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PRELIMINARY MULTIROD BURST TEST PROGRAM
RESULTS AND IMPLICATIONS OF INTEREST TO
REACTOR SAFETY EVALUATIONS*

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The Multirod Burst Test (MRBT) Program, in progress at Oak Ridge National Laboratory, is investigating LWR cladding deformation in single- and multirod test arrays under conditions representative of reflood and refill phases of a LOCA. In these tests internally pressurized, unirradiated Zircaloy-4 tubes containing electrically heated fuel simulators are tested to failure in a low-pressure, superheated-steam environment. The tubes are "uniformly" heated over a 915-mm length; the simulator pressure, due to the small enclosed gas volume, also varies with temperature (and deformation) during the test.

To date 53 single rod transient burst tests have been conducted with a heating rate of 28°C/sec. The data base covers a range of burst pressures from 770 to 19,150 kPa; the corresponding burst temperatures range from 1170 to 690°C. Four additional transient burst tests at lower heating rates (two each at 5 and 10°C/sec) and four isothermal (∿0°C/sec heating rate) creep rupture tests have been conducted to scope the effect of heating rate. Initial conditions for these tests were adjusted to cause failure at ∿750°C.

Two 4 × 4 multirod tests (B-1 and B-2), one with and one without the shroud being heated, have been conducted with a bundle heating rate of ∿29°C/sec; initial pressure conditions for these tests were selected to cause failure at about 860°C. An additional 4 × 4 array (B-3) was tested using a bundle heating rate of ∿10°C/sec; the shroud was also heated in this test. Initial conditions were adjusted to cause failure at ∿760°C.

Posttest examination (including flow tests) of the B-1 and B-2 test arrays, is essentially complete, and pertinent data are included in this summary. Although examination of the B-3 array is in progress, very little data are available at this time.

The burst temperature—burst pressure data are in agreement with single rod test data obtained with comparable heating rates. However, greater deformation was observed in the bundle tests than would have been expected from our single rod tests; this may be the result of greater temperature uniformity in the bundles. On the other hand, deformation in the B-1 and B-2 test arrays was essentially the same, even though the boundary conditions were quite different (i.e., the shroud was heated in B-1 and unheated in B-2).

Preparations are in progress for testing another 4 × 4 array (B-4) in April 1979; present plans are for this to be an isothermal (∿760°C) creep rupture test, with the shroud being heated to the same temperature as the bundle.

Work on this program is routinely reported in a series of reports entitled *Multirod Burst Test Program Quarterly Progress Report*. Significant results appear in the following reports of this series:

Report Number	Period Covered
ORNL/NUREG/TM-36	January—March 1976
ORNL/NUREG/TM-74	April—June 1976
ORNL/NUREG/TM-77	July—September 1976
ORNL/NUREG/TM-95	October—December 1976
ORNL/NUREG/TM-108	January—March 1977
ORNL/NUREG/TM-135	April—June 1977
ORNL/NUREG/TM-200	July—December 1977
ORNL/NUREG/TM-217	January—March 1978

Pertinent topical reports include:

1. R. H. Chapman, compiler, *Characterization of Zircaloy-4 Tubing Procured for Fuel Cladding Research Programs*, ORNL/NUREG/TM-29, (July 1976).
2. W. E. Baucum and R. E. Dial, *An Apparatus for Spot Welding Sheathed Thermocouples to the Inside of Small-Diameter Tubes at Precise Locations*, ORNL/NUREG/TM-33, (August 1976).
3. W. A. Simpson, Jr., et al., *Infrared Inspection and Characterization of Fuel-Pin Simulators*, ORNL/NUREG/TM-55, (November 1976).
4. R. H. Chapman, et al., *Effect of Creep Time and Heating Rate on Deformation of Zircaloy-4 Tubes Tested in Steam with Internal Heaters*, ORNL/NUREG/TM-245 (October 1978).

ORNL WS-1233

MULTIROD BURST TEST PROGRAM IS A STUDY OF CLADDING DEFORMATION UNDER CONDITIONS REPRESENTATIVE OF REFLOOD AND REFILL PHASES OF A LOSS-OF-COOLANT ACCIDENT

- ELECTRICALLY HEATED FUEL ROD SIMULATORS
- SINGLE ROD TESTS FOR PARAMETRIC EFFECTS
- MULTIROD TESTS FOR FLOW RESTRICTION

RESULTS ARE OF IMPORTANCE IN DETERMINING IF CORE GEOMETRY REMAINS AMENABLE TO COOLING

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ORNL WS-1234

MULTIROD BURST TEST PROGRAM

OBJECTIVES

- RUPTURE TEMPERATURE-PRESSURE-STRAIN RELATIONSHIP
- EXTENT AND DISTRIBUTION OF DEFORMATION
- FLOW RESISTANCE AS A FUNCTION OF DEFORMATION
- EFFECTS OF ROD-TO-ROD INTERACTION ON FAILURE BEHAVIOR
- BASIS FOR MULTIROD DEFORMATION FROM SINGLE ROD TESTS
- INTERNALLY CONSISTENT DATA SET FOR STATISTICAL ANALYSIS

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ORNL WS-1236

TEST PARAMETERS SIMULATE NUCLEAR FUEL RODS AND LOCA CONDITIONS

- INTERNAL ELECTRICAL HEATER
- 915 mm "UNIFORM" HEATED LENGTH
- ~0–30°C/SEC CLAD HEATING RATE
- 47 CM^3 GAS VOLUME
- SUPERHEATED STEAM ENVIRONMENT
- 770–19150 kPa BURST PRESSURE RANGE
- 1170–690°C BURST TEMPERATURE RANGE

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ORNL WS 1235

SIGNIFICANT PROGRAM ACCOMPLISHMENTS

SINGLE ROD BURST TESTS

- 53 TESTS WITH 28°C/SEC HEATING RATE
- 2 TES˜S WITH 10°C/SEC HEATING RATE
- 2 TESTS WITH 5°C/SEC HEATING RATE
- 4 TESTS WITH ~0°C/SEC HEATING RATE (I.E., ISOTHERMAL CREEP RUPTURE TESTS)

4 X 4 BUNDLE BURST TESTS

- 1 HEATED SHROUD TEST WITH 28°C/SEC HEATING RATE
- 1 UNHEATED SHROUD TEST WITH 28°C/SEC HEATING RATE
- 1 HEATED SHROUD TEST WITH 10°C/SEC HEATING RATE

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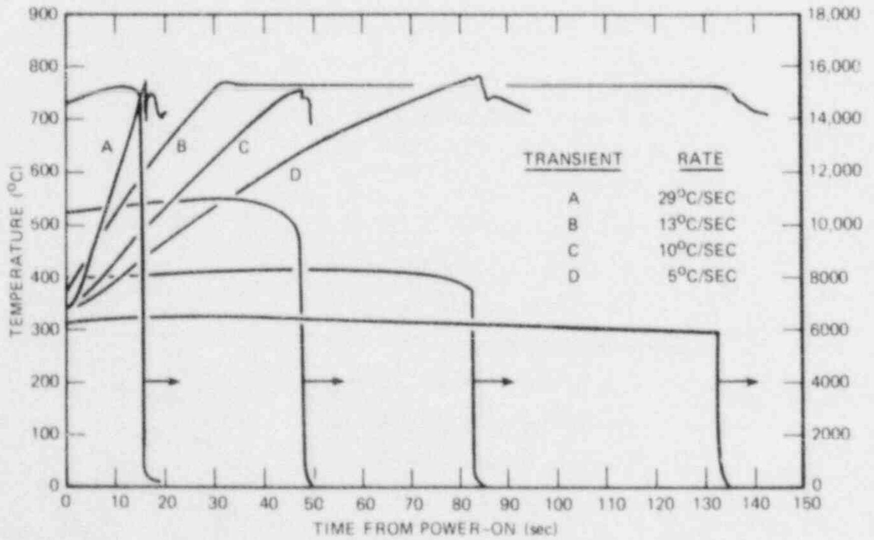
TRANSIENTS FOR LOW HEATING RATE AND CREEP RUPTURE INTERNALLY HEATED SINGLE ROD TESTS IN STEAM



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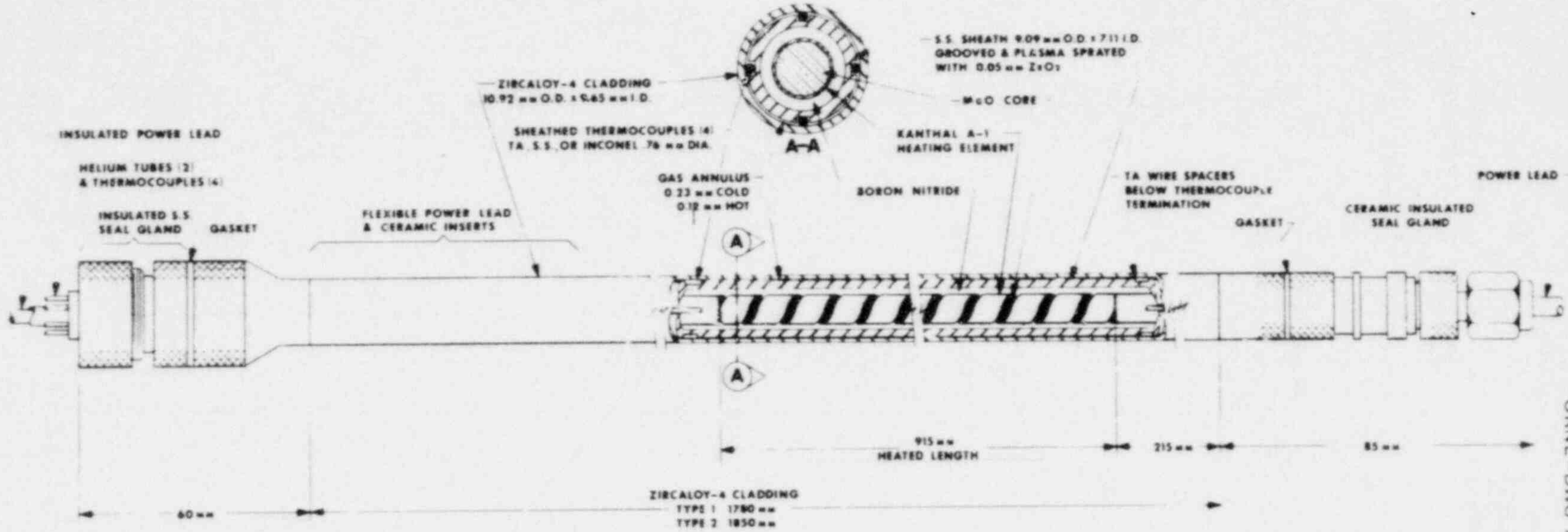
ELECTRICALLY HEATED TEST ASSEMBLY PROVIDES REALISTIC SIMULATION OF NUCLEAR FUEL ROD



ORNL-DWG 77-8293

ORNL–DWG 77–8294R

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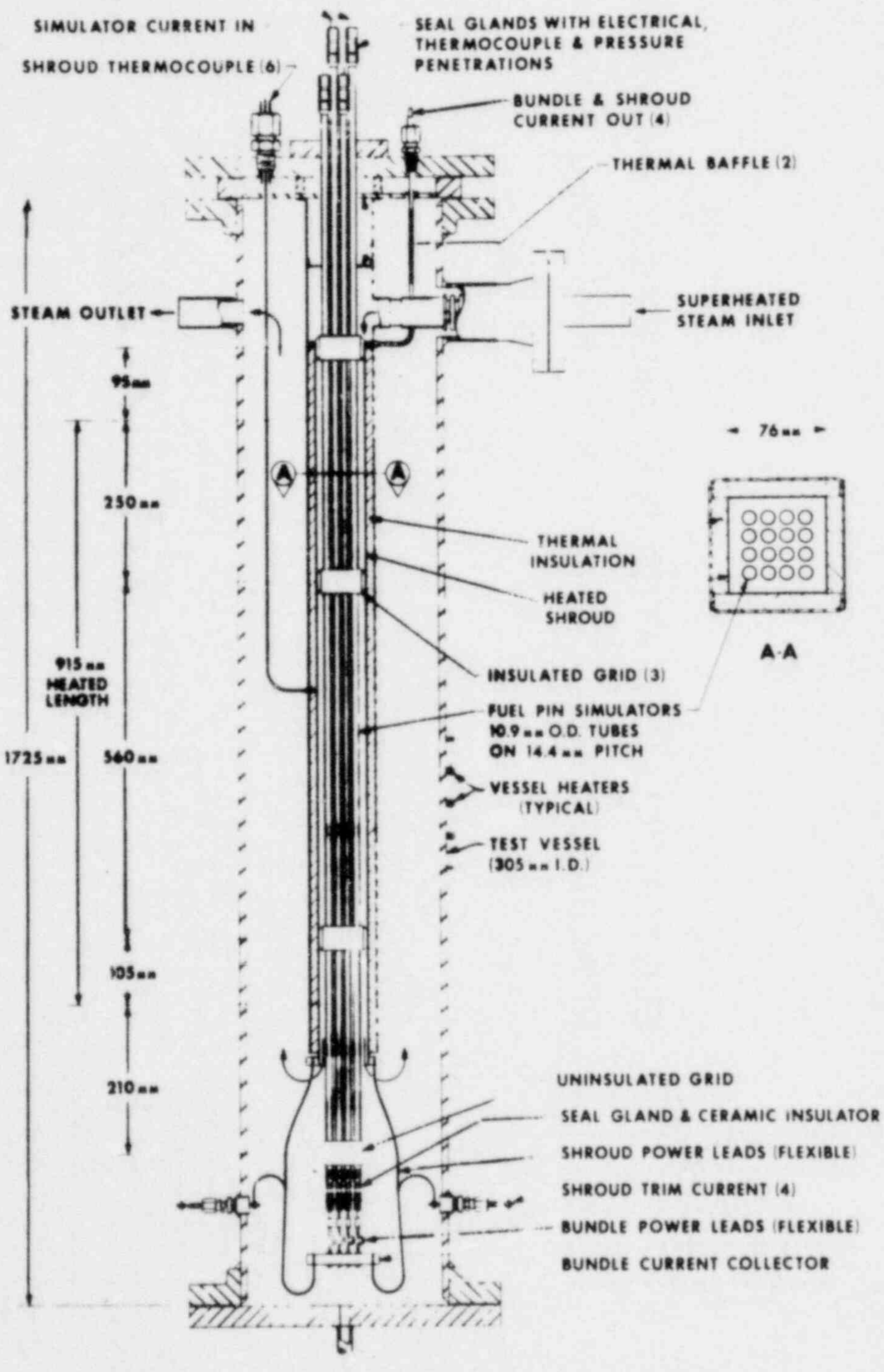
BUNDLE TESTS PROVIDE BETTER SIMULATION OF REACTOR CONDITIONS THAN SINGLE ROD TESTS



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COMPARISON OF B-1, B-2, AND B-3 TESTS

	B-1	B-2	B-3
BUNDLE HEAT RATE (°C/SEC)	29.5	28.5	9.5
SHROUD HEAT RATE (°C/SEC)	20.0	0	7.5
INLET STEAM TEMPERATURE (°C)	349	332	320
INLET STEAM REYNOLDS NUMBER	250	290	263
INITIAL TEMPERATURE (°C)	356	334	329
INITIAL PRESSURE (KPA)	8680	8770	11610
MAXIMUM PRESSURE (KPA)	9100	9200	12110
BURST PRESSURE (KPA)	7425	7560	9425
BURST TEMPERATURE (°C)	865	857	764
BURST TIME (SEC)	17.0–17.6	17.8–18.3	44.5–47.6
BURST STRAIN (%)	32–59	34–58	?
TUBE VOLUME INCREASE (%)	27–55	28–52	?
$T_B - T_S$ AT BURST TIME (°C)	140	355	80

