1032

JIM BARTEL

Rockwell International

MIDTERM QUARTERLY REVIEW

SOLAR CENTRAL RECEIVER HYBRID

POWER SYSTEM

MATERIALS TUTORIAL PORTION

CONTRACT DE-AC03-78ET 20567

JUNE 6-7, 1979

MIDTERM QUARTERLY REVIEW

SOLAR CENTRAL RECEIVER HYBRID POWER SYSTEM

CONTRACT DE-AC03-78ET 20567

MATERIALS TUTORIAL PORTION

JUNE 6-7, 1979

ENERGY SYSTEMS GROUP
ROCKWELL INTERNATIONAL
8900 DE SOTO AVENUE
CANOGA PARK, CALIFORNIA 91304

SJD:531

AGENDA

JUNE 6 I. 9:00 - 9:15 INTRODUCTION AND SUMMARY - T. SPRINGER

II. 9:15 - 9:45 SYSTEM MATERIAL REQUIREMENTS - L. GLASGOW

A. TEMPERATURE EXTREMES AND MEANS

B. STRAIN CYCLES

C. ENVIRONMENTAL EXPOSURES

1. ATMOSPHERIC (RECEIVER)
2. COMBUSTION CHAMBER (FOSSIL HEATER)
3. FEEDWATER (STEAM GENERATOR)

III. 9:45 - 11:30 MATERIAL OPTIONS AND CONSIDERATIONS - J. PAGE

A. MATERIAL CHARACTERISTICS

1. CARBON STEEL
2. LOW-ALLOY STEEL
3. AUSTENIC STAINLESS STEEL
4. HIGH-NICKEL ALLOY STEEL
5. TRANSITION WELDS AND JOINTS

AGENDA
(CONTINUED)

B. MATERIALS IN THE ENVIRONMENT

1. AIR
2. STEAM
3. BURNER

C. MATERIALS AND SODIUM

1. GENERAL EFFECTS
2. CARBON TRANSPORT

IV. 11:30 12:00 SELECTED MATERIALS BY COMPONENT - W. WILLCOX

A. RECEIVER

B. FOSSIL-FIRED HEATER

1. FURNACE
2. HIGH-TEMPERATURE CONVECTION
3. LOW-TEMPERATURE CONVECTION

C. RISER

D. DOWNCOMER

AGENDA
(CONTINUED)

E. STORAGE

F. STEAM GENERATOR COMPLEX

1. EVAPORATOR AND SEPARATOR
2. SUPERHEATER AND REHEATER

G. PUMPS

1. CASE AND IMPELLER
2. BEARINGS

H. VALVES

1. BODY
2. HARD FACING

I. TRANSITIONS

V. 12:00 - 1:00 LUNCH

VI. 1:00 - 1:45 BASIS OF MATERIAL SELECTION

A. HEATER (B&W)

SJD:531

AGENDA
(CONTINUED)

B. BALANCE-OF-PLANT - J. PAGE

1. EQUIPMENT AND PLANT COMPONENTS
2. HEATER TUBE SODIUM ASPECTS
3. CHLORIDE STRESS

VII. 1:45 - 2:30 DESIGN FEATURES TO ACCOMMODATE THE MATERIAL - L. GLASGOW

A. BUFFERING

1. BUFFERED TANKS
2. MIXING T'S

B. ENVIRONMENTAL PROTECTION

COVERED RECEIVER (TEMPERATURE MAINTENANCE)

C. SODIUM PURITY

COLD TRAPS

D. HARD FACING, VALUES AND PUMPS

AGENDA
(CONTINUED)

E. FEEDWATER

1. SEPARATOR TANK
2. H_2O PURITY CONTROL

F. CYCLIC DRAINING OF RECEIVER

VIII. 2:30 - 5:00 REACTOR AND TEST LOOP EXPERIENCE

2:30 - 3:00	A. FOSSIL-FIRED HEATER (H1 AND H2) - W. WILLCOX	
	B. LIQUID METAL EXPERIENCE - W. WOLFE	
3:00 - 3:30	BUS TO SPTF	
3:30 - 3:40	VUGRAPH PRESENTATION OF SPTF	
3:40 - 4:00	TOUR SPTF	
4:00 - 4:45	A. SODIUM/WATER REACTION EXPERIMENTS - W. DEBEAR, B-38	
	B. SCTI VUGRAPH PRESENTATION	
	C. TOUR SCTI	

AGENDA
(CONTINUED)

SECOND DAY

JUNE 7 IX. 8:15 - 8:45 IMPACT OF SERI CONFERENCE - J. PAGE

A. TOPICS PRESENTED AT SERI CONFERENCE

B. DISCUSSION OF SPECIFIC AREAS

1. SODIUM PURITY LEVELS
2. HYDROGEN LEVELS
3. OXYGEN LEVELS

C. COMMENTS ON SLL ASSESSMENT DOCUMENT

X. 8:45 - 9:15 COAL PLANT STACK GAS CLEANUP - R. OLDENKAMP

A. REMOVAL OF PARTICULATES

B. SO_2 REMOVAL

INTRODUCTION AND SUMMARY

MID-TERM QUARTERLY REVIEW

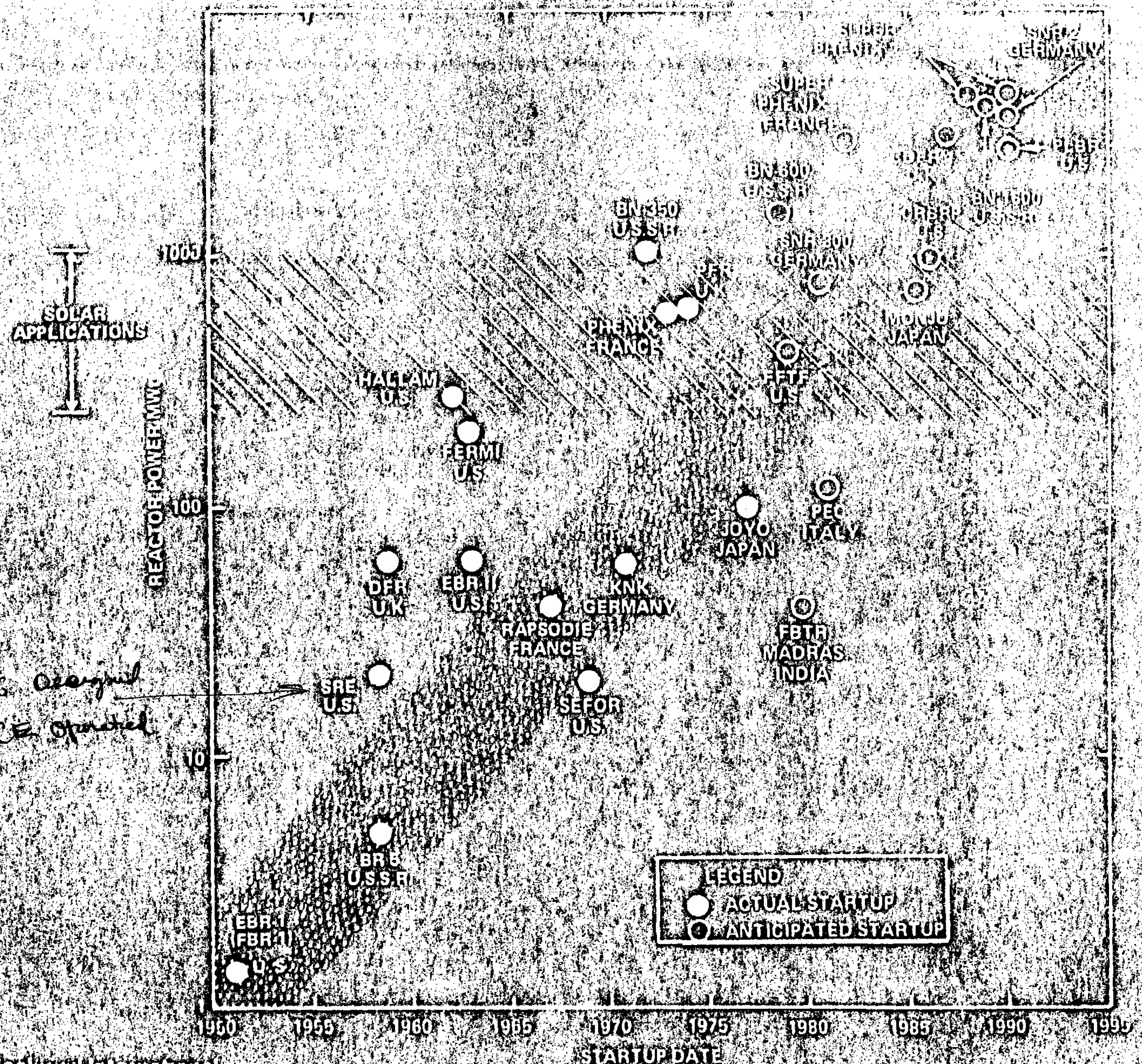
MATERIALS TUTORIAL SUMMARY

- USE OF SODIUM AS HEAT TRANSPORT FLUID IS NOT NOVEL
  - 30 YEARS OF EXPERIENCE AND $3 BILLION ALREADY INVESTED IN DEVELOPMENT
  - 120 SODIUM LOOPS DESIGNED, BUILT, AND OPERATED IN U.S. AND WORLD
  - 9 SODIUM-COOLED POWER PLANTS CURRENTLY IN OPERATION (UP TO 350 MWE)
  - 14 SODIUM-COOLED POWER PLANTS UNDER CONSTRUCTION (UP TO 1200 MWE @ $1 BILLION EACH)
- SODIUM SYSTEMS HAVE A SAFETY RECORD BETTER THAN U.S. INDUSTRY AS A WHOLE
- USE OF SODIUM AS A COOLANT IN THE SOLAR CENTRAL RECEIVER CONCEPT DOES NOT REPRESENT A DEPARTURE FROM THE ESTABLISHED STATE OF THE ART OF SODIUM TECHNOLOGY IN TERMS OF SIZE, TEMPERATURE, FLOW RATE, PRESSURE, AND MATERIALS OF CONSTRUCTION
- RECEIVER HAS UNIQUE AREAS OF CONCERN IN TERMS OF CYCLE LIFE

Rockwell International
Energy Systems Group

JLC:64

WORLD LMFBR PLANTS (PROGRESS GROWTH)



