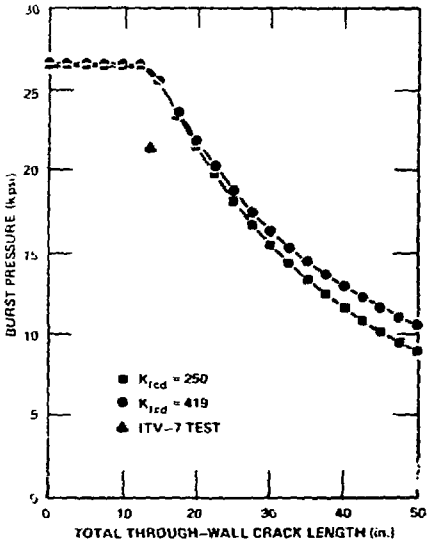
BURST PRESSURE VS CRACK LENGTH FOR HSST INTERMEDIATE VESSEL



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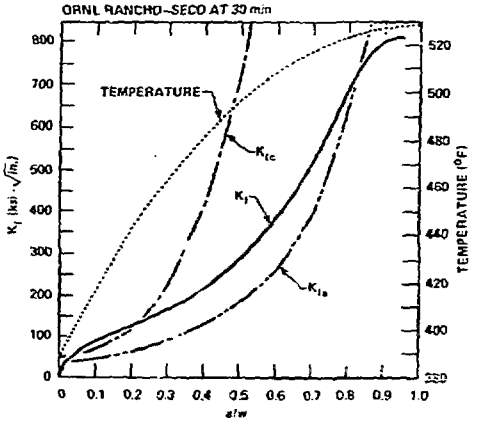
PRESSURIZED–THERMAL–SHOCK TRANSIENTS PRODUCE CONDITIONS THAT MAY RESULT IN PROPAGATION OF INNER-SURFACE FLAW



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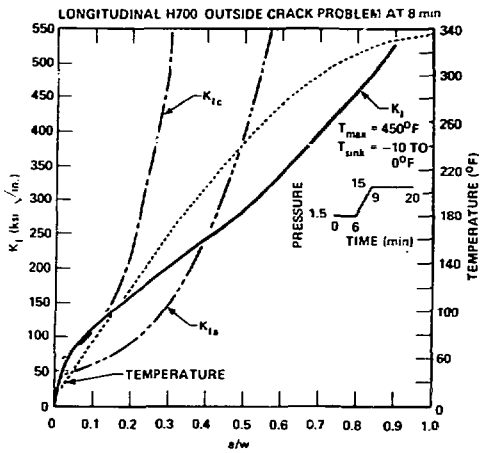
CONDITIONS IN HSST INTERMEDIATE VESSEL ARE SIMILAR TO PWR VESSEL UNDER PRESSURIZED–THERMAL–SHOCK TRANSIENT



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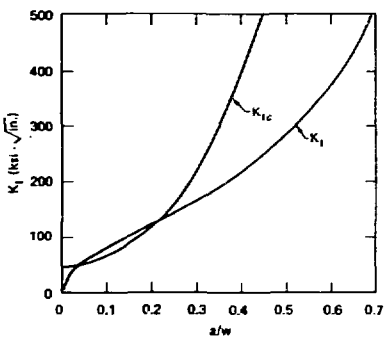
RANCHO–SECO PRESSURIZED THERMAL SHOCK, K_I VERSUS a/w AT 30 MINUTES



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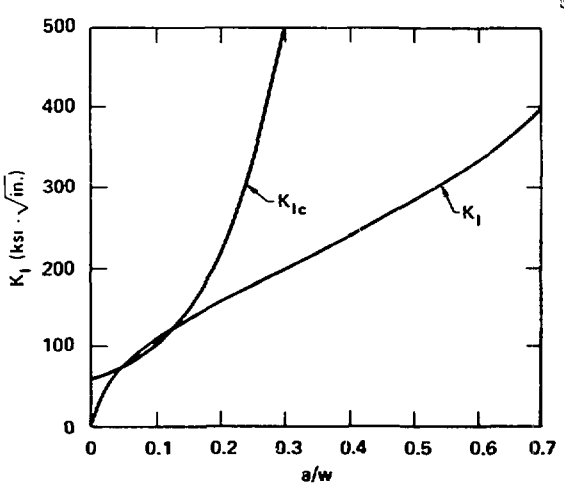
ORNL PTS, K_I VERSUS a/w AT 8 MINUTES



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PRESSURIZED–THERMAL–SHOCK EXPERIMENT INVOLVES TESTS ON THREE VESSELS TO VALIDATE PREDICTIONS OF FLAW BEHAVIOR UNDER COMBINED LOADS

EXPERIMENT	OBJECTIVE
PTS–1	WARM PRESTRESSING EFFECTIVENESS AND ARREST ON DUCTILE SHELF
PTS–2	ARREST ON DUCTILE SHELF IN LOW UPPER SHELF MATERIAL
PTS–3	STAINLESS STEEL CLADDING EFFECTIVENESS IN RESTRICTING SMALL FLAW GROWTH