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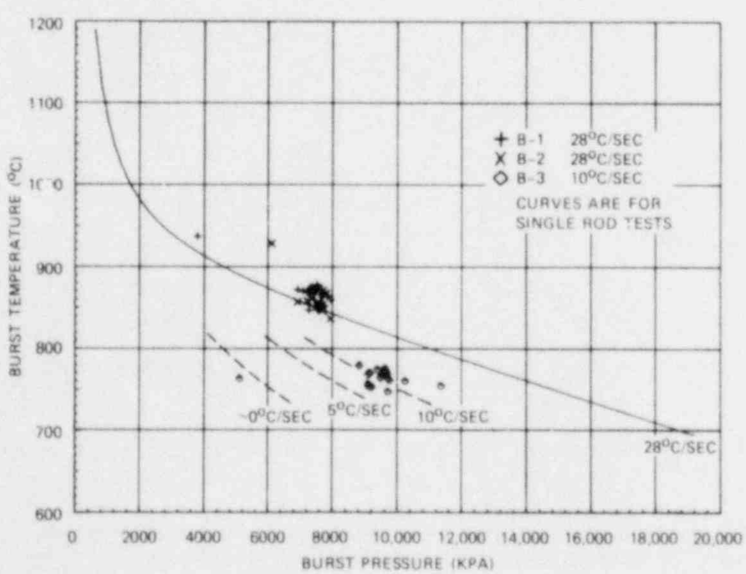
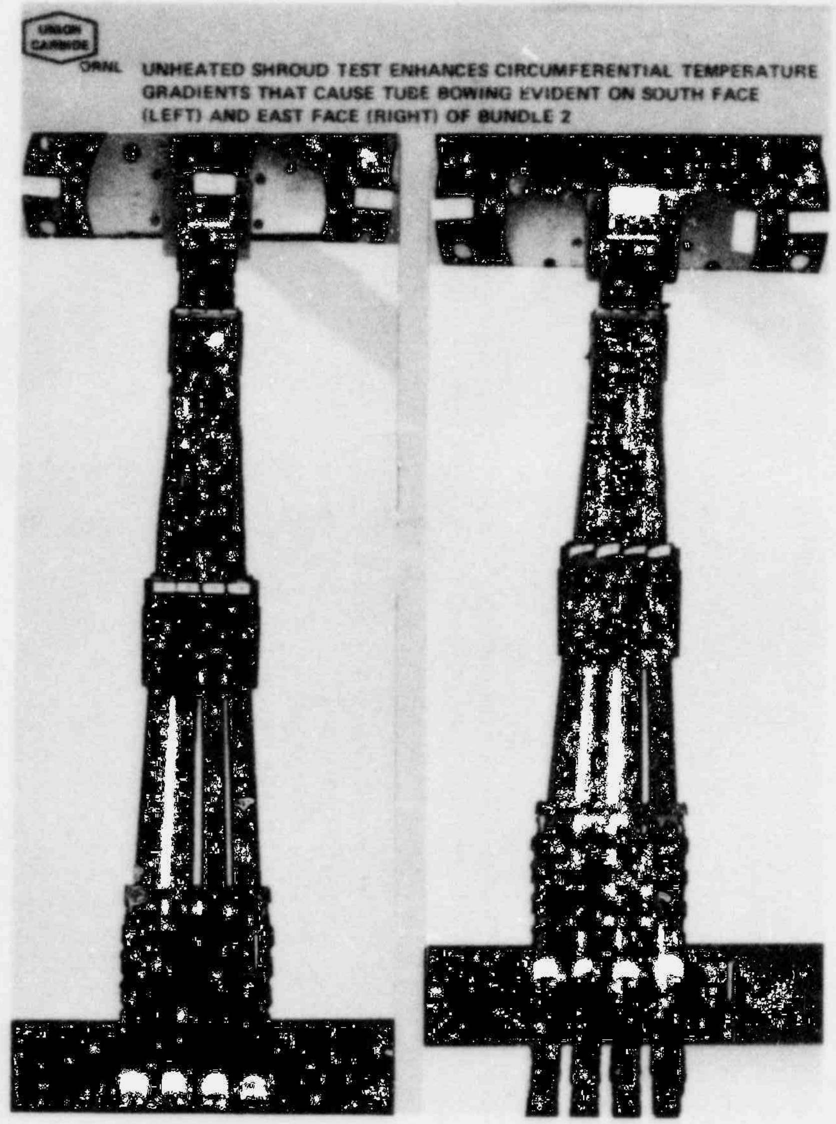
B-1, B-2, AND B-3 BURST TEMPERATURES AGREE WITH SINGLE ROD TEST RESULTS THAT SHOW BURST PRESSURE DECREASES WITH HEATING RATE



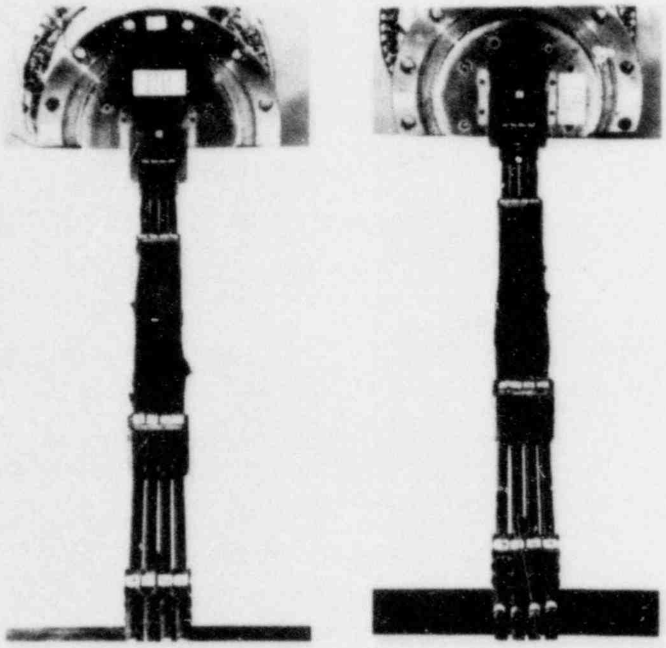
ORNL-PHOTO 6786-77F

ORNL-PHOTO 5027-77



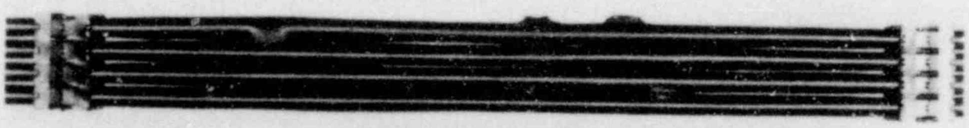
ORNL PHOTO 3882-78A

LOW HEATING RATE (~10°C/SEC) APPARENTLY CAUSED GREATER DEFORMATION IN B-3 TEST AS EVIDENT ON NORTH FACE (LEFT) AND EAST FACE (RIGHT)

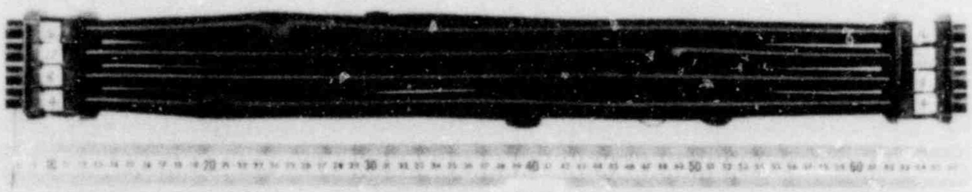


ORNL PHOTO 5089-78

COMPARISON OF DEFORMATION IN B-1 AND B-3 TESTS REFLECTS DIFFERENCE IN HEATING RATE



EAST FACE OF B-1



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EAST FACE OF B-3

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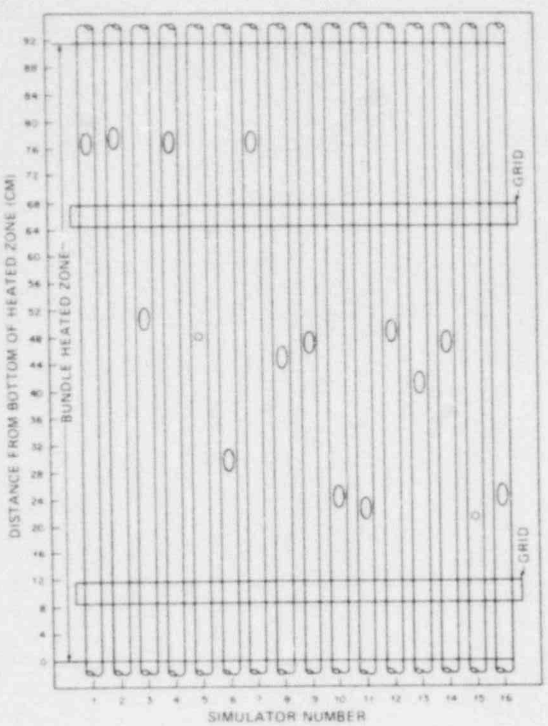
AXIAL DISTRIBUTION OF BURSTS IN B-1 TEST



ORNL-DWG 78-18195

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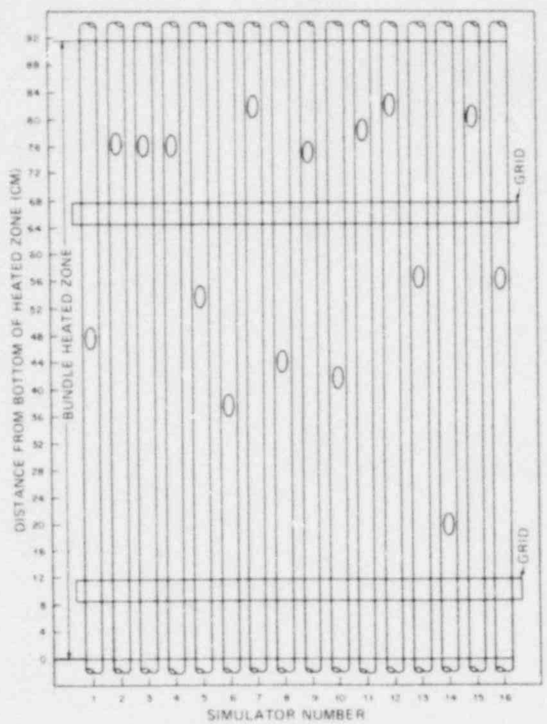
AXIAL DISTRIBUTION OF BURSTS IN B-2 TEST



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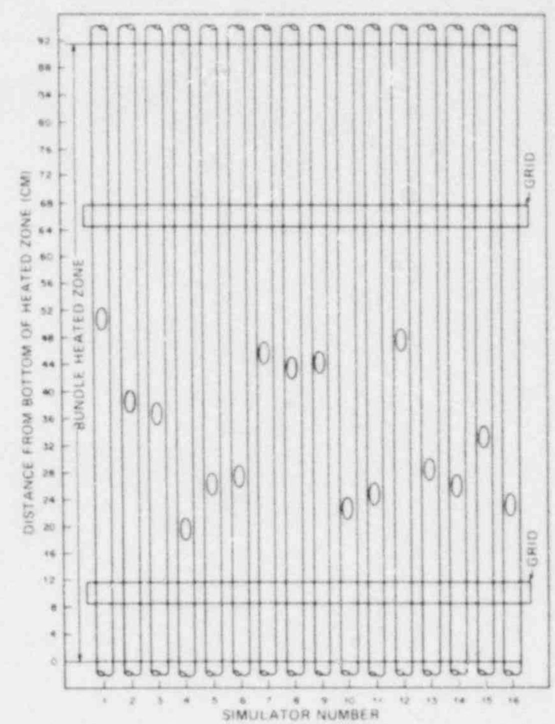
AXIAL DISTRIBUTION OF BURSTS IN B-3 TEST



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STEAM FLOW RATE HAS AN EFFECT ON BURST LOCATION

- STEAM FLOW WAS LOWER IN B-1 AND B-2 THAN IN SINGLE ROD TESTS
  B-1 RE ≈250; B-2 RE ≈290; SR RE 600-800
- SOME BURSTS IN B-1 (4) AND B-2 (8) ABOVE UPPER GRID BUT IN AGREEMENT WITH IR-SCAN
- HEATER FROM B-2 ROD 4 TESTED IN TWO SINGLE ROD TESTS WITH GRIDS
  - ONE AT STEAM FLOW NORMALLY USED IN SR TESTS
  - ONE AT STEAM FLOW SOMEWHAT LOWER THAN B-2 TEST
- RESULTS:
  - BURST OCCURRED BELOW GRID WITH NORMAL STEAM FLOW
  - BURST OCCURRED ABOVE GRID WITH LOW STEAM FLOW
  - STEAM TEMPERATURE MEASUREMENTS SHOW SHORT THERMAL ENTRANCE ZONE FOR LOW RE
- CONCLUSIONS:
  - LOW STEAM FLOW COMBINED WITH CHARACTERISTICS OF HEATERS CAUSED BURSTS TO OCCUR ABOVE UPPER GRID IN B-1 AND B-2
  - BURST LOCATIONS CAN BE LOWERED (AND POSSIBLY CLUSTERED) IN BUNDLES BY INCREASING THE STEAM FLOW
  - DEFORMATION NOT SENSITIVE TO STEAM FLOW RATE FOR 200 < RE < 800
  - CONVECTIVE HEAT LOSSES TO STEAM BECOME MORE IMPORTANT ON TUBE TEMPERATURE PROFILE WITH DECREASING HEATING RATES

ORNL-DWG 78-11144

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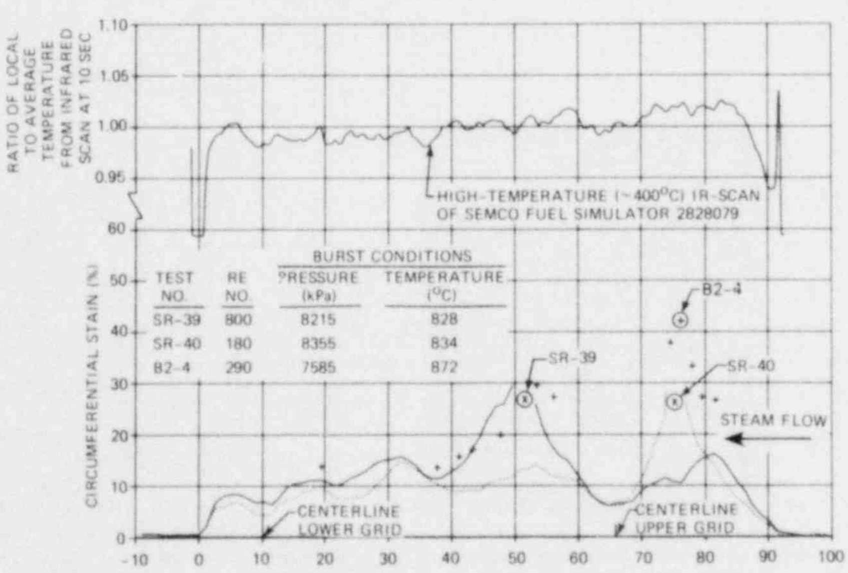
BURST LOCATION CAN BE DISPLACED BY CHANGE IN STEAM FLOW