ESG Original
SCE Operated

Rockwell International
Atomics International Division

78-I26-16-4

SYSTEM MATERIAL REQUIREMENTS

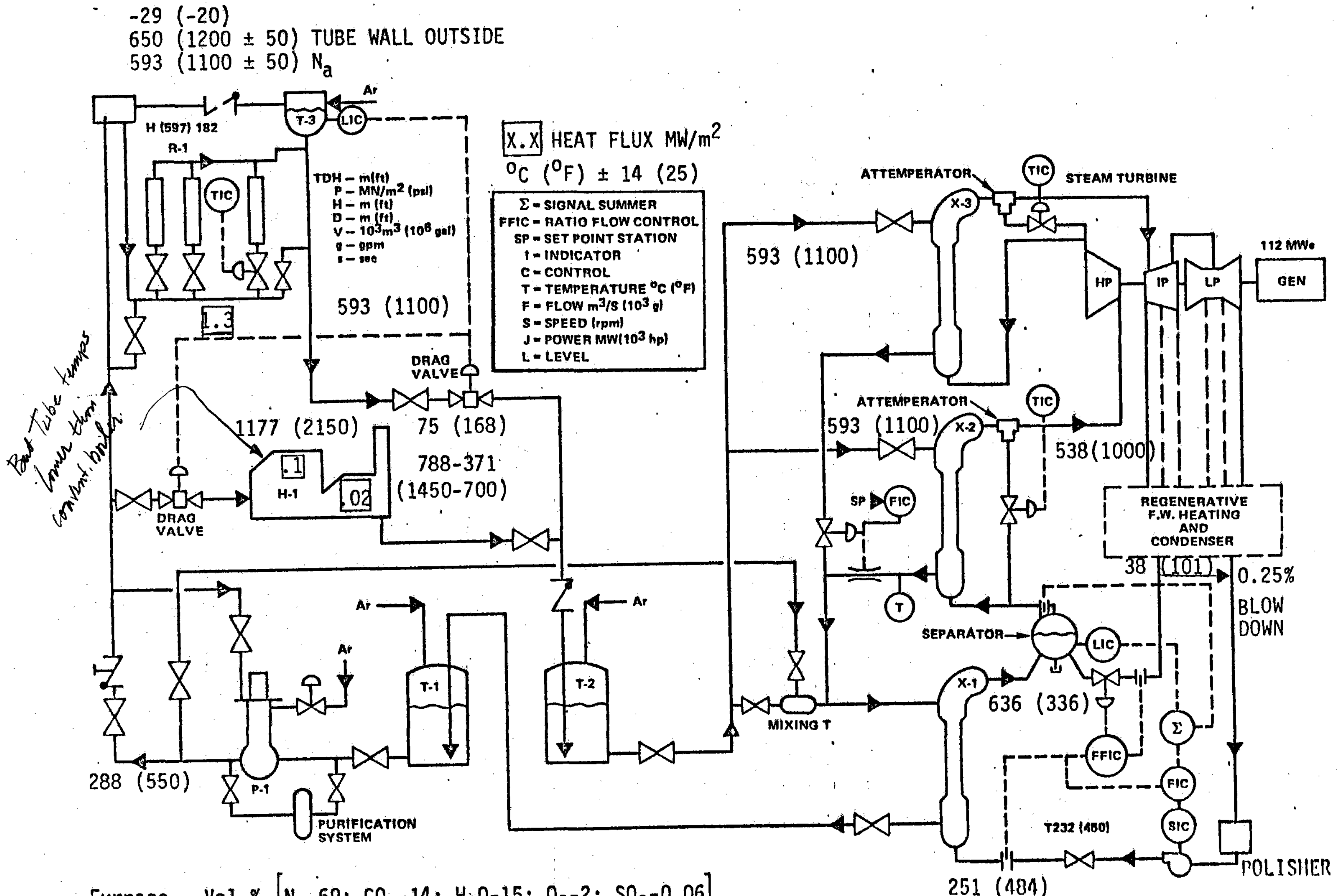
STRUCTURAL MATERIAL SELECTION FOR SODIUM SYSTEMS

THE USE OF SODIUM AS A HEAT TRANSFER FLUID HAS NO EFFECT ON STRUCTURAL MATERIALS SELECTION

Rockwell International
Energy Systems Group

78-D1-133-7

SOLAR CENTRAL RECEIVER HYBRID POWER SYSTEM



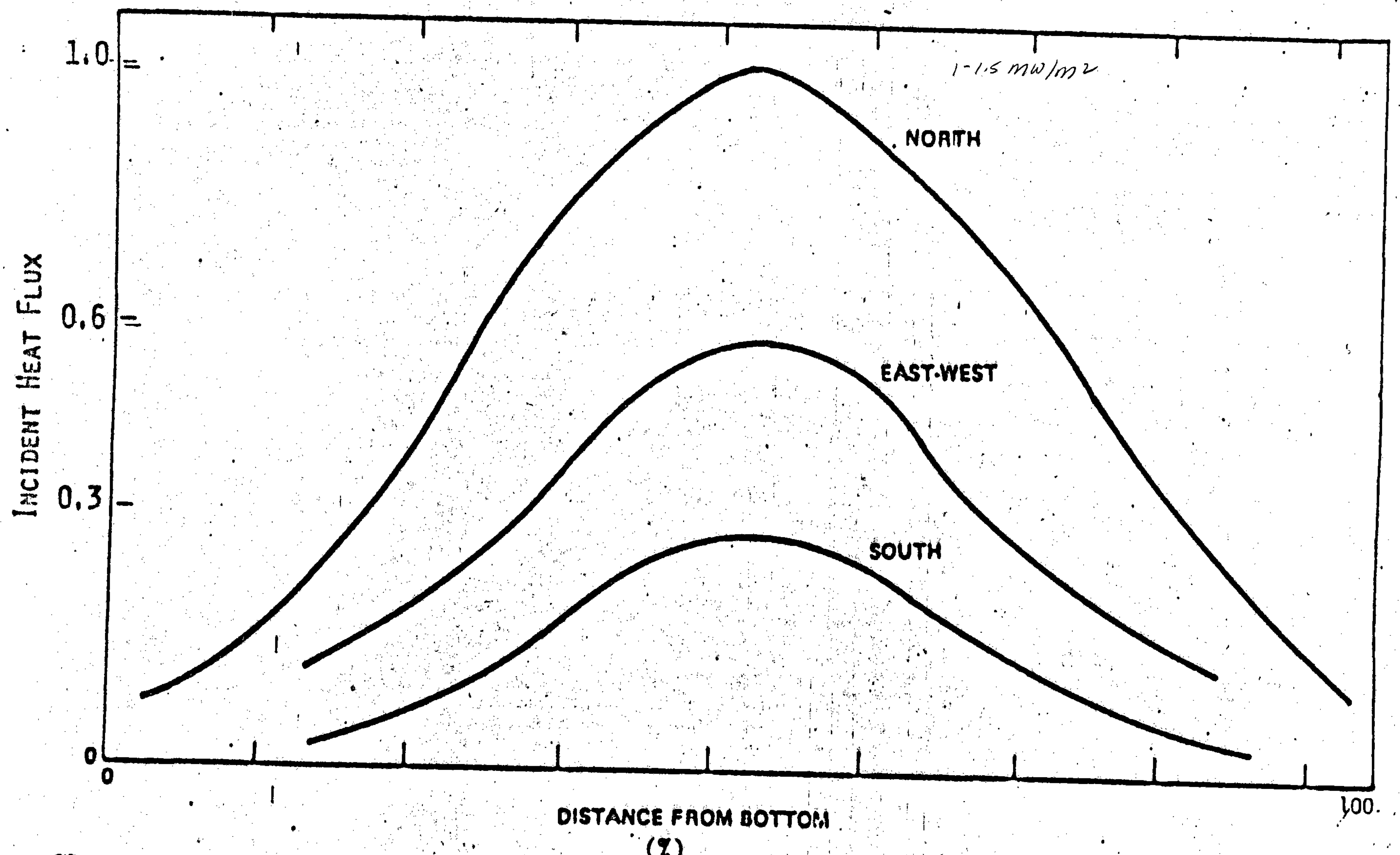
Furnace - Vol % [N_2-69; CO_2-14; H_2O-15; O_2-2; SO_2-0.06]

Fly Ash - .001 #/ft^3

Rockwell International

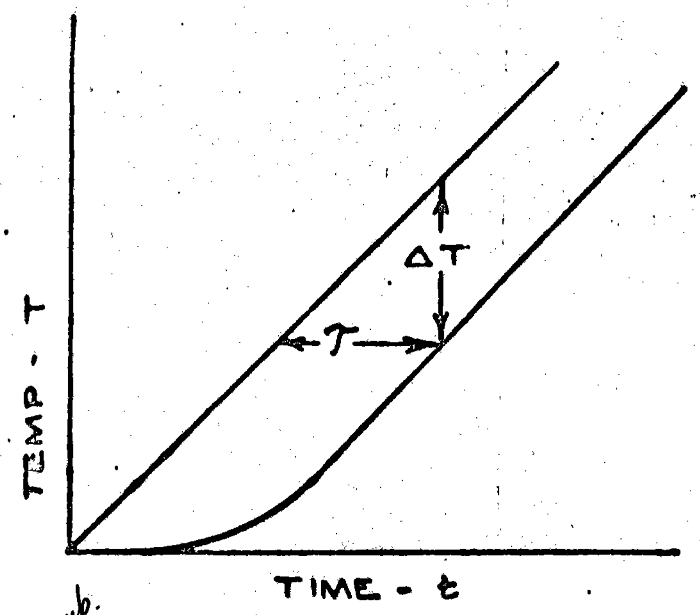
Energy Systems Group

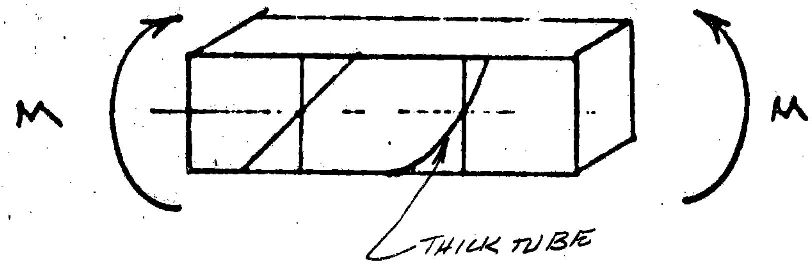
RECEIVER HEAT FLUX PROFILES (EQUINOX NOON)

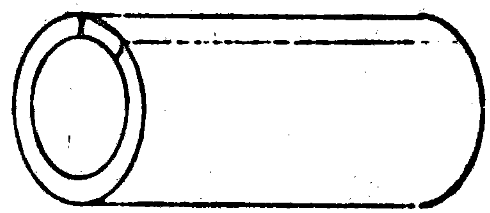


Rockwell International
Atomics International Division

00-103420A







Rule of Thumb.