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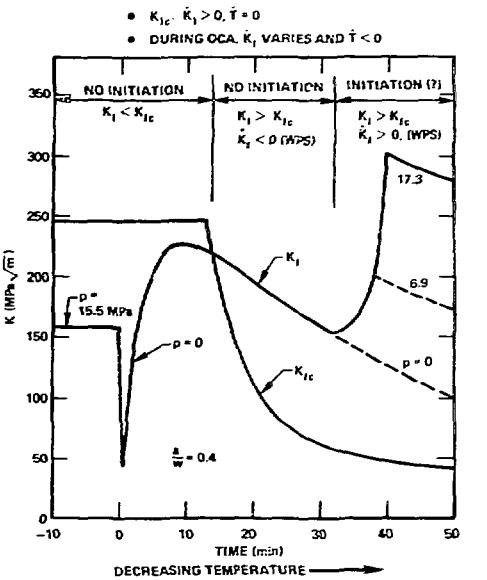
WPS (LOAD AND THERMAL HISTORIES) AFFECTS CRITICAL VALUES OF K_I FOR CRACK INITIATION



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PRESSURIZED–THERMAL–SHOCK TEST MATRIX

TEST NO	MATERIAL TOUGHNESS	WPS EFFECTS	ARREST CONDITION	FLAW GEOMETRY	CLADDING
PTS 1	HIGH SHELF	YES	TRANSITION AND DUCTILE SHELF IN RISING K FIELD	LONG	NO
PTS 2	LOW SHELF	NO	DUCTILE SHELF IN RISING K FILED	LONG	NO
PTS 3	HIGH SHELF	NO	TRANSITION	SHORT	YES

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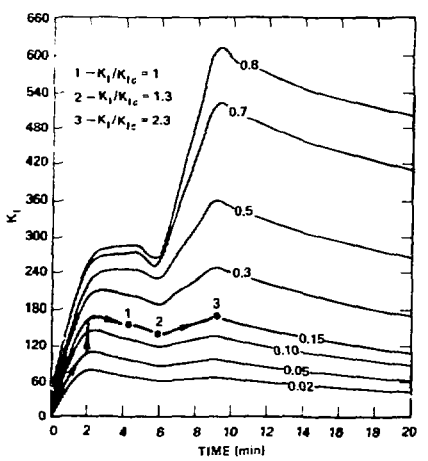
PTS–1 WILL DEMONSTRATE WARM PRESTRESSING EFFECTIVENESS



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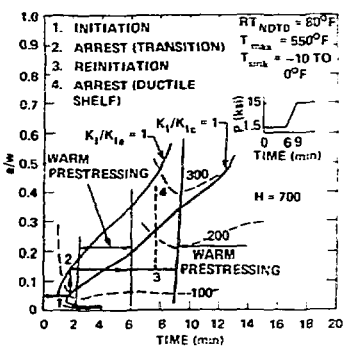
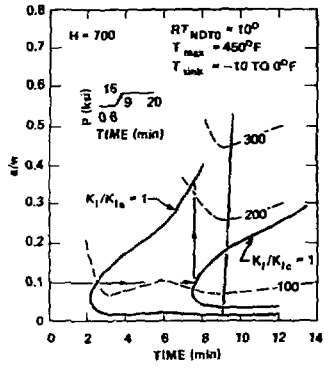
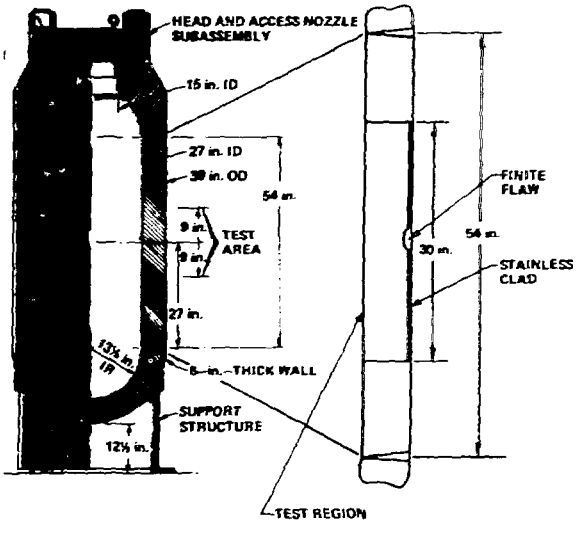
CRITICAL CRACK DEPTH CURVES FOR LONGITUDINAL OUTSIDE CRACK, PTS–1



CRITICAL CRACK DEPTH CURVES FOR LONGITUDINAL OUTSIDE CRACK, PTS–2



SHORT FLAW CONFIGURATION WITH STAINLESS STEEL CLADDING



THE FLEXIBILITY OF THE INTERMEDIATE VESSEL TEST CONCEPT WILL PRODUCE DATA ON MAJOR PTS ISSUES

- ARREST
- WARM PRESTRESSING
- FLAW GEOMETRY
- CLADDING