TEST NO.	RE NO.	BURST CONDITIONS PRESSURE (kPa)	TEMPERATURE (°C)
SR-39	800	8215	828
SR-40	180	8355	834
B2-4	290	7585	872

ORNL WS 437A

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BUNDLE STRAIN METHODOLOGY

- CAST BUNDLE IN EPOXY AND SECTION AT ~15 MM INTERVALS
- MAKE ~1X AND ~5X PHOTOGRAPHS OF EACH SECTION
- DIGITIZE INSIDE AND OUTSIDE PERIPHERY (20-40 POINTS ON 5X PHOTO) OF EACH TUBE IN SECTIONS AND RECORD DATA ON MAGNETIC TAPE FOR COMPUTER PROCESSING
- FIT DIGITIZED DATA (CUBIC SPLINE ROUTINE) AND PROCESS DATA
  - CALCULATE ID & OD CIRCUMFERENCE AND AREAS, CENTROIDS, AND STRAIN
  - PLOT SECTION PROFILES WITH CENTROIDS, LABEL ROD AND STRAIN
  - FIT (LEAST SQUARES) ORIGINAL GRID PATTERN TO POSTTEST TUBE CENTROIDS
  - PUNCH DATA ON CARDS FOR SUBSEQUENT PROCESSING
- PLOT DEFORMATION AND HEAT GENERATION PROFILES FOR INDIVIDUAL TUBES
- CALCULATE VOLUME INCREASE OF EACH TUBE OVER HEATED LENGTH
- CALCULATE MAXIMUM AND MINIMUM FLOW RESTRICTION FOR SECTION
  - MAXIMUM RESTRICTION FOR BURST TUBES CONSIDERS FLAREOUT AS BLOCKAGE
  - MINIMUM RESTRICTION CONSIDERS TUBE OF CIRCULAR CROSS SECTION WHOSE PERIMETER EQUALS THAT OF THE BURST TUBE (CONDITION PRIOR TO BURST)
  - BOTH DEFINITIONS USE ACTUAL TUBE OUTSIDE AREA FOR NON-BURST TUBES
- PLOT BUNDLE MAXIMUM AND MINIMUM FLOW AREA RESTRICTION PROFILES

ORNL-DWG 78-18194

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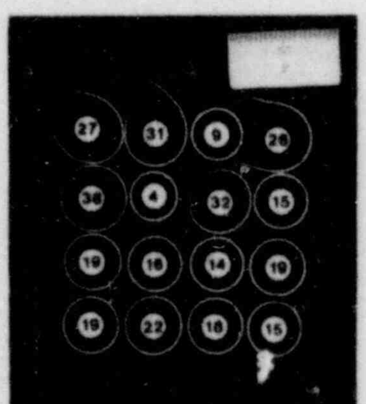
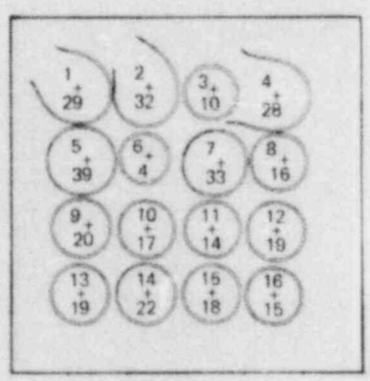
COMPUTER PROCESSING OF DATA PROVIDES ACCURATE INDICATION OF STRAIN AND ACCURATELY REPRODUCES SECTION GEOMETRY



PHOTOGRAPH OF B-1 SECTION AT 77.3-CM ELEVATION



COMPUTER SIMULATION OF B-1 SECTION AT 77.3-CM ELEVATION

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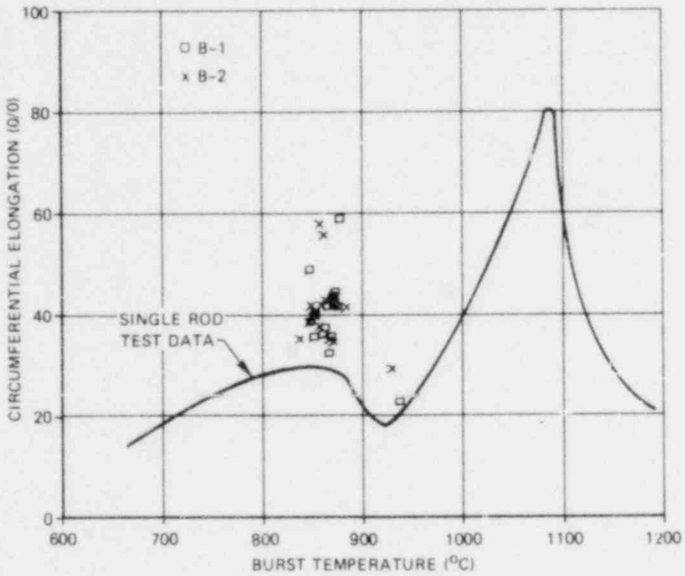
BURST STRAINS IN B-2 ABOUT THE SAME AS IN B-1 BUT GREATER THAN IN SINGLE ROD TESTS WITH UNHEATED SHROUD



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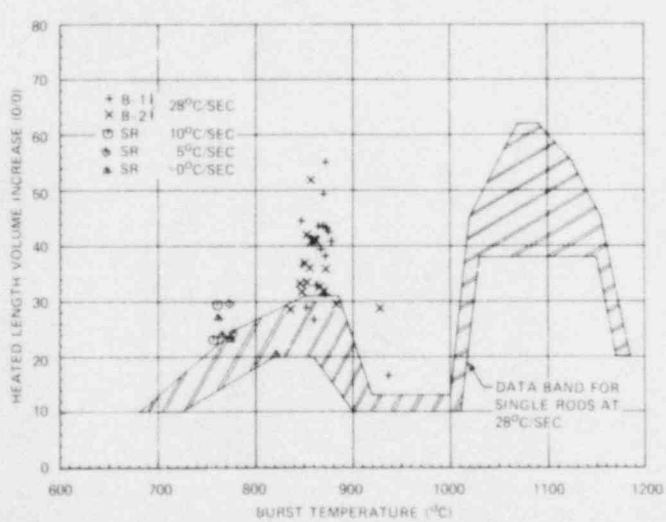
VOLUME INCREASE (I.E., AVERAGE STRAIN) IN B-1 WITH HEATED SHROUD ABOUT SAME AS B-2 WITH UNHEATED SHROUD AND BOTH GREATER THAN SINGLE ROD TESTS WITH UNHEATED SHROUD



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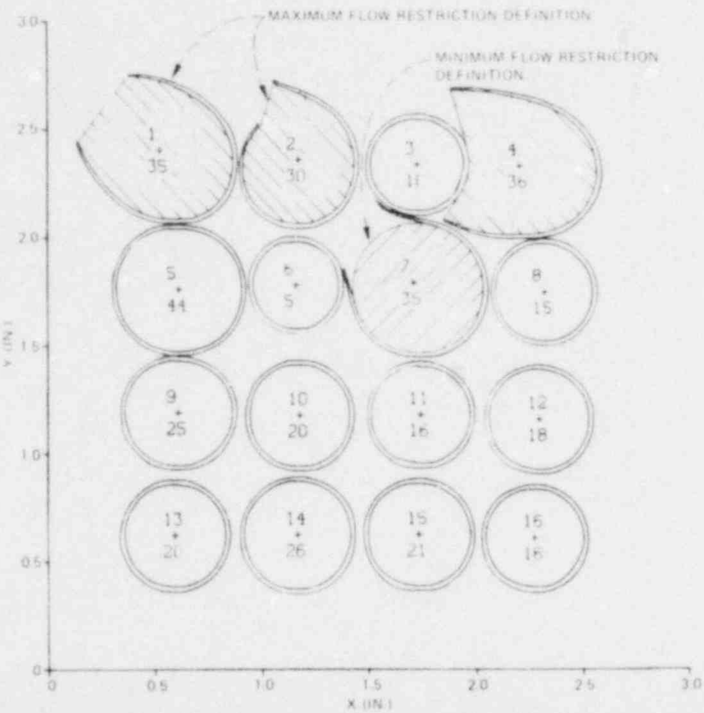
COMPUTER SIMULATION OF B-1 SECTION AT 76.5 CM ELEVATION SHOWING MAXIMUM AND MINIMUM FLOW RESTRICTION DEFINITIONS



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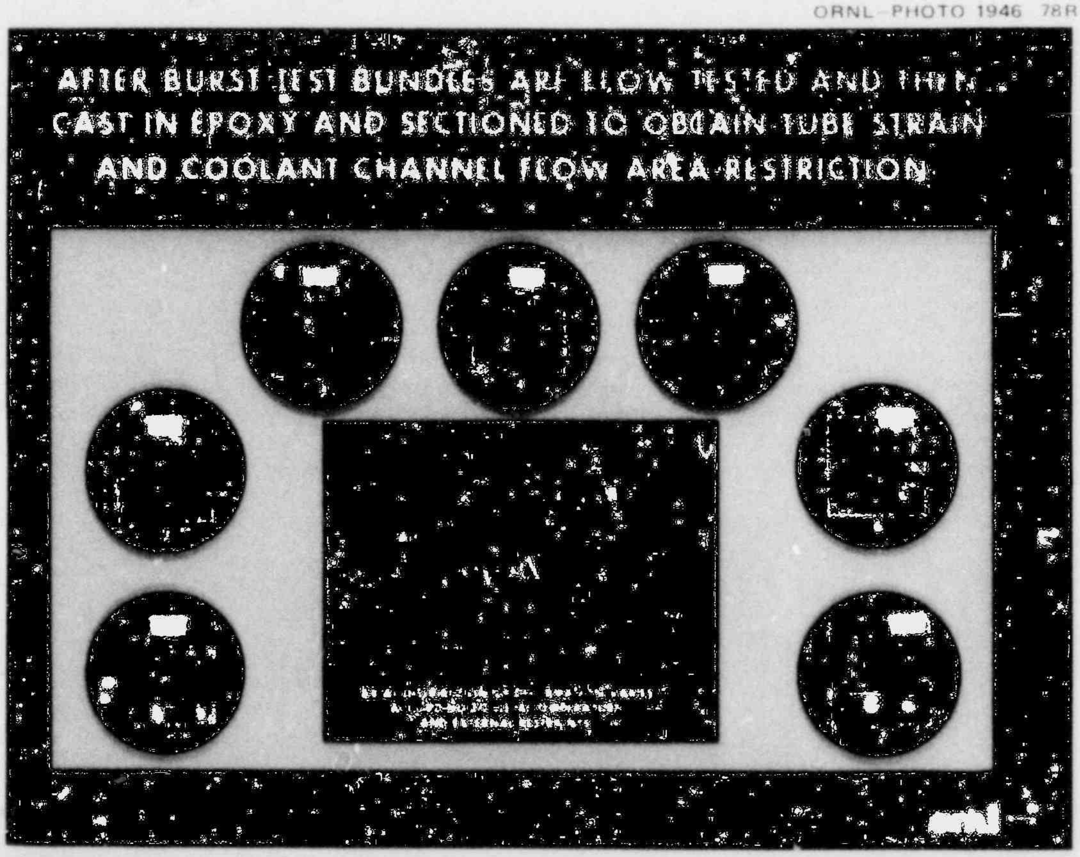

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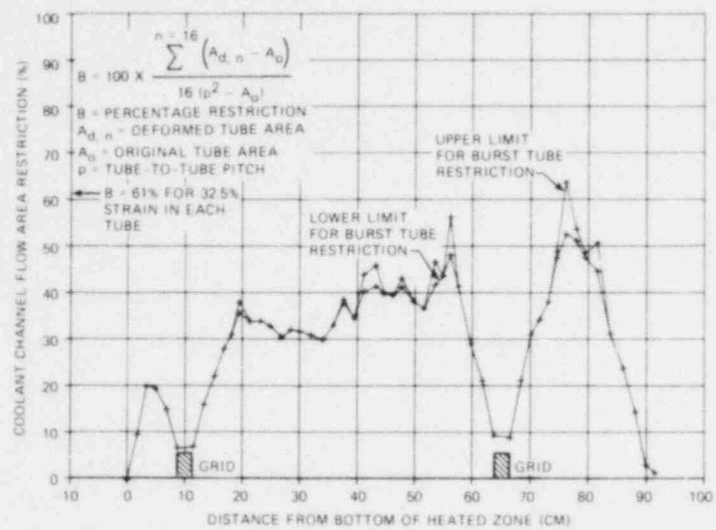
UPPER AND LOWER BOUNDS OF B–2 COOLANT CHANNEL FLOW AREA BASED ON ROD CENTERED UNIT CELL CONCEPT



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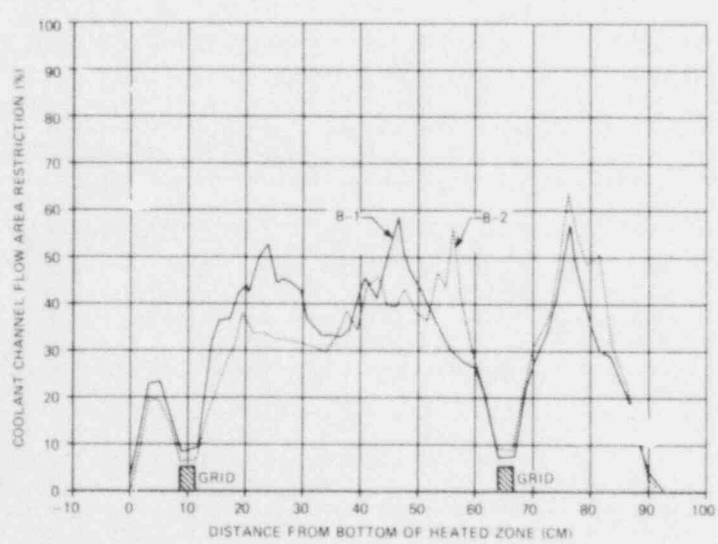
COMPARISON OF B–1 AND B–2 COOLANT CHANNEL RESTRICTION BASED ON MAXIMUM FLOW RESTRICTION DEFINITION



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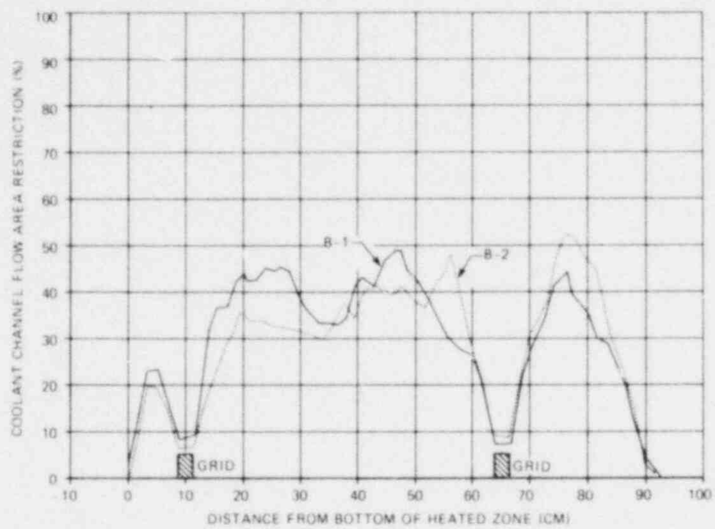
COMPARISON OF B-1 AND B-2 COOLANT CHANNEL RESTRICTION BASED ON MINIMUM FLOW RESTRICTION DEFINITION



ORNL–DWG 78–6634R

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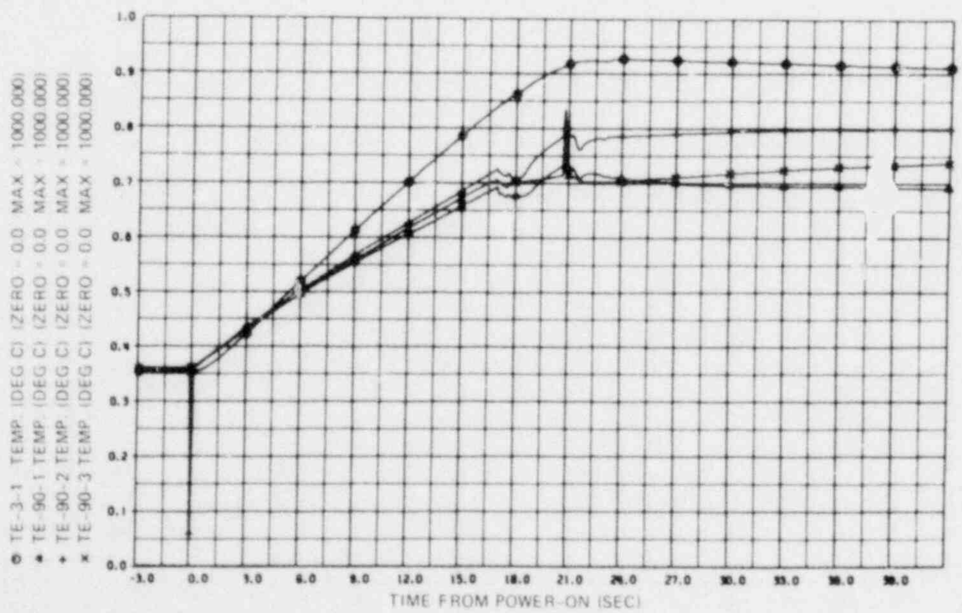
COMPARISON OF SHROUD TEMPERATURES WITH ROD 3 IN B-1 TEST