$$\left|\frac{dT}{dt}\right|_{max} \approx \frac{1}{L^2_{INCH}} \frac{{}^\circ F}{SEC}$$

thickness

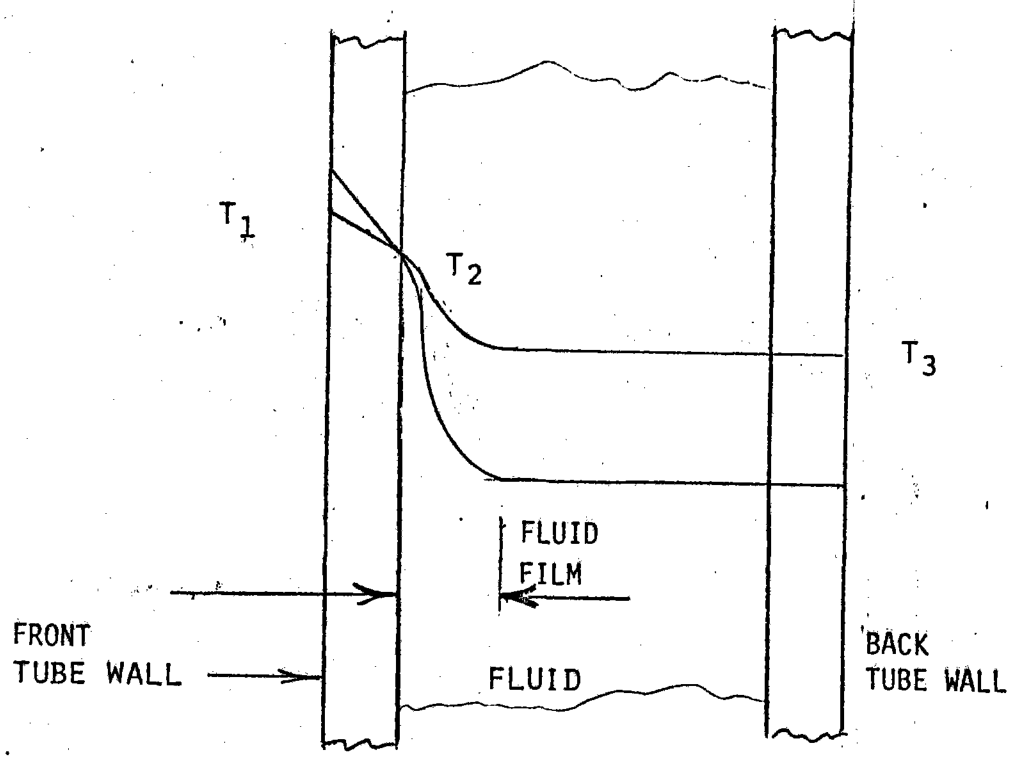
$$S_t = \frac{F_s E \alpha \Delta T}{(1-\mu)}$$

$$F_s = f\left(\frac{1}{B_i} = \frac{K}{h\delta}\right) \quad (0,1)$$

Caused by high thermal conductivity

Sharp
THERMAL TRANSIENT STRESS

RECEIVER TUBE TEMPERATURE PROFILE



CONCLUSION:

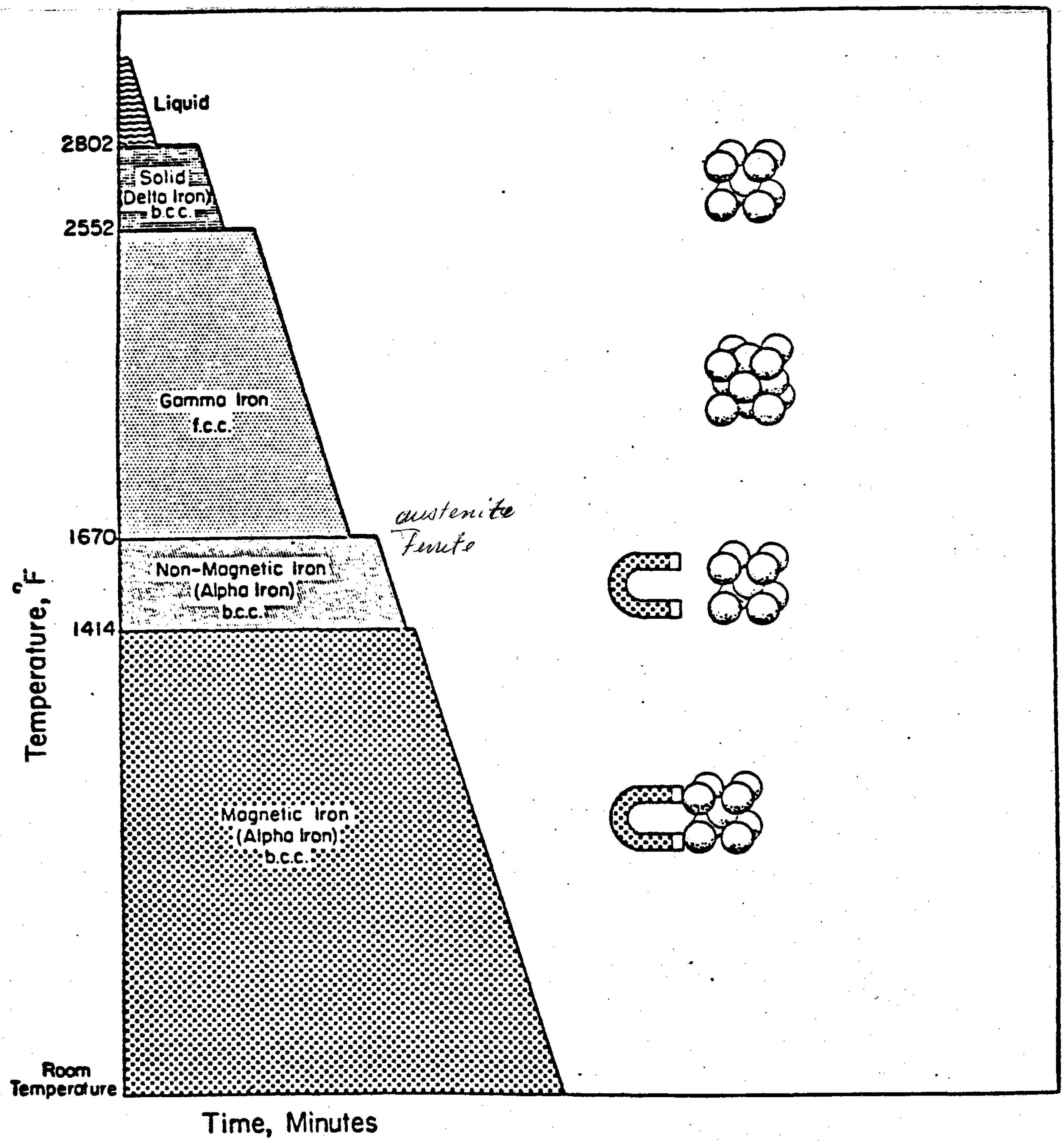
THERE ARE NO ENVIONMENTS WHICH HAVE NOT BEEN ENCOUNTERED PREVIOUSLY.

Rockwell International
Energy Systems Group

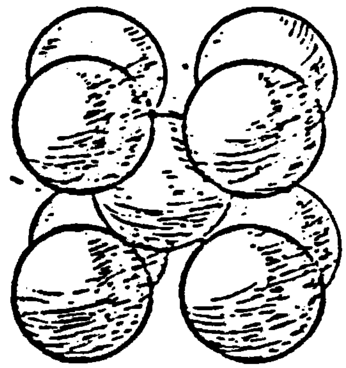
MATERIAL OPTIONS AND CONSIDERATIONS

SECTION III-A

MATERIALS CHARACTERISTICS



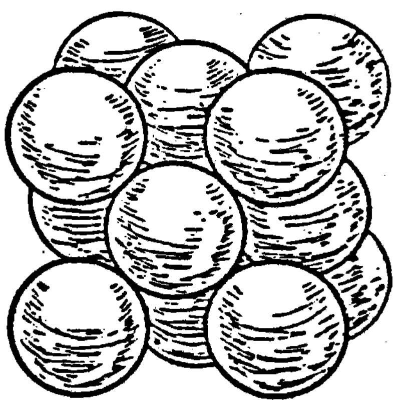
Changes in Pure Iron as it Cools from the Molten State to Room



Ferrite
(α Iron)

Body-Centered Cubic Structure of Alpha Iron

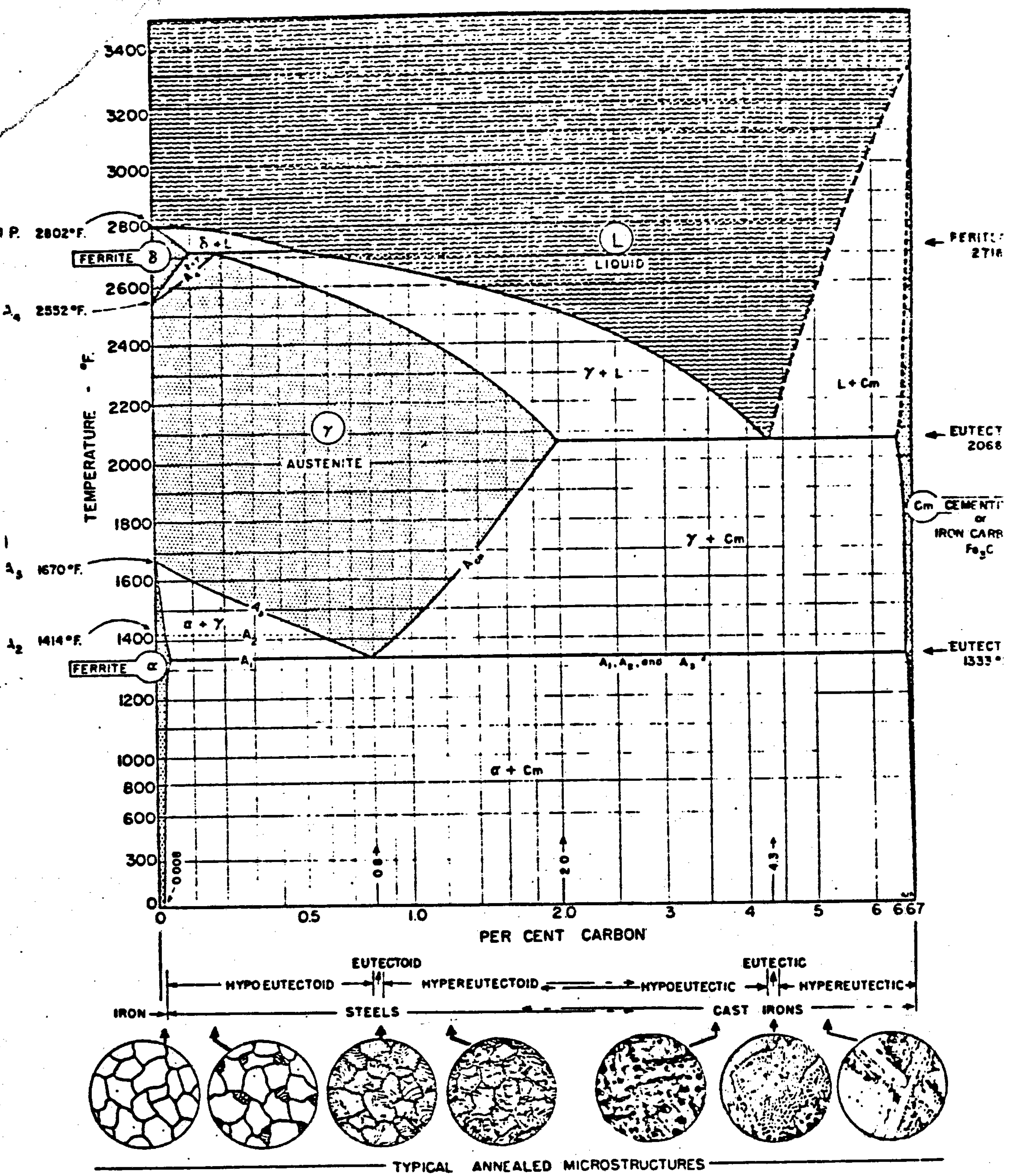
(ASM)



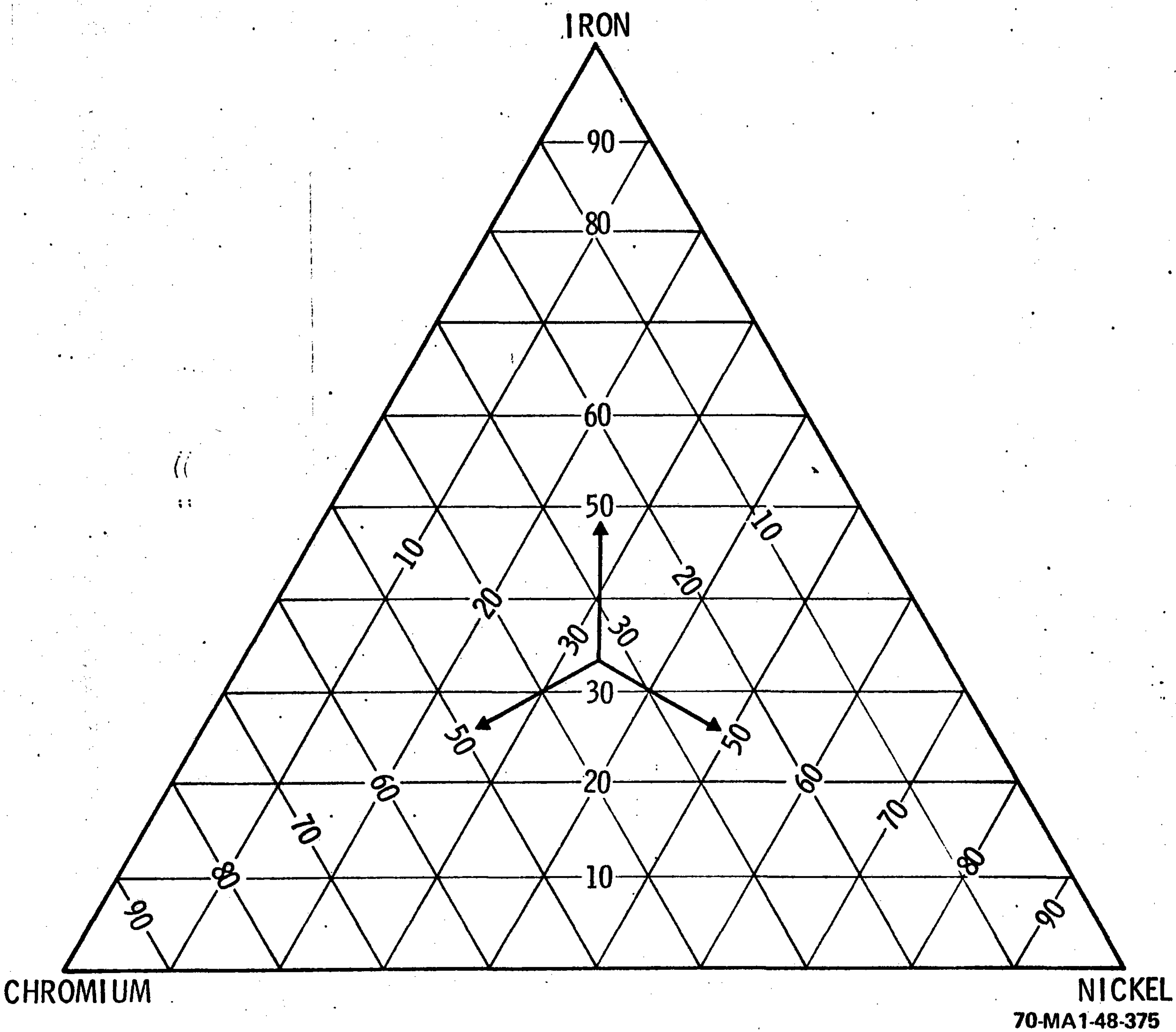
Austenite
(γ Iron)

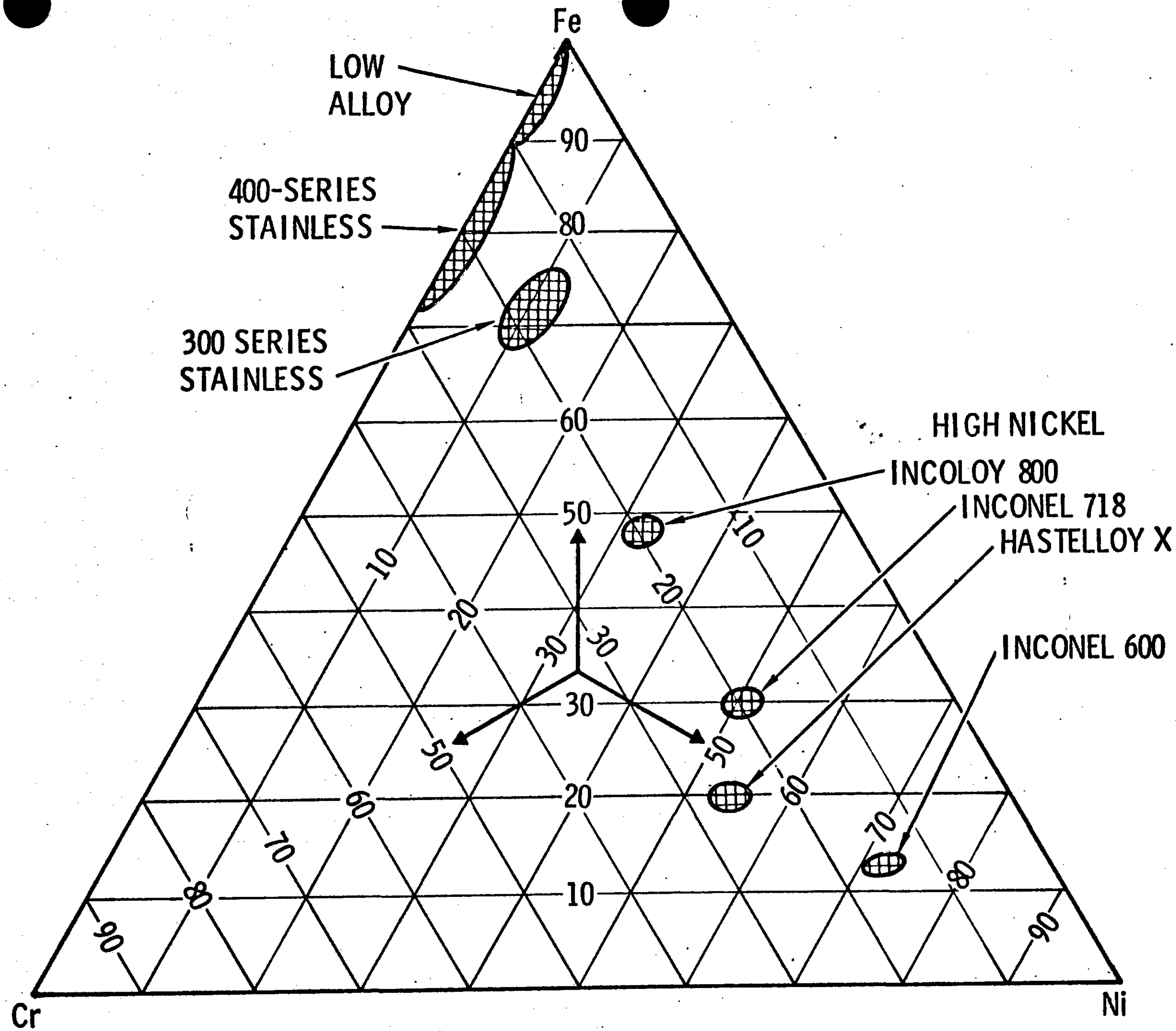
Face-Centered Cubic Structure of Gamma Iron

(ASM)

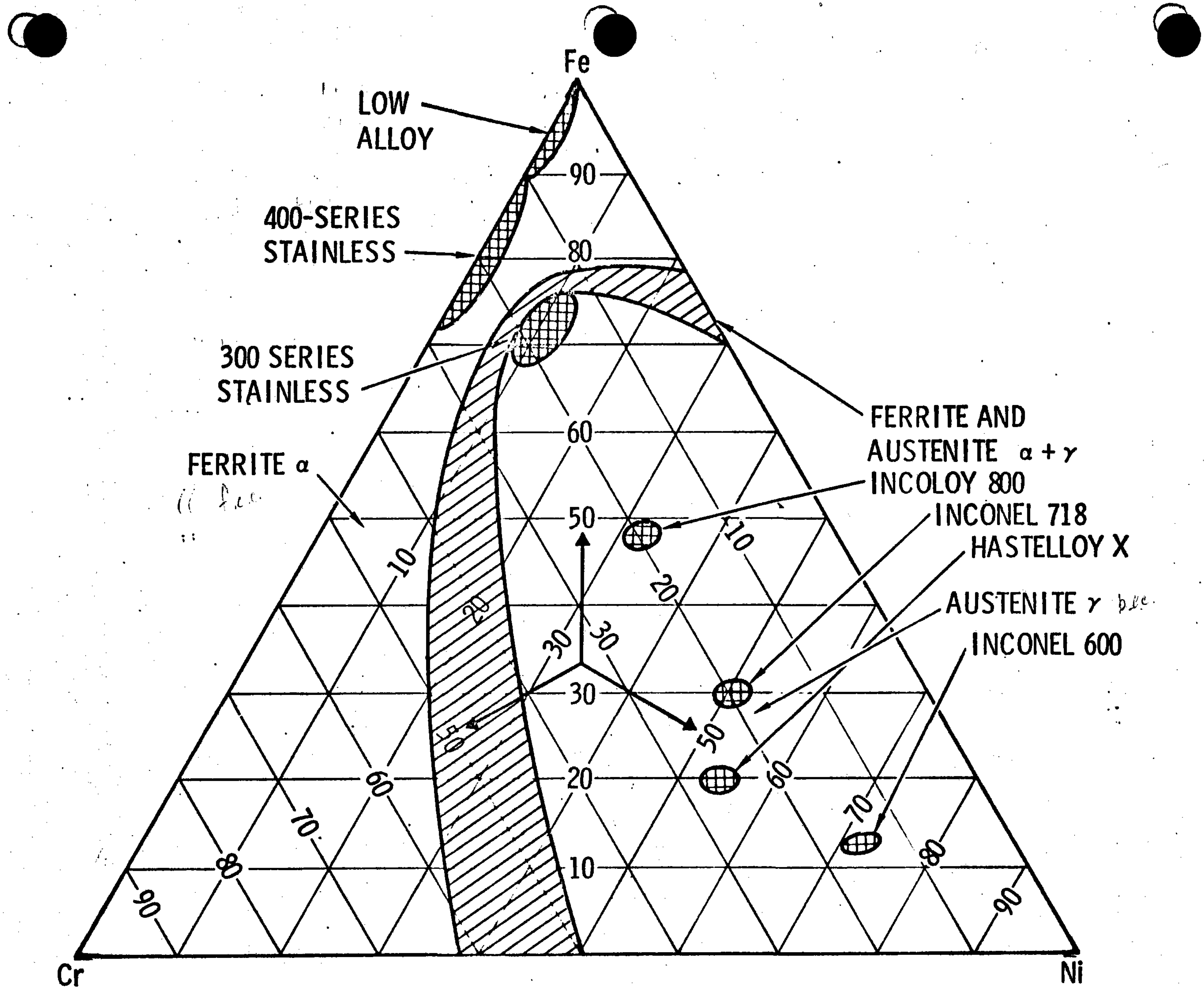


The Iron-Carbon Constitution Diagram
(ASM)