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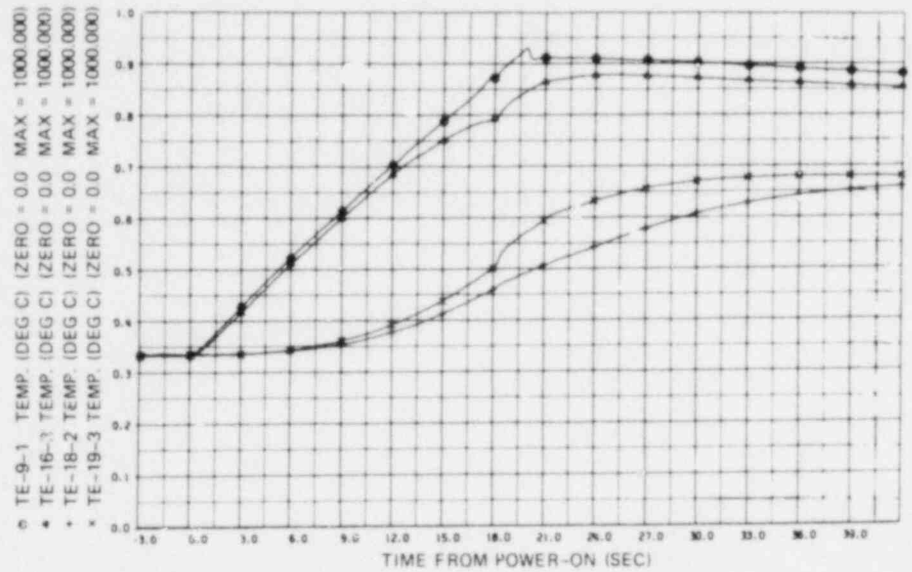
MAXIMUM AND MINIMUM SIMULATOR AND SHROUD TEMPERATURES AT TIME OF BURSTS IN B-2 TEST



ORNL-DWG 78-15528A

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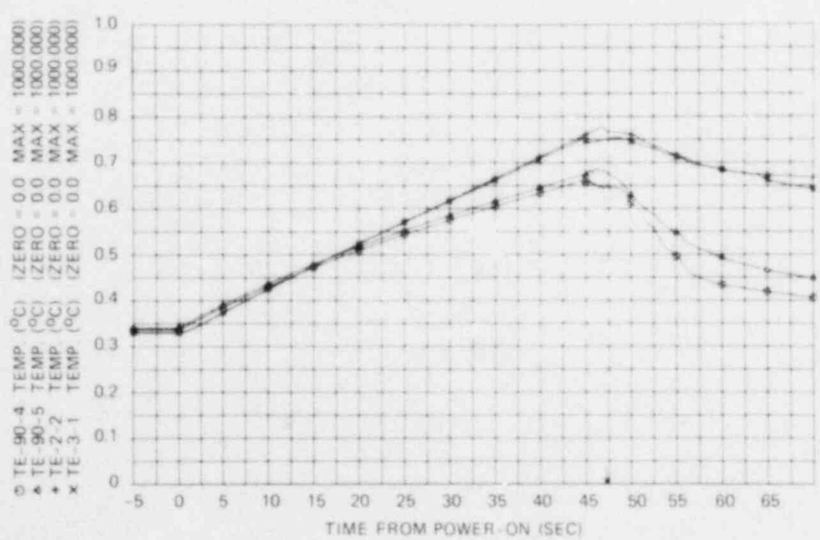
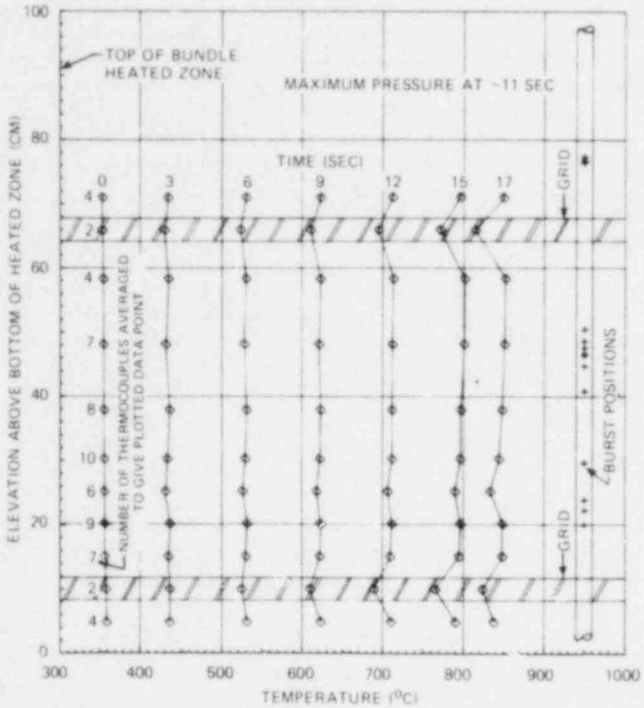
COMPARISON OF B-3 SHROUD AND BUNDLE TEMPERATURES AT ELEVATIONS 46.8 AND 76.0 CM



ORNL-DWG 78-11135A

UNION CARBIDE ORNL

AXIAL TEMPERATURE DISTRIBUTION OF B-1 WAS FAIRLY UNIFORM UNTIL TIME OF BURSTS



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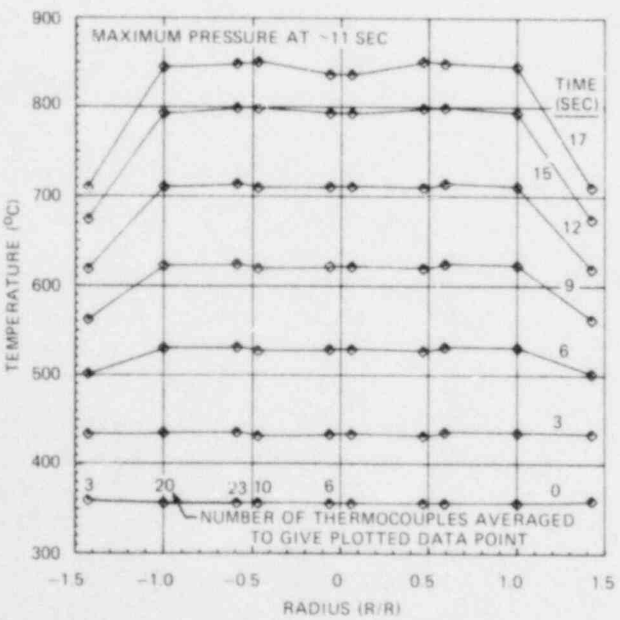
UNION CARBIDE ORNL

RADIAL TEMPERATURE DISTRIBUTION OF B-1 WAS VERY UNIFORM UNTIL TIME OF BURSTS



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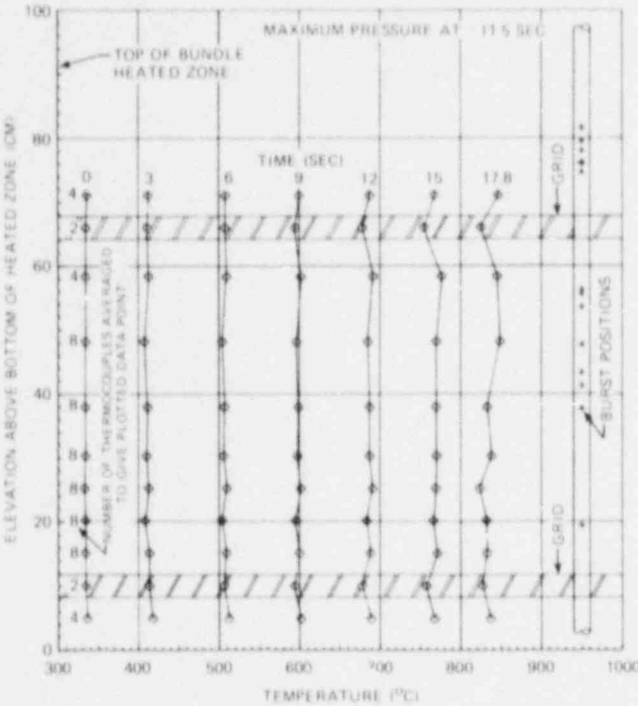
AXIAL TEMPERATURE DISTRIBUTION OF B-2 WAS FAIRLY UNIFORM UNTIL TIME OF BURSTS



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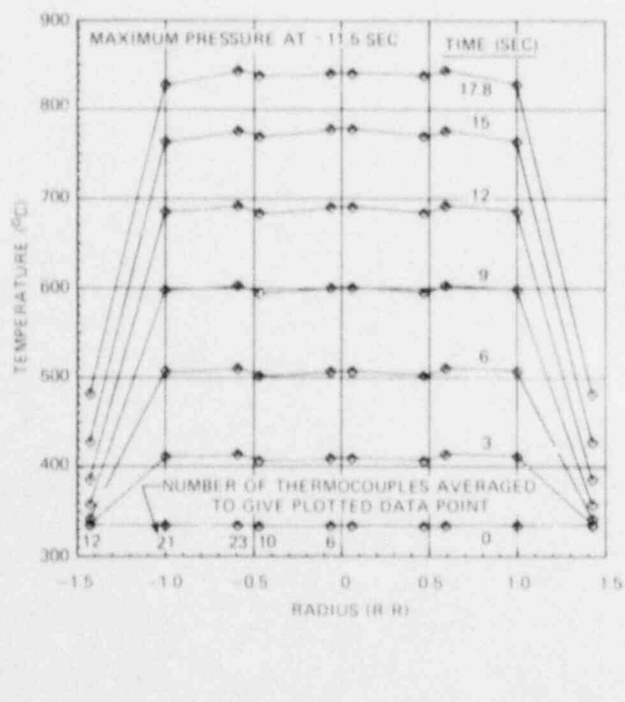
RADIAL TEMPERATURE DISTRIBUTION OF B-2 WAS VERY UNIFORM UNTIL TIME OF BU'.STS



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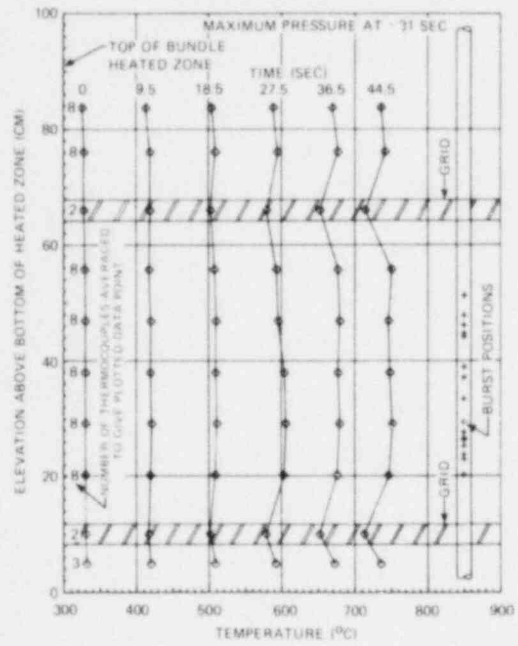
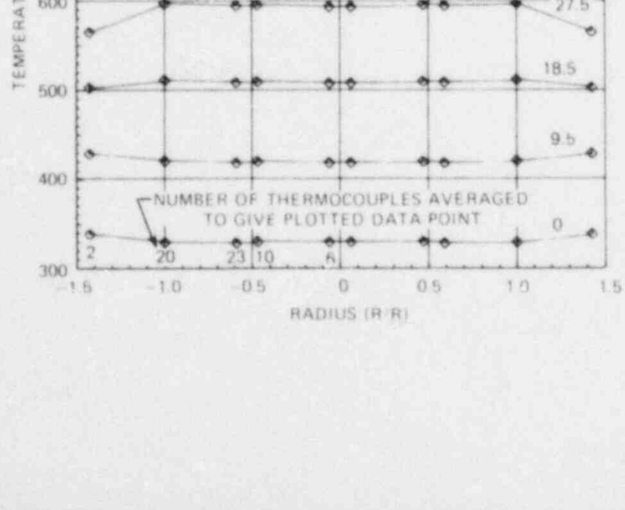
AXIAL TEMPERATURE DISTRIBUTION OF B-3 WAS FAIRLY UNIFORM UNTIL TIME OF BURSTS



ORNL DWG 78 19011

UNION CARBIDE ORNL

RADIAL TEMPERATURE DISTRIBUTION OF B-3 WAS VERY UNIFORM UNTIL TIME OF BURSTS



ORNL–WS–442

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BUNDLE FLOW TESTS

A. OBJECTIVES OF TESTS

- MEASURE AND COMPARE AXIAL PRESSURE LOSSES ALONG LENGTH OF REFERENCE AND DEFORMED BUNDLES AT SEVERAL FLOW RATES
- PREDICT MEASURED AXIAL PRESSURE LOSS PROFILES WITH COBRA-IV

B. RESULTS WILL PROVIDE

- METHOD OF EXTRAPOLATING MRBT CHANNEL RESTRICTION DATA TO OTHER TESTS AND REACTOR CORE THERMAL-HYDRAULIC ANALYSES
- INDICATION OF GEOMETRICAL DETAIL NECESSARY TO DUPLICATE MEASURED LOSSES WITH COBRA-IV

C. TEST EQUIPMENT AND CONDITIONS

- EXISTING FLOW LOOP LIMITS RE FROM 10^4 TO 10^5 FOR 4 X 4 ARRAY
- SINGLE PHASE WATER AT ROOM TEMPERATURE AND 400 KPA MAXIMUM PRESSURE
- TWO FLOW SHROUDS TO GIVE DATA ON BUNDLE BYPASS FLOW
- USE TUBE EXTENSIONS TO PROVIDE DEVELOPED VELOCITY PROFILE AT INLET
- MEASURE PRESSURE LOSSES ON TWO SIDES OF SHROUD
- NO INFORMATION ON CROSSFLOW OR VELOCITY PROFILES IN BUNDLE

ORNL–DWG 78–11145

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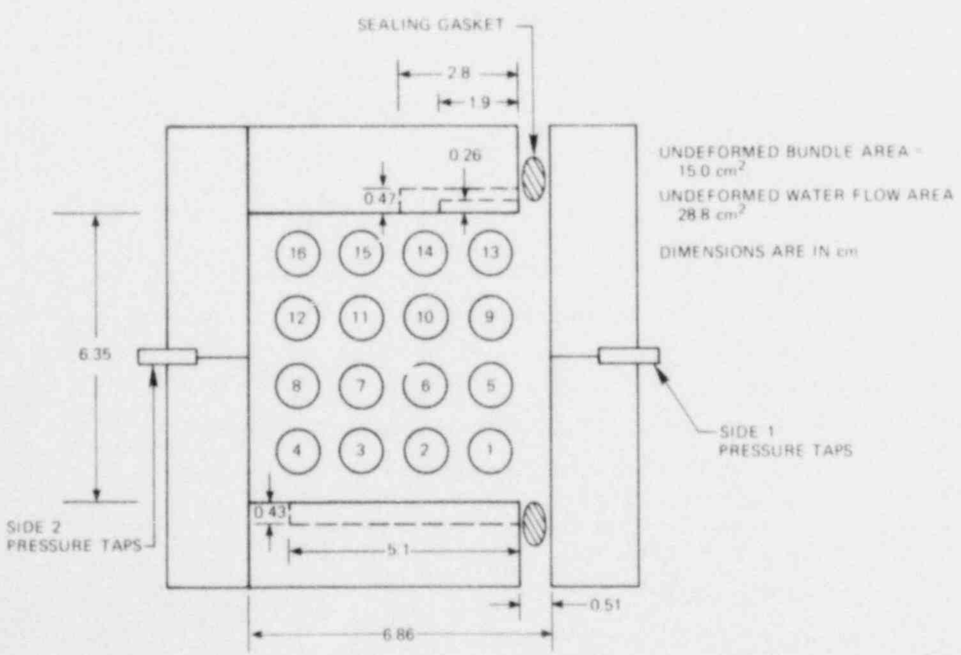
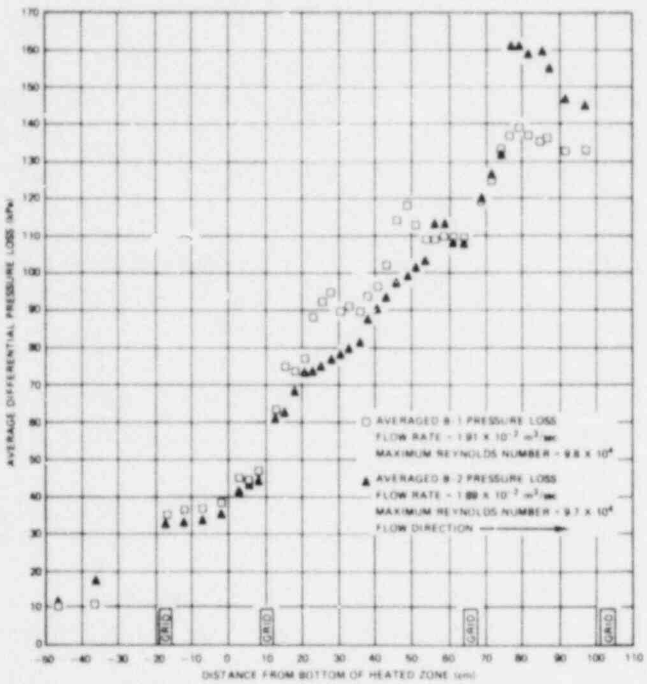
FLOW TEST CONFIGURATION OF B-1 IN SHROUD 1



ORNL–DWG 78–6680R

UNION CARBIDE ORNL

B–1 AND B–2 PRESSURE LOSS PROFILES ABOUT THE SAME IN SHROUD 1



ORNL WS 1511

UNION CARBIDE ORNL

COMPARISON OF EXPERIMENTAL DATA WITH COBRA–IV PREDICTIONS

AGREEMENT DEPENDENT ON FOUR VERY IMPORTANT FACTORS

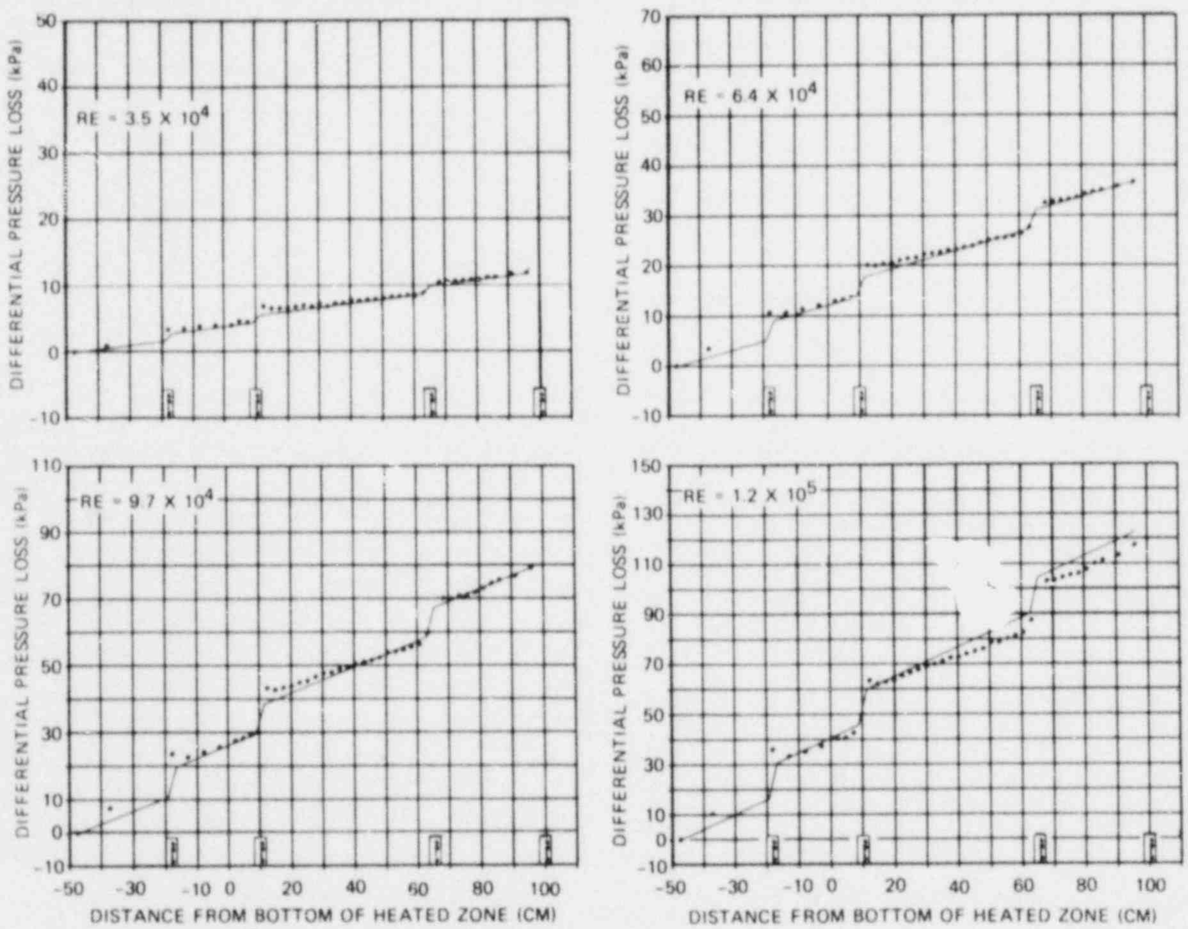
1. FRICTION FACTOR CORRELATION MUST HAVE PROPER RE AND P/D DEPENDENCE
   - TONG'S REVIEW SUGGESTS 30% INCREASE (P/D = 1.32) OVER SMOOTH TUBE
   - REVIEW OF MAREK ET AL. SUGGESTS 6% INCREASE
   - DATA FROM FLOW TESTS SUGGEST 20–28% INCREASE
2. GRID SPACER LOSS COEFFICIENT
   - EARLIER MRBT TESTS GAVE COEFFICIENT OF 0.37
   - RECENT MRBT TESTS INDICATE RANGE OF 0.50 TO 0.60
3. GEOMETRICAL DESCRIPTION OF BUNDLE SUBCHANNELS AT EACH NODE
   - TEST GEOMETRY HAS 4 TYPES OF SUBCHANNELS WITH A TOTAL OF 25
   - METHOD USED TO OBTAIN COBRA INPUT RESTRICTION DATA AT EACH NODE
     - AVERAGE TUBE DEFORMATION = 1/16 OF BUNDLE DEFORMATION
     - AVERAGE TUBE DEFORMATION (ASSUMED CIRCULAR SHAPED AND CENTERED ABOUT ORIGINAL TUBE) WAS USED FOR EACH OF THE 25 SUBCHANNELS
4. ACCURACY OF EXPERIMENTAL PARAMETERS

ORNL-DWG 78-11147

UNION CARBIDE ORNL

COBRA-IV MODELS REFERENCE BUNDLE PRESSURE LOSS PROFILE IN SHROUD 1 WITH APPROPRIATE FRICTION FACTOR MODIFICATION

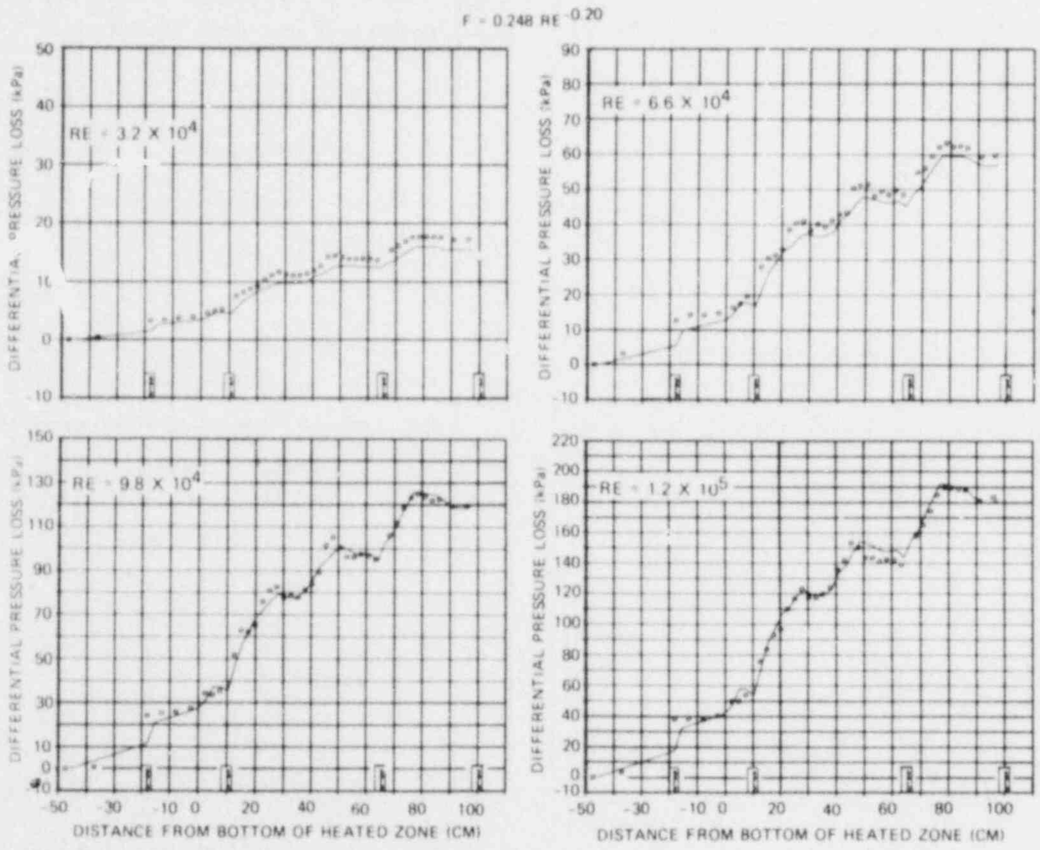
$F = 0.248\ RE^{-0.20}$



ORNL–DWG 78–11149

UNION CARBIDE ORNL

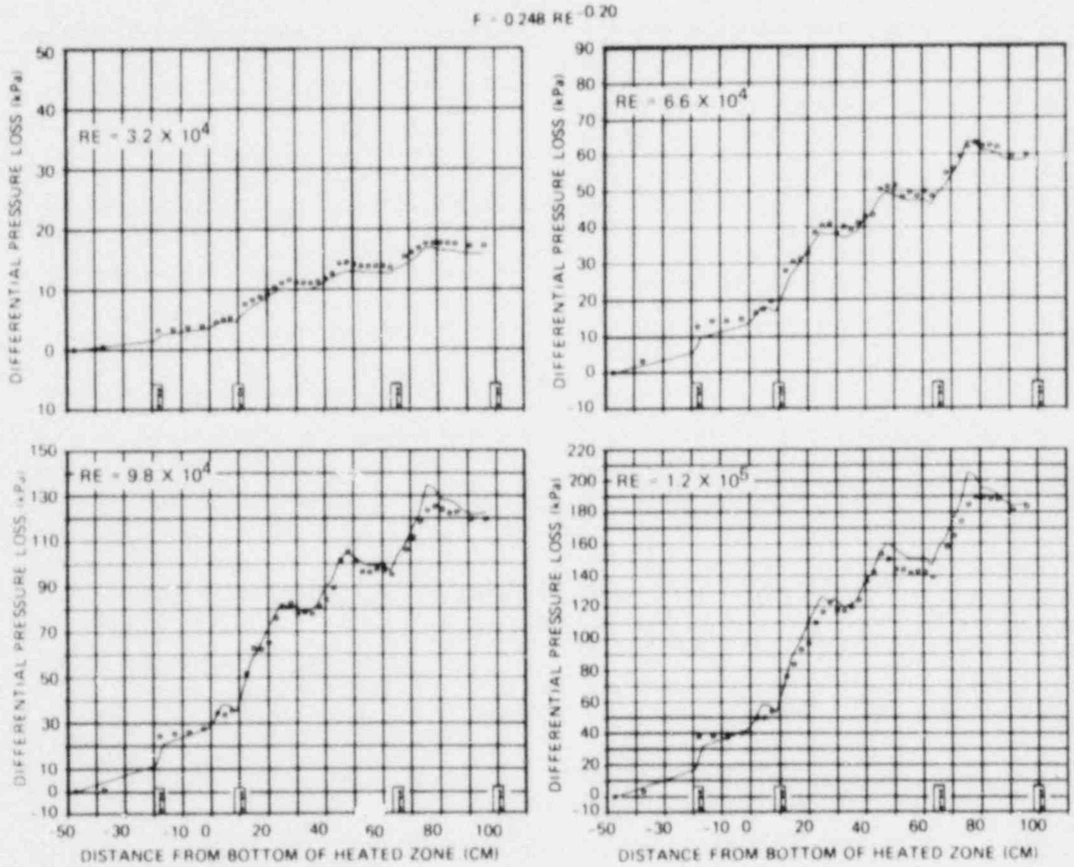
COBRA-IV MODEL OF B-1 PRESSURE LOSS PROFILE IN SHROUD 1 WITH APPROPRIATE FRICTION FACTOR MODIFICATION IS NOT CONSERVATIVE WITH MINIMUM FLOW RESTRICTION DEFINITION



ORNL-DWG 78-11148

UNION CARBIDE ORNL

COBRA-IV MODELS B-1 PRESSURE LOSS PROFILE IN SHROUD 1 WITH APPROPRIATE FRICTION FACTOR MODIFICATION AND MAXIMUM FLOW RESTRICTION DEFINITION



ORNL-WS-1510

UNION CARBIDE ORNL

SUMMARY OF FLOW TESTS

- PRESSURE LOSS DATA VS RE FOR B-1, B-2, AND REFERENCE BUNDLE IN SHROUD 1
- PRESSURE LOSS DATA VS RE FOR B-2 AND REFERENCE BUNDLE IN SHROUD 2
- NO INFORMATION ON CROSSFLOW AND VELOCITY PROFILES IN BUNDLES
- DATA AGREE WITH THEORY BUT LIMITED TO THESE FLOW CONFIGURATIONS
- AXIAL PRESSURE LOSS OF B-1 AND B-2 50-60% GREATER THAN REFERENCE BUNDLE
- PRESSURE LOSS PROFILES FOR B-1 AND B-2 NOT TO DIFFERENT
- PRESSURE LOSS PROFILE FOR B-1 CORRELATES WITH FLOW CHANNEL RESTRICTION DATA; B-2 ANALYSIS EXPECTED TO CORRELATE ALSO
- COBRA ANALYSES INDICATE 20-28% INCREASE IN FRICTION FACTOR FOR P/D = 1.32
- AVERAGE TUBE RESTRICTION DESCRIPTION ADEQUATE FOR COBRA PREDICTION OF B-1 DATA; MAY NOT BE ADEQUATE FOR B-2
- MAXIMUM FLOW RESTRICTION DEFINITION FOR B-1 BURSTS AGREES BETTER WITH DATA; MINIMUM DEFINITION AGREES BETTER WITH B-2 DATA
- COBRA ACCURATELY PREDICTS MRBT 4 X 4 DEFORMED BUNDLE PRESSURE LOSS PROFILES WITH SIMPLIFIED SPECIFICATION OF THE RESTRICTION PROVIDED FRICTION FACTOR CORRELATION AND GRID LOSS COEFFICIENT ARE SELECTED CAREFULLY
  - MAY NEED FLOW TESTS ON LARGE BUNDLES TO SELECT BEST BURST RESTRICTION DEFINITION
  - NEED BETTER UNDERSTANDING AND DATA ON FRICTION FACTOR VS RE AND P/D RATIO FOR DEFORMED AND UNDEFORMED ARRAYS