IRON
CHROMIUM
NICKEL
90
80
60
50
30
20
10
10
20
30
50
60
70
80
90
70-MA1-48-375



70-MA1-48-375A



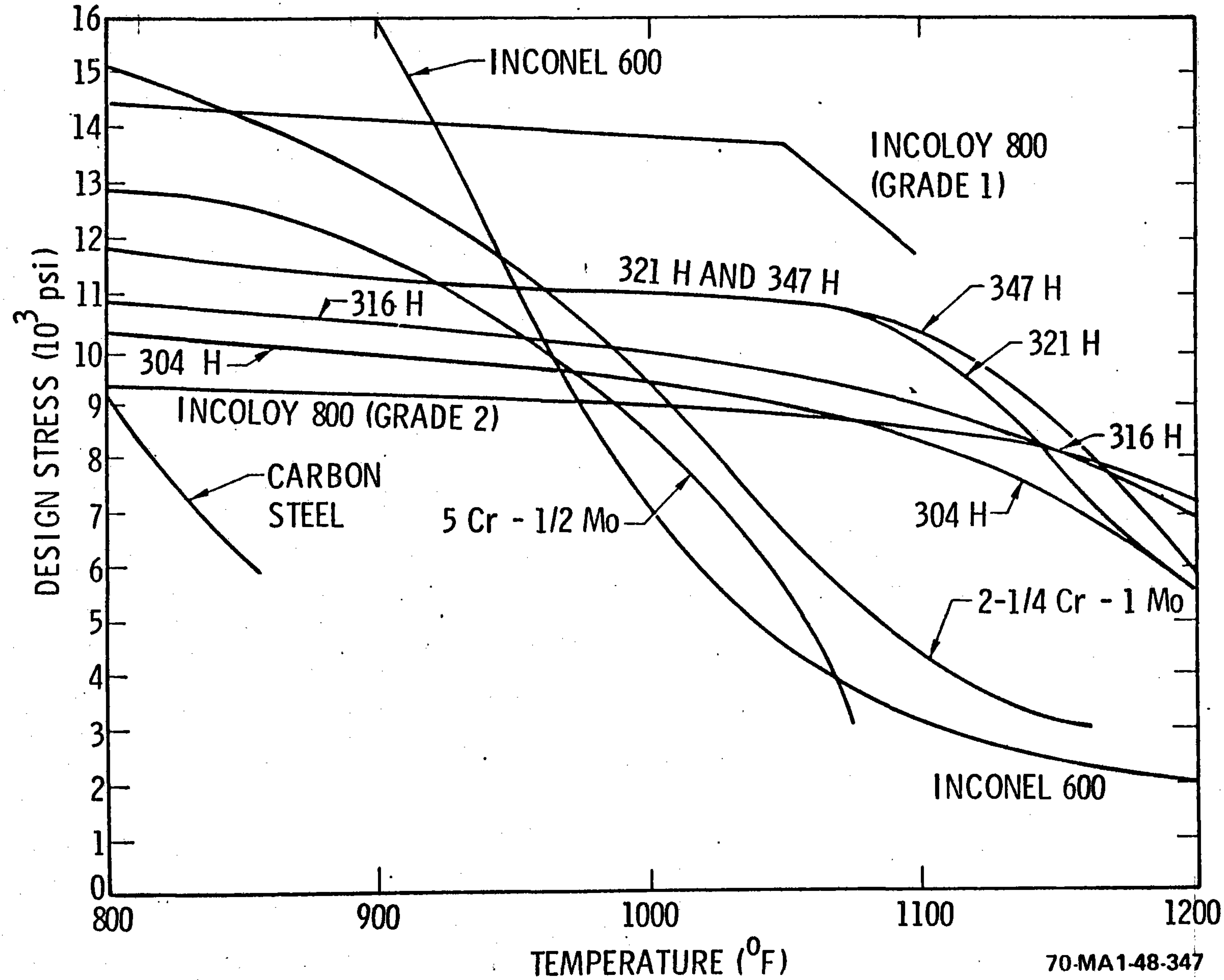
70-MA1-48-375B

NOMINAL COMPOSITION OF STRUCTURAL MATERIALS

MATERIAL	COMPOSITION, WT % (BALANCE Fe)										
	Cr	Ni	Mo	Si	Mn	Ti	Al	Nb	C	S	P
AISI 304	18	9.6	-	0.5	1.1	-	-	-	0.07	0.008	0.03
AISI 316	17	12	2.8	0.5	1.7	-	-	-	0.05	-	-
AISI 321	18	9.5		0.7	1.1	0.4	-	-	0.07	-	-
2-1/4Cr-1Mo	2.2	0.1	0.9	0.4	0.6	-	-	(1.0)	0.14	0.02	0.01
9Cr-1Mo	9	-	1.0	0.7	1.0	-	-	-	0.15	0.03	0.03
ALLOY 800	20	32	0.04	0.3	0.8	0.4	0.4	-	0.06	0.007	0.008
16-8-2	15.5	8.5	1.5	0.5	2.5				0.10	0.03	0.03
ERNiCr-3 (INCONEL 82)	20	67.0 (MIN)	(Fe 3.0)	0.5	3.0	0.75	(Cu 0.5)	2.5	0.10	0.015	0.03

ASME BOILER CODE ALLOWABLES FOR CANDIDATE MATERIALS

SECTION VII, DIV 1



70-MA1-48-347

CARBON STEEL

ADVANTAGES

- VERY LOW COST
- READY AVAILABILITY
- GOOD FABRICABILITY

  (EXCEPT WELD POROSITY) depends upon heat quality
- NO CHLORIDE SCC

  or Chloride/oxygen SCC

DISADVANTAGES

- RUSTS
- CAUSTIC S~~$$~~ CC
- ABOVE 800°F
  - GRAPHITIZES Cementite converts to carbon
  - WEAK
  - OXIDIZES
  - WILL DECARBURIZE IN SODIUM
  - MAY EMBRITTLE AT LOW TEMPS

LOW - ALLOY STEEL
(1 TO 9% CR)

ADVANTAGES	DISADVANTAGES
• LOW COST	• MAY RUST
• STRONG TO 1000°F	• MUST HEAT TREAT WELDS
• OXIDATION OK	• MAY HAVE HIGH NIL-DUCTILITY TEMP
• WON'T GRAPHITIZE	• MAY DECARBURIZE <5%
• NO CHLORIDE SCC	
• MUCH FOSSIL STEAM GENERATION EXPERIENCE	
• MUCH SODIUM STEAM GENERATION EXPERIENCE	
• REASONABLE AVAILABILITY	

75% Cr attract. Carbon.

French: EM-12

5 Cr weaker than 2¼ Chrome

USA, 9 Cr - petrochemical H_2 embrittlement

Modif 9 Cr - 1 Mo + Nb, V. low Si.

CE + ORNL

Strong as SS to 1000°F

Immune to Cl SCC.

Lower Thermal exp.

" " cond.

" not as attractive as stainless for general corrosion

Not Common

except steak knives

"400 - SERIES" STAINLESS
12-14% Cr → 25%
low Ni

(DARK HORSES - historically interstitials caused problems.)
Vacuum melt has helped minimize interstitials.

hard to weld

<u>ADVANTAGES</u>

- DOESN'T RUST
- LOWER COST
- NO CHLORIDE SCC

<u>DISADVANTAGES</u>

- HIGH-TEMP EMBRITTLEMENT
- DIFFICULT TO WELD
- CAUSTIC SCC?
- NO HIGH TEMP EXPERIENCE

"300 - SERIES" STAINLESS

ADVANTAGES

- MODERATE COST
- GOOD STRENGTH
- Very EASILY WELDED
- NO NIL-DUCTILITY
- DOESN'T RUST
- MUCH RESEARCH
- MUCH EXPERIENCE
- REASONABLE AVAILABILITY

DISADVANTAGES (result of temperature time exposure, not Na)

- SENSITIZES
- CAUSTIC SCC
- CHLORIDE SCC

drastically affected by
Pb and Sulfur / form

HIGH NICKEL ALLOYS

ADVANTAGES

- RESISTS CHLORIDE SCC
- NO NIL-DUCTILITY
- RESISTS CAUSTIC SCC

DISADVANTAGES

1-1½ year to obtain plates

- HIGH COST
- LIMITED AVAILABILITY
- WEAKENED BY LEAD AND SULFUR

readily weldable
can mean small turbine
blades, not large sections

WELDABILITY VARIES

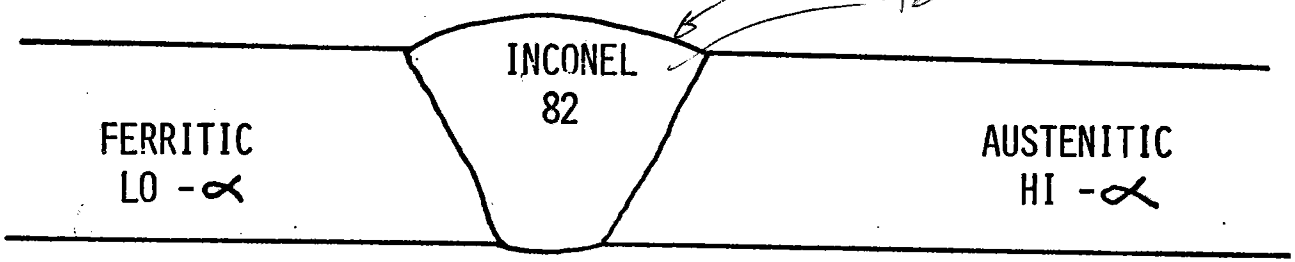
STRENGTH VARIES

TRANSITION JOINTS

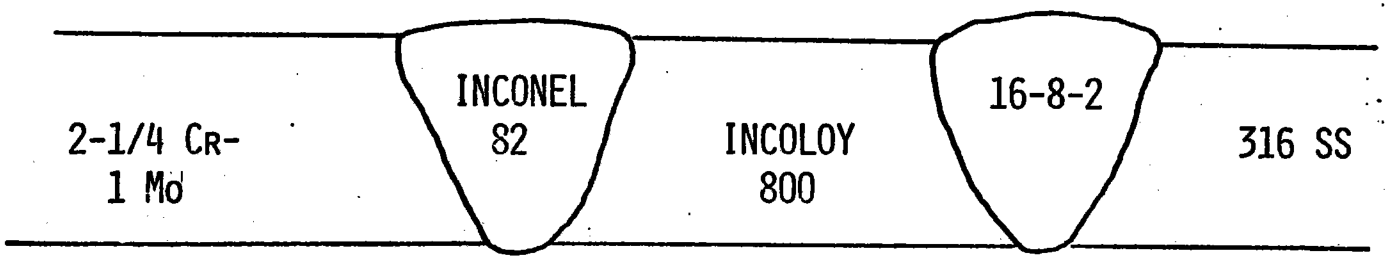
LOW TEMPERATURE (T < 700°F)

formerly INCO "A"

~~former~~ used up to 1000°F.