ORNL-WS-1237

IMPORTANT RESULTS RELATING TO ECCS ACCEPTANCE CRITERIA

SINGLE ROD BURST TESTS

- DEFORMATION MECHANISMS IDENTIFIED
- DEFORMATION LESS THAN EARLIER RESULTS
- BURST TEMPERATURE – BURST PRESSURE CORRELATION
- BURST PRESSURE DECREASES WITH DECREASING HEATING RATE

MULTIROD BURST TESTS

- DEFORMATION GREATER THAN OBSERVED IN SINGLE ROD TESTS
- NO EVIDENCE OF ROD BURST PROPAGATION
- EFFECT OF RELATIVELY COLD BOUNDARY NOT YET CLARIFIED

MULTIROD FLOW TESTS

- FLOW RESTRICTION DOES NOT APPEAR EXCESSIVE
- COBRA PREDICTIONS IN AGREEMENT WITH EXPERIMENT

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Preliminary summary of B-1 test results

Rod No.	Initial conditions: Differential pressure (kPa)	Initial conditions: Temperature (°C) TE-1	TE-2	TE-3	TE-4	Approximate maximum pressure differential (kPa)	Approximate burst conditions: Differential pressure (kPa)	Burst Temperature (°C) TE-1	TE-2	TE-3	TE-4	Time (sec)	Pretest predicted burst conditions[a]: Pressure (kPa)	Temperature (°C)	Time (sec)	Burst temperature predicted from burst pressure[b] (°C)
1	8695	354	354	355	355	9105	7750	852	852	821	844	17.15	8040	843	20	846
2	8690	360	357	354	352	9085	7415	864	848	815	867	17.20	8040	843	2[illegible]	851
3[c]	6520[c]	354	356	356	354	6520[c]	3785[c]	924	937	936	911	22.90[c]	8040	843	20	918
4	8680	360	355	355	352	9090	7945	816	854	860	810	17.05	8040	843	20	843
5	8715	355	354	354	352	9115	6930	859	840	864	872	17.65	8040	843	20	858
6	8690	354	356	355	355	9150	7615	866	872	861	826	17.10	8040	843	20	848
7	8695	356	355	357	355	9085	7255	869	827	863	833	17.30	8040	843	20	853
8	8685	353	357	359	353	9100	7405	872	840	831	856	17.20	8040	843	20	851
9	8705	353	358	357	357	9135	7100	855[d]	870	894[d]	823	17.35	8040	843	20	856
10	8680	355	354	359	356	9090	7300	873	870	826	821	17.20	8040	843	20	853
11	8625	355	356	356	352	9035	7270	844	847	838	842	17.45	8040	843	20	853
12	8645	353	356	355	[e]	9065	7685	856	863	845	[e]	17.00	8040	843	20	847
13	8700	359	359	355	353	9115	7525	832	861	878	873	17.05	8040	843	20	849
14	8685	351	357	356	354	9135	7355	818	843[d]	874[d]	875	17.40	8040	843	20	852
15	8690	356	356	356	359	9090	7325	865	821	846	845	17.40	8040	843	20	852
16	8675	354	357	355	359	9095	7530	825	846	807	848	17.20	8040	843	20	849

[a] Prediction based on results of single-rod test SR-29. (Burst temperature determined by external bare-wire thermocouples.)

[b] Based on burst temperature–burst pressure correlation from single-rod burst tests (external bare-wire thermocouples).

[c] Rod 3 developed a severe leak prior to the test and its behavior is abnormal; burst occurred 2.05 sec after power cutoff.

[d] Thermocouple became detached from wall during assembly; indicated temperature is probably higher than existed on wall.

[e] Thermocouple was inoperative during test.

Preliminary summary of B-2 test results

Rod No.	Initial conditions: Differential pressure (kPa)	Initial conditions: Temperature (°C) TE-1	TE-2	TE-3	TE-4	Approximate maximum pressure differential (kPa)	Approximate burst conditions: Differential pressure (kPa)	Approximate burst conditions: Temperature (°C) TE-1	TE-2	TE-3	TE-4	Time (sec)	Pretest predicted burst conditions[a]: Pressure (kPa)	Temperature (°C)	Time (sec)	Burst temperature predicted from burst pressure[b] (°C)
1	8810	334	335	334	335	9240	7700	790	803	825	870	18.30	8040	843	20	846
2	8805	335	335	336	339	9220	7685	818	841	846	844	18.00	8040	843	20	847
3	8795	333	334	332	336	9245	7560	852	853	845	826	18.30	8040	843	20	849
4	8775	336	336	333	337	9205	7585	861	872	807	854	18.30	8040	843	20	848
5	8775	333	334	336	336	9205	7770	854	866	835	852	17.85	8040	843	20	845
6	8785	335	335	334	335	9220	6925	857	827	843	834	17.95	8040	843	20	858
7	8740	334	333	333	333	9160	7360	824	861	838	850	17.85	8040	843	20	852
8	8750	335	334	333	334	9200	7565	856	840	813	792	17.80	8040	843	20	849
9[c]	7715[c]	335	334	332	335	7715[c]	6110[c]	928	846	864	871	20.05[c]	8040	843	20	872
10	8730	334	334	332	334	9175	7345	827	862	827	856	18.10	8040	843	20	852
11	8735	333	334	332	333	9165	7670	832	819	832	853	17.80	8040	843	20	847
12	8760	336	334	334	333	9200	7545	851	832	829	827	18.15	8040	843	20	849
13	8755	338	333	334	332	9175	7820	856	805	883	867	18.15	8040	843	20	845
14	8755	333	334	334	335	9140	7230	828	858	832	855	18.30	8040	843	20	854
15	8790	336	334	334	337	9205	7945	824	807	799	836	18.05	8040	843	20	843
16	8790	333	334	333	334	9220	7700	848	839	795	814	18.15	8040	843	20	846

[a]Prediction based on results of single-rod test SR-29. (Burst temperature determined by external bare-wire thermocouples.)

[b]Based on burst temperature–burst pressure correlation from single-rod burst tests (external bare-wire thermocouples).

[c]Rod 9 developed a moderate leak prior to the test and its behavior is abnormal.

Preliminary summary of B-3 test results[a]

Rod No.	Initial conditions: Differential pressure (kPa)	Initial conditions: Temperature (°C) TE-1	TE-2	TE-3	TE-4	Approximate maximum pressure differential (kPa)	Approximate burst conditions: Differential pressure (kPa)	Approximate burst conditions: Temperature (°C) TE-1	TE-2	TE-3	TE-4	Time (sec)	Pretest predicted burst conditions[b]: Pressure (kPa)	Temperature (°C)	Time (sec)	Burst temperature predicted from burst pressure[c] (°C)
1	11585	325	326	329	330	12060	9605	755	737	751	771	46.89	9500	761	47.1	819
2	11600	328	330	330	330	12065	8825	748	779	762	741	46.89	9500	761	47.1	830
3	11620	331	326	330	329	12135	5115[d]	674[d]	606[d]	763[d]	682[d]	63.84[d]	9500	761	47.1	889
4	11630	328	330	330	330	12130	9090	761	765	767	736	47.64	9500	761	47.1	826
5	11565	327	330	329	330	12055	9480	752	763	764	760	46.29	9500	761	47.1	821
6	11580	326	329	331	330	12055	9155	757	770	767	769	46.19	9500	761	47.1	825
7	11725[e]	332	325	330	330	11755[e]	11355[e]	724	742	754	738	44.79[e]	9500	761	47.1	795
8	11655	326	328	330	329	12180	9105	748	755	756	746	46.19	9500	761	47.1	826
9	11535	324	330	330	331	12035	9105	754	750	785[f]	731	45.74	9500	761	47.1	826
10	11575	332	330	330	330	12075	9390	739	774	761	768	45.79	9500	761	47.1	822
11	11610	327	329	331	330	12130	9625	750	739	749	775	45.14	9500	761	47.1	819
12	11685	330	330	330	321[g]	121[illegible]	9755	757	761	745	700[g]	45.59	9500	761	47.1	817
13	11570	331	329	329	330	12075	10245	737	760	755	748	44.54	9500	761	47.1	810
14	11610	326	324	329	329	12105	9690	714	728	756	769	45.59	9500	761	47.1	818
15	11650	329	329	328	329	12170	9205	753	749	751	750	46.49	9500	761	47.1	825
16	11680	325	330	329	330	12190	9705	740	747	743	731	45.79	9500	761	47.1	817

[a] These quick-look data may change as further information becomes available.

[b] Prediction based on results of single rod test SR-42, using external, bare wire thermocouple measurement for determining burst temperature.

[c] Based on correlation from single rod burst tests (at 28°C/sec heating rate), using burst pressures from Column 8 as input.

[d] Rod 3 may have developed a "pinhole" leak at ∿11200 kPa (see text for discussion); large burst occurred 16.65 sec after power was terminated.

[e] Rod 7 developed a leak prior to test; this rod was tested essentially at constant pressure due to attempt to compensate for leak.

[f] TE 9-3 was known to be detached from Zircaloy prior to test, causing a high reading; TE 9-1 reading selected as burst temperature.

[g] TE 12-4 had very slow response on both heatup and cooldown transients and its readings should be ignored.

Strain in B-1 tubes in percent

Elevation (cm)	Tube No.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.0	1.5	0.6	2.7	2.1	1.4	1.5	1.2	1.3	1.7	1.8	1.8	1.7	2.7	1.9	1.7	1.6
1.8	5.6	8.1	7.6	8.4	6.2	10.1	7.4	8.2	8.2	9.2	6.2	8.2	8.9	8.1	8.7	6.4
3.3	7.8	18.3	10.0	10.3	8.4	15.6	13.5	16.0	13.7	20.1	11.1	10.3	10.5	12.1	20.1	12.6
5.2	7.6	17.7	7.7	10.7	8.2	12.9	14.1	16.9	15.0	18.2	13.5	9.3	8.7	12.8	26.8	12.6
8.9	3.5	4.8	4.0	5.0	4.4	5.0	5.5	6.3	5.0	6.5	6.1	4.9	3.8	4.6	5.3	5.2
11.8	4.6	5.6	4.1	6.0	5.2	6.1	6.4	7.3	5.2	6.8	7.0	5.9	4.4	4.7	6.2	5.4
14.1	13.2	16.1	8.7	12.0	17.3	20.3	17.7	16.3	18.4	21.0	20.5	15.8	25.0	16.6	27.3	17.9
15.4	11.8	15.3	10.4	13.0	24.0	21.0	16.9	15.6	20.0	22.6	20.5	15.9	36.9	18.9	36.4	21.9
17.3	12.7	14.7	10.7	13.2	29.7	20.4	18.5	16.4	20.7	22.9	25.0	14.4	24.9	19.2	36.0	25.5
18.8	15.3	17.9	9.6	15.4	26.2	22.3	20.1	18.5	27.9	26.3	44.4	14.0	16.7	25.1	38.5	28.1
20.1	13.8	19.1	7.7	14.9	21.4	23.6	21.4	18.1	30.2	30.3	52.5	13.8	12.7	25.4	41.6	29.5
20.6	13.7	19.1	7.4	14.4	20.9	23.5	21.4	17.3	29.5	30.1	52.0	12.7	11.5	23.4	39.0	28.6
22.3	14.1	18.8	8.3	12.3	25.0	23.7	23.7	17.6	28.2	41.1	48.9	14.2	12.2	21.5	30.8	30.3
23.9	13.3	20.1	8.9	12.0	27.4	22.5	25.2	18.3	28.6	44.5	44.4	16.9	14.1	22.9	28.1	38.6
25.5	11.2	22.5	8.3	12.6	28.9	21.3	28.2	18.0	35.6	38.2	44.9	16.7	15.2	25.4	22.2	32.8
26.5	11.6	24.2	8.5	13.3	35.9	24.3	30.2	16.8	37.8	37.2	42.6	16.3	17.8	26.7	19.2	27.0
28.1	12.0	22.9	8.3	14.2	44.1	36.4	28.8	17.2	28.7	35.6	32.4	16.3	22.6	24.1	16.5	21.6
29.7	11.4	20.5	8.2	12.1	34.8	42.7	25.3	17.5	22.4	28.0	22.9	14.9	25.2	20.4	16.4	19.7
30.7	10.2	20.8	8.7	11.6	28.3	37.3	24.3	18.5	20.8	24.1	20.1	14.2	27.9	19.1	18.8	19.3
33.2	8.2	21.0	7.9	9.7	22.9	24.7	27.6	21.1	17.9	21.1	19.5	17.1	19.5	18.2	22.2	17.3
34.5	8.0	19.8	9.2	10.6	24.6	27.0	26.6	20.8	17.9	22.3	20.0	17.6	16.7	16.5	21.3	17.6
36.6	8.4	18.3	10.4	11.9	25.3	23.6	24.9	23.0	15.6	19.9	20.8	15.7	16.6	17.0	19.3	22.3
38.1	10.1	20.7	10.2	12.3	25.8	20.4	22.8	26.8	15.7	18.8	22.6	15.6	21.7	18.9	20.6	24.0
39.7	15.2	24.1	8.1	12.1	26.2	18.8	23.0	29.1	19.2	19.8	23.2	18.2	54.4	23.9	22.2	22.0
40.8	15.6	23.8	8.0	12.2	27.4	18.2	22.6	29.4	22.9	22.4	22.7	18.2	58.9	26.5	20.4	20.6
42.9	13.2	21.6	9.7	13.6	34.4	15.9	21.5	34.9	32.2	23.8	19.7	20.6	26.6	29.4	19.3	21.3
44.7	14.5	22.3	11.9	14.6	37.7	15.3	24.4	41.9	39.6	21.7	19.5	26.4	23.9	39.1	23.5	23.3
46.7	14.9	21.9	10.3	15.2	41.8	15.4	29.3	35.5	43.7	21.3	20.0	31.7	28.7	41.6	25.7	19.8
47.5	14.4	21.1	9.5	15.2	42.5	17.2	30.0	30.9	47.1	23.0	20.5	35.4	26.7	38.1	25.3	18.3
48.6	12.8	19.3	12.3	15.7	37.5	16.0	27.3	28.0	39.0	22.7	18.1	37.4	24.0	31.4	23.6	18.8
50.4	14.7	17.7	22.8	14.6	33.3	15.4	22.7	24.7	37.5	22.6	18.1	31.2	24.2	27.8	20.4	19.2
52.4	18.3	18.4	10.3	11.7	26.1	15.0	21.3	23.9	36.8	23.1	18.6	23.5	23.9	26.0	20.4	17.3
54.0	17.3	18.8	7.8	11.1	23.6	13.4	20.1	19.5	32.2	21.2	17.4	18.2	21.4	21.9	23.2	15.2
55.6	13.2	15.8	6.9	11.2	26.3	12.1	17.4	18.5	28.2	19.1	16.4	15.3	17.1	17.5	21.2	14.5
57.8	11.4	14.5	6.9	11.5	28.5	9.0	17.0	21.0	21.8	15.5	14.1	14.6	15.4	15.9	17.1	14.8
60.1	14.2	15.0	6.2	14.8	20.2	8.1	22.8	18.0	18.9	14.6	13.8	11.6	16.2	17.7	15.3	10.5
61.7	10.9	11.9	5.2	11.7	15.3	7.0	16.8	13.0	12.8	13.7	11.3	9.9	14.6	13.3	13.3	9.0
64.1	3.8	4.0	2.1	4.4	5.8	2.5	4.5	4.9	4.2	4.6	4.1	4.1	5.2	4.8	5.4	4.9
66.9	4.5	5.0	2.0	4.2	5.7	2.2	5.7	5.4	5.7	4.8	4.8	3.9	5.0	4.6	5.6	3.8
68.8	15.5	12.6	5.0	12.1	20.6	4.9	16.0	12.2	13.8	13.7	13.3	12.2	12.1	12.6	13.5	10.3
70.3	22.6	16.1	7.9	14.4	31.6	5.4	19.4	14.2	16.9	17.2	13.9	14.6	12.9	16.9	13.1	12.7
72.7	25.4	22.0	9.5	16.9	43.2	4.4	26.4	17.3	24.5	17.2	15.2	14.6	13.0	23.4	16.1	13.7
74.2	32.3	27.8	10.3	22.4	45.2	5.3	36.4	17.0	31.0	19.7	17.0	14.1	14.9	28.2	20.1	14.2
76.5	35.6	30.5	10.3	36.1	44.8	5.2	35.7	15.7	25.5	20.4	16.1	18.7	20.8	26.9	21.2	16.5
77.3	29.2	32.4	10.2	28.0	39.7	4.8	33.4	16.2	20.4	17.1	14.8	19.9	19.8	23.0	18.4	15.9
80.2	25.7	31.5	9.0	21.1	26.6	5.6	23.6	18.2	22.7	15.6	17.2	17.7	21.2	23.1	18.2	12.8
81.6	20.5	27.9	8.6	18.3	22.5	6.1	19.7	12.6	17.6	14.4	16.3	15.1	16.6	20.5	19.9	11.9
83.5	19.0	27.6	8.1	13.5	23.5	7.8	17.1	10.7	18.2	14.5	15.1	14.4	17.5	17.5	21.4	13.1
85.1	13.3	25.8	5.1	7.9	19.0	4.9	11.6	9.9	19.5	11.1	12.6	12.4	19.5	14.0	17.2	12.7
86.5	12.6	17.4	4.3	6.3	12.9	4.3	8.8	9.2	19.5	10.4	11.5	10.9	18.8	10.5	12.8	11.3
87.9	9.5	7.7	3.4	5.2	5.9	2.8	5.9	7.0	11.4	7.5	7.8	7.6	11.3	6.3	8.1	9.6
90.0	4.9	2.6	1.3	3.7	2.0	1.5	3.1	2.5	1.5	2.5	2.9	0.7	1.7	2.5	4.0	3.8
92.5	-0.2	-0.2	0.3	0.9	-0.2	-0.1	0.0	0.2	0.2	-0.0	0.4	0.4	0.1	0.4	0.5	0.5

Upper limit of deformed B-1 tube areas (mm^2)

Elevation (cm)	Tube No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
0.0	96	94	98	97	96	96	95	96	96	96	97	96	98	97	96	96	1549
1.8	104	109	108	109	105	113	108	109	109	111	105	109	111	109	110	105	1742
3.3	108	131	113	113	110	125	120	125	121	135	115	113	114	117	135	118	1919
5.2	108	129	108	114	109	119	121	128	123	130	120	111	110	119	150	118	1926
8.9	100	102	101	103	102	103	104	105	103	106	105	103	100	102	103	103	1651
11.8	102	104	101	104	103	105	105	107	103	106	107	104	101	102	105	103	1671
14.1	115	126	110	117	128	135	129	126	131	137	135	125	146	127	151	130	2080
15.4	117	124	114	119	144	137	128	125	134	140	135	125	175	132	174	139	2167
17.3	119	123	114	115	157	135	131	126	136	141	146	122	146	133	173	147	2175
18.8	124	130	112	124	149	140	135	131	153	149	195	121	127	146	179	153	2273
20.1	121	132	108	123	138	143	138	130	158	157	217	121	118	147	189	156	2303
20.6	121	132	108	122	136	142	137	128	157	156	215	118	116	142	180	154	2274
22.3	121	132	109	118	146	143	143	129	153	176	269	122	117	138	159	227	2409
23.9	120	134	111	117	151	140	146	130	154	209	217	127	121	141	153	283	2464
25.5	115	140	109	118	155	137	153	130	172	177	196	127	124	147	139	165	2312
26.5	116	144	110	120	172	144	158	127	177	175	190	126	129	150	133	151	2330
28.1	117	141	109	122	194	173	155	128	155	172	164	126	140	144	127	138	2311
29.7	116	136	109	117	170	253	146	129	140	153	141	123	146	135	126	133	2281
30.7	113	13[illegible]	110	116	154	176	144	131	136	144	135	122	153	132	131	133	2173
33.2	105	136	109	112	141	145	152	137	130	137	133	128	133	130	139	128	2107
34.5	109	134	111	114	145	150	149	136	130	139	134	129	127	126	137	129	2108
36.6	110	130	113	117	147	143	145	141	125	134	136	125	127	128	133	140	2100
38.1	113	136	113	118	148	135	141	150	125	132	140	125	138	132	136	143	2131
39.7	124	144	109	117	149	132	141	156	133	134	141	130	221	143	139	139	2259
40.8	125	143	109	117	152	130	140	156	141	140	141	130	281	149	135	136	2333
42.9	119	138	112	120	169	125	138	170	163	143	134	136	150	156	133	137	2251
44.7	122	140	117	122	177	124	144	244	182	138	133	149	143	180	142	142	2409
46.7	123	139	113	124	188	124	156	171	291	137	134	162	155	262	147	134	2568
47.5	122	137	112	124	193	128	158	160	201	141	135	210	150	178	147	130	2433
48.6	119	133	118	125	176	126	151	153	180	140	130	222	143	161	142	132	2359
50.4	123	129	160	122	168	124	140	145	177	140	130	161	144	152	135	133	2289
52.4	130	131	113	116	148	123	137	143	175	141	131	142	143	148	135	128	2195
54.0	128	132	108	115	143	120	134	133	163	137	129	130	138	139	141	124	2121
55.6	120	125	106	115	149	117	129	131	153	132	126	124	128	129	137	122	2052
57.8	116	122	106	116	154	111	128	137	138	124	121	123	124	125	128	123	2004
60.1	122	123	105	123	135	109	141	130	132	123	121	116	126	129	124	114	1979
61.7	115	117	103	116	124	107	127	119	119	121	115	113	122	120	120	111	1875
64.1	100	101	97	101	104	98	102	102	101	102	101	101	103	102	103	102	1630
66.9	102	102	97	101	104	97	104	103	104	102	102	101	103	102	104	100	1636
68.8	124	118	103	117	136	102	126	117	121	120	120	117	117	118	120	113	1898
70.3	140	126	109	122	162	103	133	122	128	128	121	122	119	127	119	118	2006
72.7	147	139	112	127	192	102	149	128	145	128	124	122	119	142	126	120	2129
74.2	163	153	113	140	197	103	177	128	160	134	128	121	123	153	135	122	2257
76.5	243	181	113	258	196	103	225	125	147	135	126	131	136	150	137	127	2540
77.3	215	214	113	230	182	102	166	126	135	128	123	134	134	141	131	125	2406
80.2	147	161	111	137	149	104	143	130	140	125	128	129	137	141	130	119	2140
81.6	136	153	110	131	140	105	134	118	129	122	126	123	127	135	134	117	2047
83.5	132	152	109	120	142	108	128	114	130	122	124	122	129	129	137	119	2026
85.1	120	148	103	109	132	103	116	113	133	115	118	118	133	121	128	119	1935
86.5	118	129	101	105	119	101	110	111	133	114	116	115	132	114	119	115	1860
87.9	112	108	100	103	104	99	104	107	116	108	108	108	116	105	109	112	1726
90.0	102	98	96	100	97	96	99	98	96	98	99	94	96	98	101	100	1576
92.5	93	93	94	95	93	93	93	93	94	93	94	94	93	94	94	94	1503

Lower limit of B-1 deformed tube areas (mm^2)

Elevation (cm)	Tube No.																Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
0.0	96	94	98	97	96	96	95	96	96	96	97	96	98	97	96	96	1549
1.8	104	109	108	109	105	113	108	109	109	111	105	109	111	109	110	105	1742
3.3	108	131	113	113	110	125	120	125	121	135	115	113	114	117	135	118	1919
5.2	108	129	108	114	109	119	121	128	123	130	120	111	110	119	150	118	1926
8.9	100	102	101	103	102	103	104	105	103	106	105	103	100	102	103	103	1651
11.8	102	104	101	104	103	105	105	107	103	106	107	104	101	102	105	103	1671
14.1	119	126	110	117	128	135	129	126	131	137	135	125	146	127	151	130	2080
15.4	117	124	114	119	144	137	128	125	134	140	135	125	175	132	174	139	2167
17.3	119	123	114	119	157	135	131	126	136	141	146	122	146	133	173	147	2175
18.8	124	130	112	124	149	140	135	131	153	149	195	121	127	146	179	153	2273
20.1	121	132	108	123	138	143	138	130	158	157	217	121	118	147	187	156	2301
20.6	121	132	108	122	136	142	137	128	157	156	215	118	116	142	180	154	2274
22.3	121	132	109	118	146	143	143	129	153	176	207	122	117	138	159	159	2279
23.9	120	134	111	117	151	140	146	130	154	195	195	127	121	141	153	179	2324
25.5	115	140	109	118	155	137	153	130	172	177	196	127	124	147	139	165	2312
26.5	116	144	110	120	172	144	158	127	177	175	190	126	129	150	133	151	2330
28.1	117	141	109	122	194	173	155	128	155	172	164	126	140	144	127	138	2311
29.7	116	136	109	117	170	190	146	129	140	153	141	123	146	135	126	133	2218
30.7	113	136	110	116	154	176	144	131	136	144	135	122	153	132	131	133	2173
33.2	109	136	109	112	141	145	152	137	130	137	133	128	133	130	139	128	2107
34.5	109	134	111	114	145	150	149	136	130	139	134	129	127	126	137	129	2108
36.6	110	130	113	117	147	143	145	141	125	134	136	125	127	128	133	140	2100
38.1	113	136	113	118	148	135	141	150	125	132	140	125	138	132	136	143	2131
39.7	124	144	109	117	149	132	141	156	133	134	141	130	221	143	139	139	2259
40.8	125	143	109	117	152	130	140	156	141	140	141	130	236	149	135	136	2288
42.9	119	138	112	120	169	125	138	170	163	143	134	136	150	156	133	137	2251
44.7	122	140	117	122	177	124	144	188	182	138	133	149	143	180	142	142	2352
46.7	123	139	113	124	188	124	156	171	193	137	134	162	155	187	147	134	2395
47.5	122	137	112	124	190	128	158	160	201	141	135	171	150	178	147	130	2391
48.6	119	133	118	125	176	126	151	153	180	140	130	176	143	161	142	132	2314
50.4	123	129	141	122	166	124	140	145	177	140	130	161	144	152	135	133	2270
52.4	130	131	113	116	148	123	137	143	175	141	131	142	143	148	135	128	2195
54.0	128	132	108	115	143	120	134	133	163	137	129	130	138	139	141	124	2121
55.6	120	125	106	115	149	117	129	131	153	132	126	124	128	129	137	122	2052
57.8	116	122	106	116	154	111	128	137	138	124	121	123	124	125	128	123	2004
60.1	122	123	105	123	135	109	141	130	132	123	121	116	126	129	124	114	1979
61.7	115	117	103	116	124	107	127	119	119	121	115	113	122	120	120	111	1875
64.1	100	101	97	101	104	98	102	102	101	102	101	101	103	102	103	102	1630
66.9	102	102	97	101	104	97	104	103	104	102	102	101	103	102	104	100	1636
68.8	124	118	103	117	136	102	126	117	121	120	120	117	117	118	120	113	1898
70.3	140	126	109	122	162	103	133	122	128	128	121	122	119	127	119	118	2006
72.7	147	139	112	127	192	102	149	128	145	128	124	122	119	142	126	120	2129
74.2	163	153	113	140	197	103	174	128	160	134	128	121	123	153	135	122	2254
76.5	172	159	113	173	196	103	172	125	147	135	126	131	136	150	137	127	2309
77.3	156	164	113	153	182	102	166	126	135	128	123	134	134	141	131	125	2221
80.2	147	161	111	137	149	104	143	130	140	125	128	129	137	141	130	119	2140
81.6	136	153	110	131	140	105	134	118	129	122	126	123	127	135	134	117	2047
83.5	132	152	109	120	142	108	128	114	130	122	124	122	129	129	137	119	2026
85.1	120	148	103	109	132	103	116	113	133	115	118	118	133	121	128	119	1935
86.5	118	129	101	105	119	101	110	111	133	114	116	115	132	114	119	115	1860
87.9	112	108	100	103	104	99	104	107	116	108	108	108	116	105	109	112	1726
90.0	102	98	96	100	97	96	99	98	96	98	99	94	96	98	101	100	1576
92.5	93	93	94	95	93	93	93	93	94	93	94	94	93	94	94	94	1503