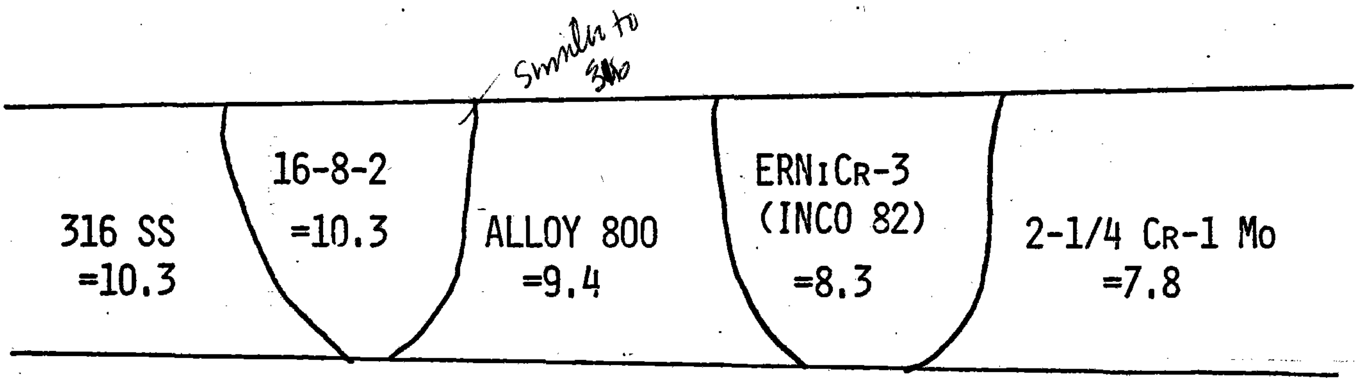
HIGH TEMPERATURE (T > 700°F)



DISSIMILAR METAL WELDS - TRANSITION JOINTS PROGRAM
(316 SS/2-1/4 Cr - 1 Mo)

- CONDUCTED BY DOE AT ORNL
- DESIGN ANALYSIS - GE
- MECHANICAL PROPERTIES - ORNL
- WELD & ISI PROCEDURES - ORNL
- LIFE TESTS - ETEC/ESG

- PROGRAM INCEPTION - 1976
- BUDGET 1.25 M/Yr.
- COMPLETION - LATE 1980
- TRANSITION JOINT SCHEMATIC:

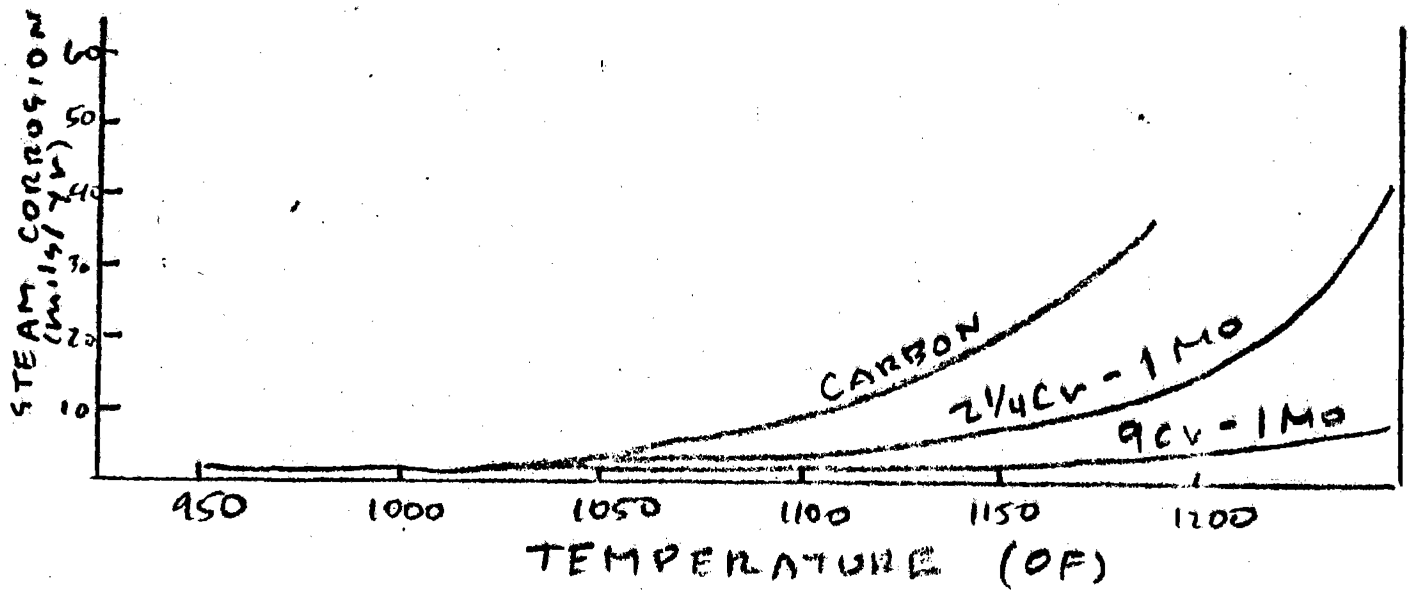


OTHER MATERIALS

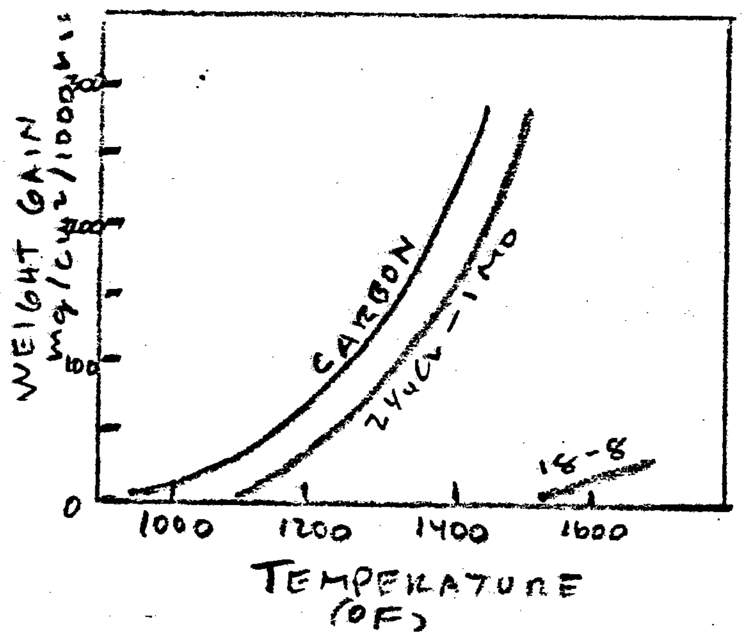
- BRAZING - NI BASE ALLOYS - as an industry can be faulted because have not utilized brazing as much as could
- ANTI GALL & SELF WELD - STELLITES
- SEAL MATERIALS - ELASTOMERS
- INERT GASES - HELIUM, ARGON
- COOLANTS - DOWTHERM, NaK, WATER

SECTION III-B

MATERIALS IN THE ENVIRONMENT

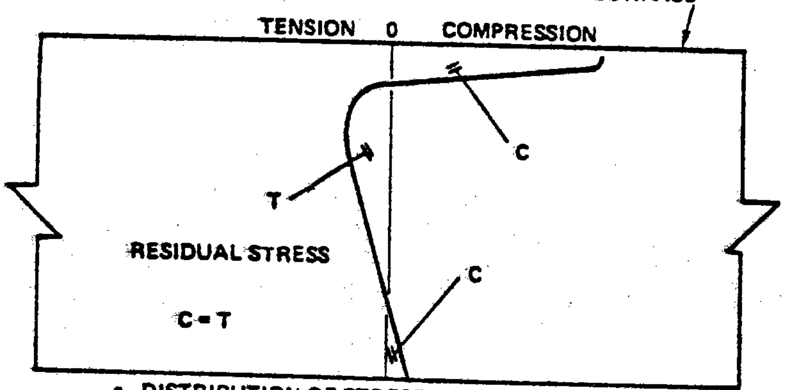


STEAM CORROSION

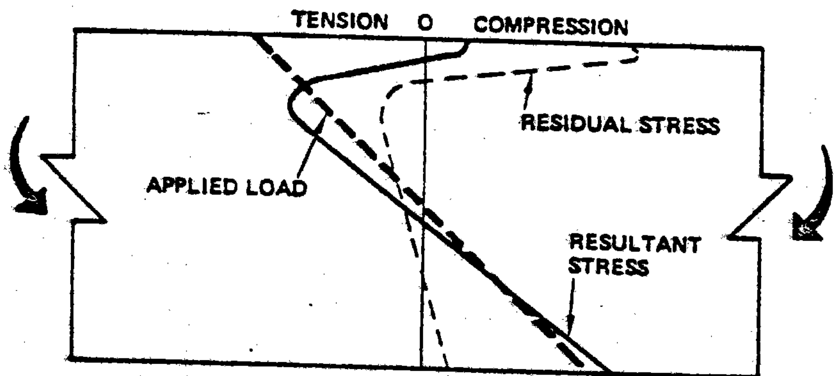


OXIDATION IN AIR

STRESS DISTRIBUTION IN A SHOT PEENED BEAM



a. DISTRIBUTION OF STRESS IN A SHOT-PEENED BEAM WITH NO EXTERNAL LOAD

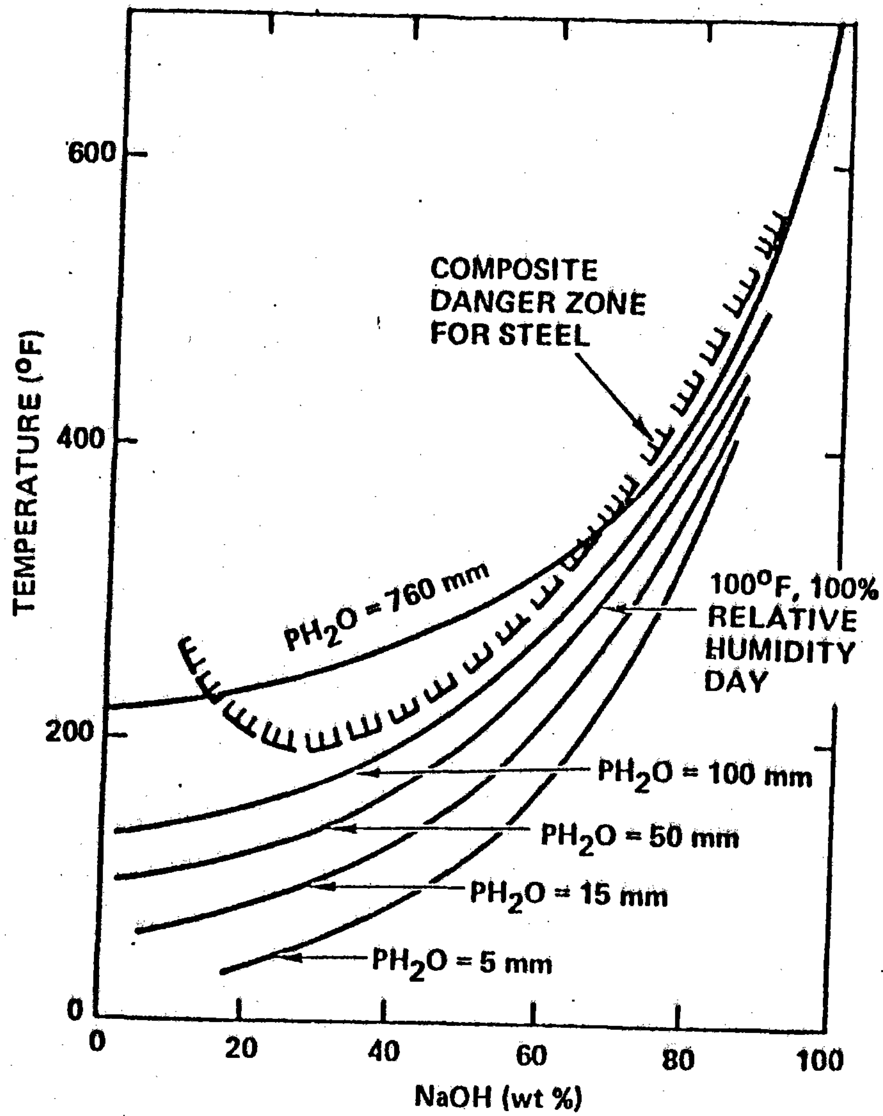


b. RESULTANT DISTRIBUTION OF STRESS IN A SHOT-PEENED BEAM WITH EXTERNAL LOAD APPLIED SOLID LINE IS THE RESULTANT

71-014-59-6

Figure 86a

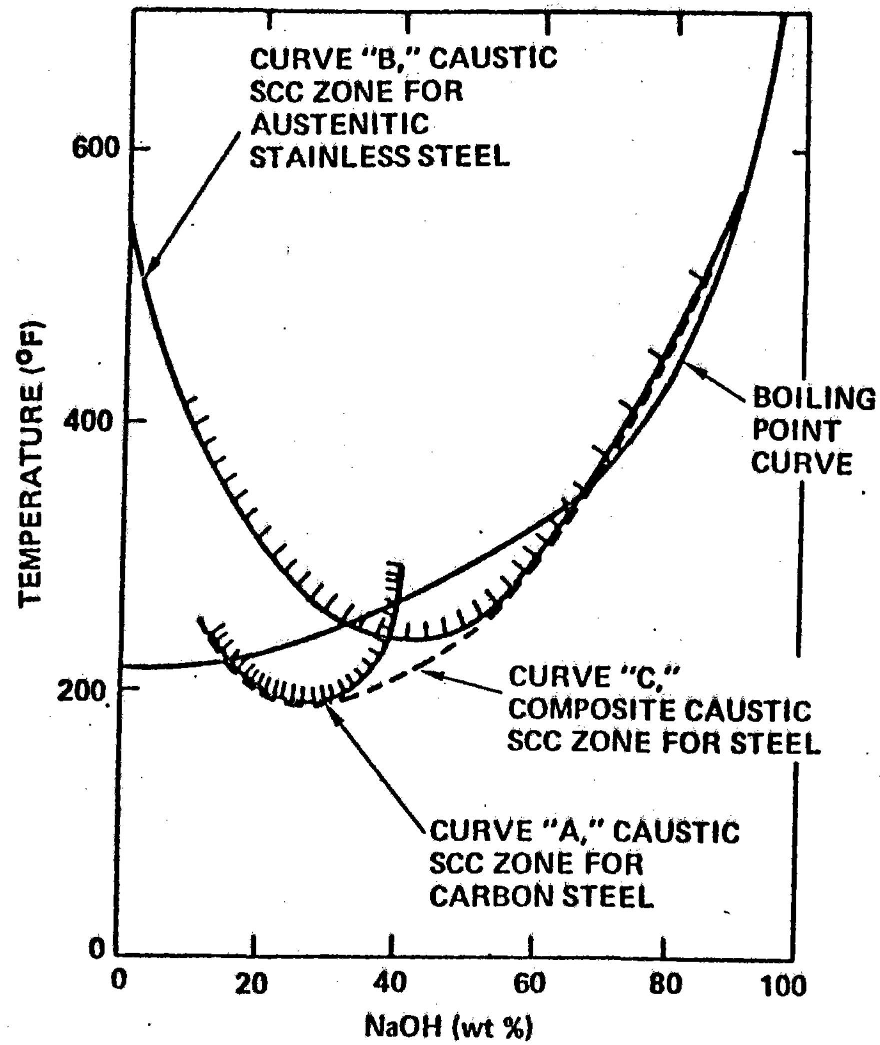
EQUILIBRIUM CONCENTRATION OF NaOH AS A FUNCTION OF TEMPERATURE AND VAPOR PRESSURE OF H_2O