Strain in B-2 tubes in percent

Elevation (cm)	Tube No.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.0	-0.2	-0.2	-0.3	0.3	0.0	-0.4	-0.1	0.3	-0.8	-0.6	-0.4	0.1	-0.9	-0.5	-0.4	0.0
1.8	4.4	5.7	6.0	5.8	4.1	7.1	7.4	6.9	4.6	5.1	5.1	7.2	4.1	6.3	4.8	4.8
3.4	10.5	11.3	12.3	10.6	10.5	18.8	14.1	11.6	8.2	10.6	10.9	13.0	8.9	15.0	9.6	7.7
5.0	10.4	11.5	11.0	11.5	9.9	17.1	12.8	11.1	8.5	10.7	11.0	11.2	9.3	13.2	10.4	8.3
6.5	8.5	9.7	8.0	7.8	7.6	13.5	10.4	7.5	7.0	9.0	9.0	8.5	7.4	9.8	7.5	6.6
8.8	4.6	4.9	3.9	4.1	3.9	5.0	4.4	4.2	3.1	3.1	3.9	3.9	3.5	3.7	3.1	3.1
11.5	3.7	3.9	3.9	4.4	3.7	5.6	4.3	4.5	3.4	3.7	4.8	4.6	3.5	4.2	2.9	4.2
13.3	8.6	7.7	5.2	7.9	6.7	14.7	12.1	9.8	9.3	9.4	13.2	10.5	8.2	10.3	5.1	6.5
15.1	13.3	11.4	11.5	9.5	8.5	20.9	15.1	13.2	10.7	12.4	16.8	15.6	11.6	17.3	6.8	7.1
16.8	15.3	16.3	14.6	11.6	11.7	22.9	15.7	16.2	10.9	16.2	18.3	17.5	14.4	28.4	11.2	10.5
18.1	15.8	18.2	17.6	13.0	14.3	23.2	15.6	18.7	11.0	16.5	16.9	17.9	15.7	37.8	12.3	11.7
19.5	15.2	19.5	19.7	13.7	18.7	22.4	17.9	21.1	14.7	21.5	16.6	20.7	20.9	41.8	12.6	12.9
21.4	15.8	17.5	19.9	10.8	18.0	21.6	17.9	22.8	13.8	22.6	15.2	24.7	19.5	32.4	11.1	11.8
23.2	15.5	16.1	21.4	9.7	18.3	24.7	18.4	27.0	14.9	23.3	15.1	21.8	18.5	25.8	13.1	13.3
25.0	16.2	13.8	24.4	11.0	17.4	23.4	21.0	27.4	15.4	21.0	13.5	18.5	16.0	22.3	15.5	14.7
26.5	15.4	11.5	25.9	13.5	14.6	19.8	23.4	20.7	14.5	21.1	13.5	18.7	14.9	15.7	17.3	11.8
28.5	16.5	12.7	29.8	16.7	15.1	21.0	24.5	17.4	14.8	23.8	14.3	19.5	14.8	15.5	18.4	10.7
30.0	14.7	12.4	32.5	18.6	14.9	21.5	23.3	16.1	13.2	23.3	15.1	18.8	12.4	15.8	17.5	11.7
32.0	12.6	15.3	28.0	19.8	14.7	20.8	21.8	16.2	13.3	21.0	14.4	20.2	12.8	17.3	13.7	13.5
34.0	11.6	15.4	22.0	17.7	14.8	23.8	19.4	15.1	13.8	18.6	14.8	20.7	16.1	17.7	12.7	13.2
35.5	12.9	18.0	21.6	14.0	15.3	44.3	17.4	16.1	13.5	20.1	16.7	18.1	16.5	22.7	13.9	11.7
37.7	13.5	18.7	24.0	13.5	17.9	57.8	15.7	20.7	15.0	25.0	16.2	15.5	14.6	30.1	16.2	12.7
39.5	12.2	15.0	20.1	13.8	15.6	39.6	18.4	23.4	13.5	32.6	14.4	14.2	12.3	28.9	16.0	13.3
41.2	18.8	15.7	23.7	15.6	16.6	35.3	23.1	29.6	16.2	42.8	16.9	18.9	17.5	26.8	17.3	16.9
43.3	22.2	15.6	29.5	17.0	15.6	44.3	19.7	37.6	14.2	33.0	16.8	21.0	17.1	21.3	15.3	18.3
44.7	23.4	15.0	37.7	18.3	14.9	40.7	17.3	33.0	14.4	27.3	16.0	18.4	15.9	18.9	12.9	21.6
46.2	27.8	17.0	38.4	19.7	16.0	36.4	17.2	23.3	17.0	23.2	16.1	18.1	14.7	17.9	11.8	29.0
47.7	34.5	18.9	30.8	19.8	19.0	37.3	20.1	18.2	21.1	24.5	17.7	18.8	16.0	18.3	13.5	30.8
49.7	28.5	19.6	21.5	18.9	20.7	34.9	20.6	17.4	19.0	22.2	19.9	20.4	14.3	19.2	16.5	22.2
51.6	21.0	20.0	16.0	23.4	27.1	28.9	17.3	18.4	17.7	20.5	18.5	22.1	14.5	20.8	17.4	19.6
53.5	18.1	19.7	19.3	29.4	35.0	25.9	20.1	17.5	19.5	21.8	18.3	25.7	22.0	23.5	20.6	28.2
54.9	19.1	21.9	19.2	27.2	29.0	26.0	22.6	17.6	18.1	22.6	17.6	27.1	29.9	24.2	20.5	37.1
56.2	20.7	25.3	21.3	27.2	25.2	25.6	23.6	22.2	17.6	24.8	17.7	28.1	41.4	27.7	23.2	41.7
57.6	17.1	22.3	21.4	28.1	21.5	21.3	19.3	24.1	14.7	21.6	13.6	23.4	34.6	25.2	20.4	32.4
59.8	13.4	14.7	18.7	23.7	15.0	17.7	16.9	16.8	12.9	17.3	10.9	17.4	16.1	18.2	14.1	17.0
61.8	11.0	10.3	12.4	12.7	10.5	13.6	14.8	11.8	11.2	13.6	10.5	14.0	13.1	12.1	10.5	10.8
63.8	5.1	5.3	4.9	6.1	5.1	5.5	5.7	6.0	3.7	5.4	5.2	5.8	6.4	5.7	5.0	6.4
66.5	4.8	4.9	5.2	6.5	4.7	5.8	6.3	5.9	4.1	5.1	5.5	5.2	5.5	5.0	4.0	5.1
68.4	10.2	10.8	13.6	10.8	11.0	17.7	18.1	11.6	12.4	13.7	15.0	11.0	10.9	10.8	8.2	9.3
70.1	14.6	18.3	19.7	15.9	16.0	27.0	23.1	16.7	17.0	17.8	20.7	16.8	9.7	19.1	12.6	12.6
71.6	15.0	22.2	21.3	21.5	20.6	27.0	21.8	17.8	19.4	18.1	20.2	16.6	9.7	25.8	12.7	14.3
73.1	16.1	25.1	24.8	30.5	22.0	25.6	23.1	19.3	23.0	18.7	20.9	17.7	10.8	26.7	13.5	17.6
74.6	21.7	33.0	37.4	37.8	23.3	30.6	27.7	22.1	29.2	22.2	26.4	19.7	16.5	24.8	17.0	20.1
76.2	23.2	38.5	40.3	42.0	22.0	35.4	31.9	22.3	23.9	25.3	34.4	23.2	17.3	22.7	22.2	22.5
78.0	24.3	29.0	33.6	33.2	23.6	28.8	34.2	21.9	20.2	27.6	39.8	26.3	17.3	23.1	31.4	23.1
79.5	22.9	20.7	22.4	27.1	23.9	22.5	39.7	21.6	19.6	28.0	35.2	29.4	16.7	22.2	35.1	22.0
81.6	17.3	17.9	16.8	26.5	19.0	23.8	55.6	16.3	19.1	28.3	25.9	39.7	14.3	18.7	25.2	16.2
83.8	11.4	15.9	15.6	18.9	14.1	24.0	32.7	12.8	16.1	21.1	20.1	21.8	10.6	16.1	14.4	11.6
86.0	8.0	13.8	12.7	12.9	15.4	14.8	20.7	11.5	13.9	23.0	14.6	11.8	7.5	14.3	9.8	10.8
88.1	6.5	8.1	6.3	7.5	10.3	9.2	12.2	8.4	7.8	12.1	7.8	7.1	5.2	9.7	6.8	8.4
89.5	1.2	1.6	1.7	3.0	1.9	1.9	2.4	1.2	1.5	3.5	0.7	3.3	-0.1	2.4	0.3	1.1
91.5	0.4	0.4	0.8	1.2	1.1	0.1	1.0	-0.1	0.5	1.7	0.5	0.9	0.1	1.5	0.4	0.5

Upper limit of B-2 deformed tube areas (mm^2)

Elevation (cm)	Tube No.																TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
0.0	93	93	93	94	93	92	93	94	92	92	92	93	91	92	92	93	1490
1.8	102	104	105	104	101	107	107	106	102	103	103	107	101	105	102	102	1670
3.4	114	115	117	114	114	132	121	116	109	114	115	119	111	123	112	108	1862
5.0	114	116	115	116	113	128	119	115	110	114	115	115	111	119	114	109	1850
6.9	110	112	109	108	108	120	114	108	107	111	111	110	107	112	108	106	1767
8.8	102	103	101	101	100	103	101	101	99	95	101	100	100	100	99	99	1616
11.5	100	101	101	102	100	104	101	102	100	100	102	102	100	101	99	107	1622
13.3	110	108	111	108	106	123	117	112	111	112	119	114	109	113	103	106	1791
15.1	120	116	116	112	110	136	124	119	114	118	127	125	116	128	106	107	1902
16.8	124	126	122	116	116	141	125	126	115	126	131	129	122	154	115	114	2009
18.1	125	130	129	119	122	142	125	131	115	127	128	130	125	177	118	116	2065
19.5	133	133	134	121	131	140	130	137	123	138	127	136	136	233	118	119	2195
21.4	134	129	134	114	130	138	130	141	121	140	124	145	133	164	115	117	2115
23.2	133	126	138	112	131	145	131	151	123	142	123	139	131	148	119	120	2118
25.0	126	121	144	115	129	142	137	152	124	137	120	131	126	140	124	123	2096
26.5	124	116	148	120	122	134	142	136	122	137	120	132	123	125	128	117	2054
28.5	127	118	157	127	123	137	145	129	123	143	122	133	123	124	131	114	2083
30.0	123	118	164	131	123	138	142	126	120	142	124	132	118	125	129	116	2076
32.0	118	124	153	134	123	136	138	126	120	137	122	135	119	128	121	120	2060
34.0	116	124	139	129	123	143	133	123	121	131	123	136	126	129	119	119	2042
35.9	115	130	138	121	124	194	129	126	120	134	127	130	127	140	121	116	2105
37.7	120	131	143	120	130	248	125	136	123	146	126	124	122	158	126	118	2205
39.5	117	123	135	121	125	182	131	142	120	164	122	122	118	155	125	120	2128
41.2	132	125	143	125	126	171	141	157	126	256	127	132	129	150	128	127	2302
43.3	139	125	156	128	125	194	133	259	122	165	127	137	128	137	124	131	2338
44.7	142	123	177	131	123	185	128	165	122	151	126	131	125	132	119	138	2225
46.2	152	128	179	134	126	174	128	142	128	142	126	130	123	130	117	155	2218
47.7	204	132	160	134	132	176	135	130	137	145	129	132	125	131	120	160	2288
49.7	155	133	138	132	136	170	136	129	132	135	134	135	122	133	127	139	2196
51.6	136	134	126	142	151	155	128	131	129	136	131	139	122	136	129	133	2166
53.5	130	134	133	156	261	148	134	129	133	138	130	147	139	142	136	153	2352
54.9	132	139	133	151	155	148	140	129	130	140	129	151	158	144	135	175	2296
56.2	136	146	137	151	146	147	143	139	129	145	129	153	253	152	142	271	2527
57.6	128	140	138	153	138	137	133	144	123	138	120	142	169	146	135	164	2254
59.8	120	123	131	143	123	129	127	127	119	128	115	129	126	130	121	128	2027
61.8	115	113	118	118	114	120	123	117	115	120	114	121	119	117	114	114	1881
63.8	103	103	103	105	103	104	104	105	100	103	103	104	105	104	103	105	1665
66.5	102	102	103	106	102	104	105	104	101	103	104	103	104	103	101	103	1658
68.4	113	115	120	114	115	129	130	116	118	121	123	115	115	114	109	111	1886
70.1	123	130	134	125	126	151	141	127	128	125	136	127	112	132	118	118	2065
71.6	123	139	137	138	136	151	138	129	133	130	135	127	112	148	119	122	2124
73.1	126	146	145	159	139	147	141	133	141	131	136	129	114	150	120	129	2195
74.6	138	165	174	177	142	159	152	139	184	139	149	134	127	145	128	135	2394
76.2	142	203	264	288	139	171	162	139	143	146	168	141	128	140	139	140	2663
78.0	144	155	166	166	143	155	168	139	135	152	228	149	128	141	161	141	2478
79.5	141	136	140	151	143	140	182	138	134	153	170	156	127	139	189	139	2384
81.6	128	130	127	149	132	143	295	126	132	154	148	228	122	131	146	126	2425
83.8	116	125	125	132	121	143	164	119	126	137	135	138	114	126	122	116	2066
86.0	109	121	118	119	124	123	136	116	121	141	122	117	108	122	112	114	1930
88.1	106	109	105	108	113	111	117	109	108	117	108	107	103	112	106	109	1758
89.9	95	96	96	99	97	97	98	95	96	100	94	99	93	98	94	95	1550
91.5	94	94	95	95	95	93	95	93	94	96	94	95	93	96	94	94	1518

Lower limit of B-2 deformed tube area (mm^2)

Elevation (cm)	Tube No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	TOTAL
0.0	92	93	93	94	93	92	93	94	92	92	92	93	91	92	92	93	1490
1.8	102	104	105	104	101	107	107	106	102	103	103	107	101	105	102	102	1670
3.4	114	115	117	114	114	132	121	116	109	114	115	119	111	123	112	108	1862
5.0	114	116	115	116	113	128	119	115	110	114	115	115	111	119	114	109	1850
6.5	110	112	109	108	108	120	114	108	107	111	111	110	107	112	108	106	1767
8.8	102	103	101	101	100	103	101	101	99	99	101	100	100	100	99	99	1616
11.5	100	101	101	102	100	104	101	102	100	100	102	102	100	101	99	101	1622
13.3	110	108	111	108	106	123	117	112	111	112	119	114	109	113	103	106	1791
15.1	120	116	116	112	110	136	124	119	114	118	127	125	116	128	106	107	1902
16.8	124	126	122	116	116	141	125	126	115	126	131	129	122	154	115	114	2009
18.1	125	130	129	119	122	142	125	131	115	127	128	130	125	177	118	116	2065
19.5	133	133	134	121	131	140	130	137	123	138	127	136	136	188	118	119	2150
21.4	134	129	134	114	130	138	130	141	121	140	124	145	139	164	115	117	2115
23.2	133	126	138	112	131	145	131	151	123	142	123	139	131	148	119	120	2118
25.0	126	121	144	115	129	147	137	152	124	137	120	131	126	140	124	123	2096
26.5	124	116	148	120	122	134	142	136	122	137	120	132	123	125	128	117	2054
28.5	127	118	157	127	123	137	145	129	123	143	122	133	123	124	131	114	2083
30.0	123	118	164	131	123	138	142	126	120	142	124	132	118	125	129	116	2076
32.0	118	124	153	134	123	136	138	126	120	137	122	135	119	128	121	120	2060
34.0	116	124	139	129	123	143	133	123	121	131	123	136	126	129	119	119	2042
35.5	119	130	138	121	124	194	129	126	120	134	127	130	127	140	121	116	2105
37.7	120	131	143	120	130	233	125	136	123	146	126	124	122	158	126	118	2190
39.5	117	123	135	121	125	182	131	142	120	164	122	122	118	155	125	120	2128
41.2	132	125	143	125	126	171	141	157	126	191	127	132	129	150	128	127	2237
43.3	139	125	156	128	125	194	133	177	122	165	127	137	128	137	124	131	2256
44.7	142	123	177	131	123	185	128	165	122	151	126	131	125	132	119	138	2225
46.2	152	128	179	134	126	174	128	142	128	142	126	130	123	130	117	155	2218
47.7	165	132	160	134	132	176	135	130	137	145	129	132	125	131	120	160	2253
49.7	155	133	138	132	136	170	136	129	132	135	134	135	122	133	127	139	2196
51.6	136	134	126	142	151	155	128	131	129	136	131	139	122	136	129	133	2166
53.5	130	134	133	156	170	148	134	129	133	138	130	147	139	142	136	153	2261
54.5	132	139	133	151	155	148	140	129	130	140	129	151	158	144	135	175	2296
56.2	136	146	137	151	146	147	143	139	129	145	129	153	187	152	142	188	2378
57.6	128	140	138	153	138	137	133	144	123	138	120	142	169	146	135	164	2254
59.8	120	123	131	143	123	129	127	127	119	128	115	129	126	130	121	128	2027
61.8	115	113	118	118	114	120	123	117	115	120	114	121	119	117	114	114	1881
63.8	103	103	103	105	103	104	104	105	100	103	103	104	105	104	103	105	1665
66.5	102	102	103	106	102	104	105	104	101	103	104	103	104	103	101	103	1658
68.4	113	115	120	114	115	129	130	116	118	121	123	115	115	114	109	111	1886
70.1	123	130	134	125	126	151	141	127	128	125	136	127	112	132	118	118	2065
71.6	123	139	137	138	136	151	138	129	133	130	135	127	112	148	119	122	2124
73.1	126	146	145	159	139	147	141	133	141	131	136	129	114	150	120	129	2195
74.6	138	165	174	177	142	159	152	139	156	135	149	134	127	145	128	135	2366
76.2	142	179	184	188	139	171	162	139	143	146	168	141	128	140	139	140	2459
78.0	144	155	166	166	143	155	168	139	135	152	183	149	128	141	161	141	2432
79.5	141	136	140	151	143	140	182	138	134	153	170	156	127	139	170	139	2366
81.6	128	130	127	149	132	143	226	126	132	154	148	182	122	131	146	126	2311
83.8	116	125	125	132	121	143	164	119	126	137	135	138	114	126	122	116	2066
86.0	109	121	118	119	124	123	136	116	121	141	122	117	108	122	112	114	1930
88.1	106	109	105	108	113	111	117	109	108	117	108	107	103	112	106	109	1758
89.5	95	96	96	99	97	97	98	95	96	100	94	99	93	98	94	95	1550
91.5	94	94	95	95	95	93	95	93	94	96	94	95	93	96	94	94	1518