Atomics International Division
Rockwell International

74-A23-28-10

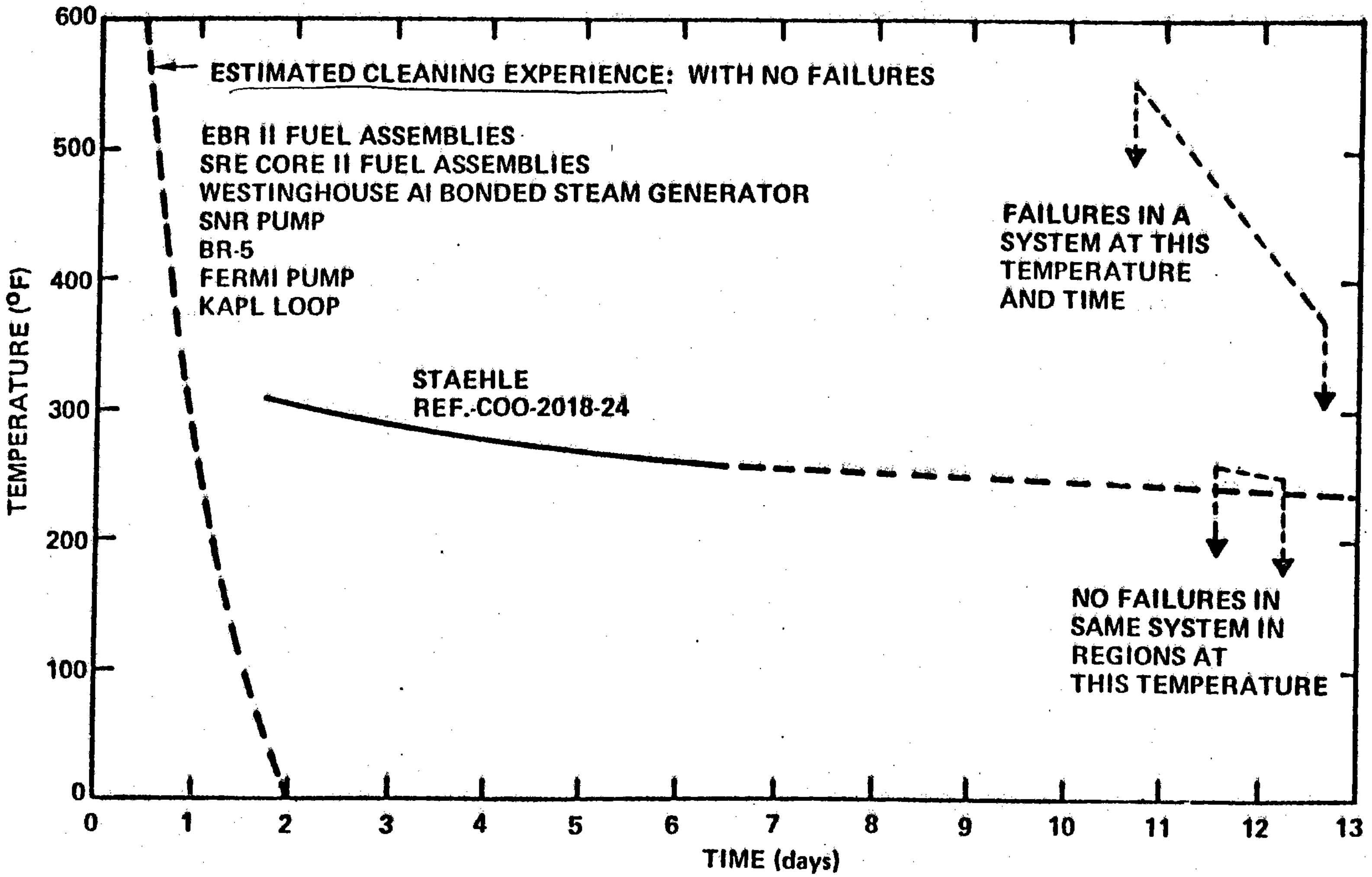
BOUNDARIES OF CAUSTIC SCC DANGER ZONES



Atomics International Division
Rockwell International

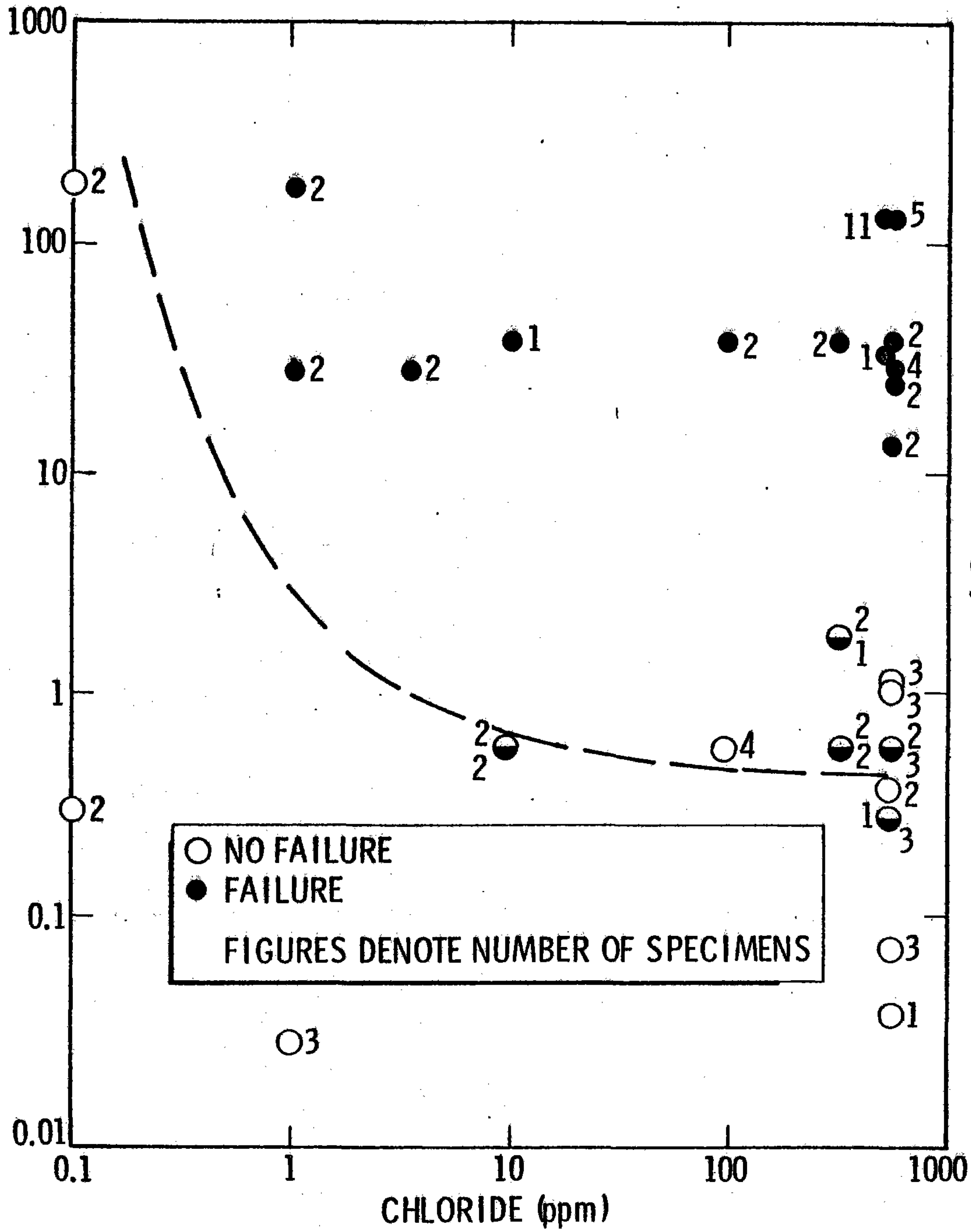
74-A23-28-11

REPORTED CAUSTIC STRESS CORROSION IN 300 SERIES STAINLESS STEELS



Atomics International Division
Rockwell International

74-A23-28-9

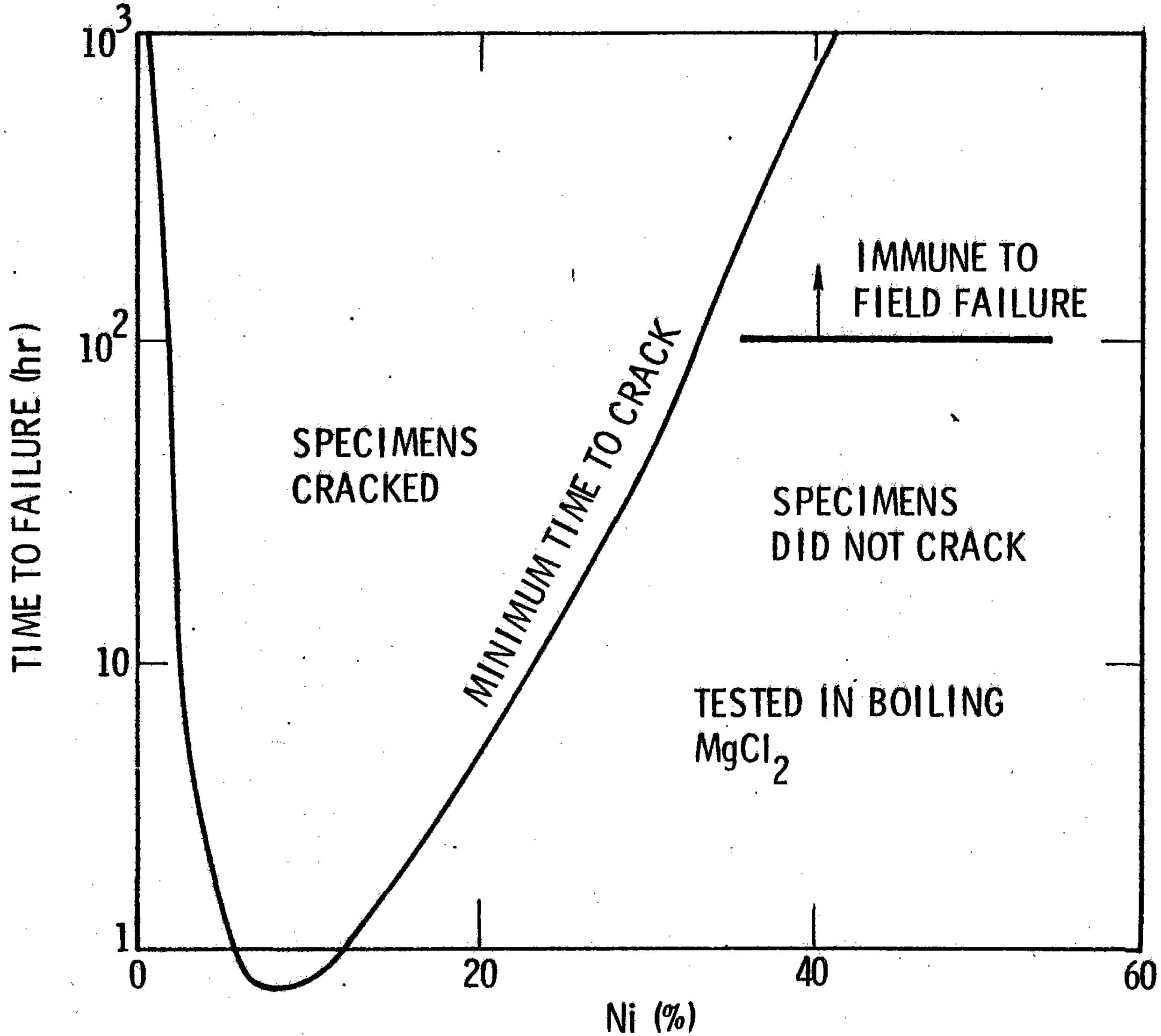


V-A-86

SYNERGISTIC EFFECT OF CHLORIDE & OXYGEN ON STRESS CORROSION CRACKING OF STAINLESS STEEL

70-MA1-48-344

Ni ALLOY STRESS CORROSION

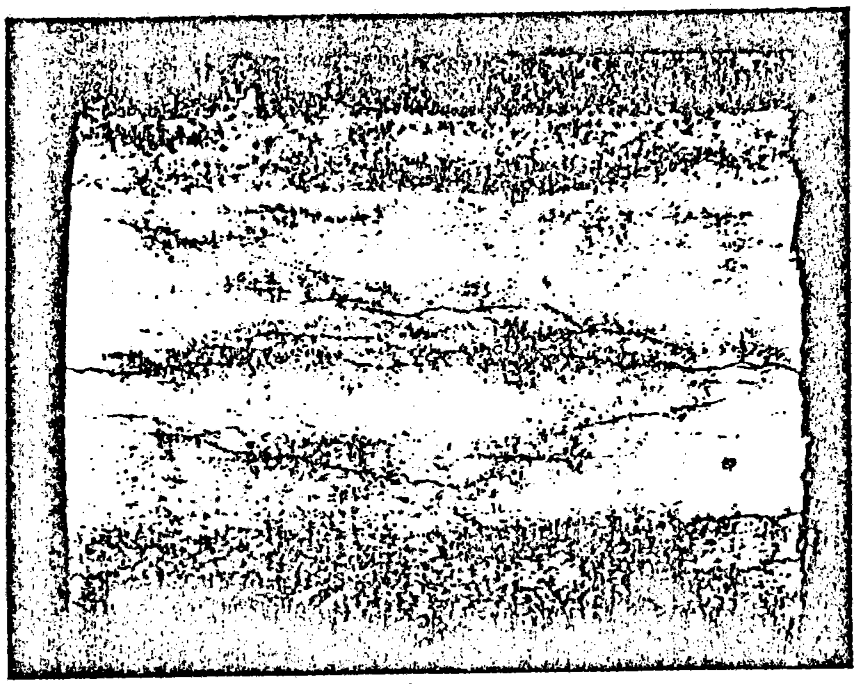


— Incoloy 800 Ni comp. selected for resistance to SCC.

If you had to pick an alloy best fr. SCC. pick 8% Ni like 304 316

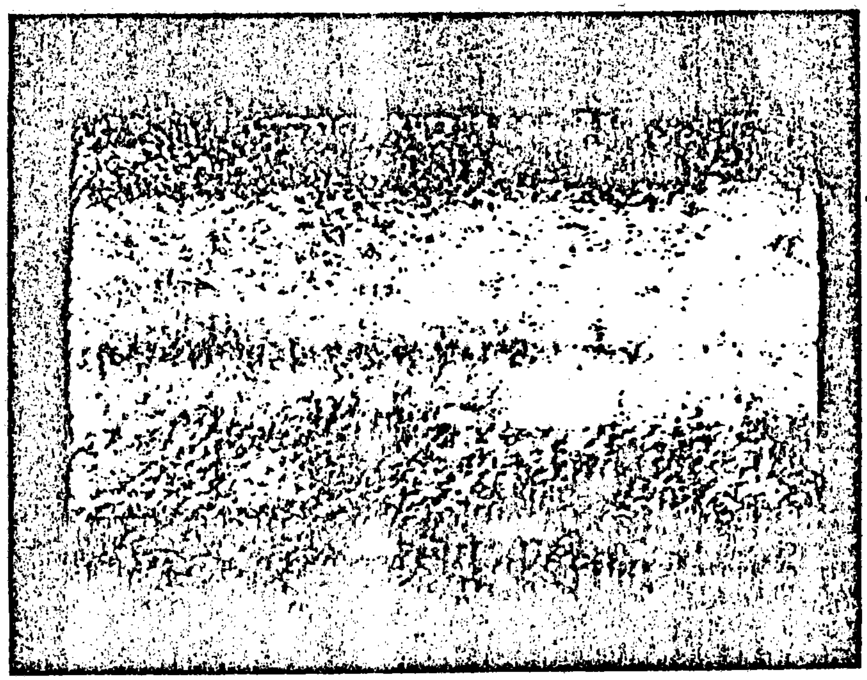
70-MA1-48-346

PEENED TYPE 304 SS AFTER STRESS CORROSION TESTS



8X

UNPEENED



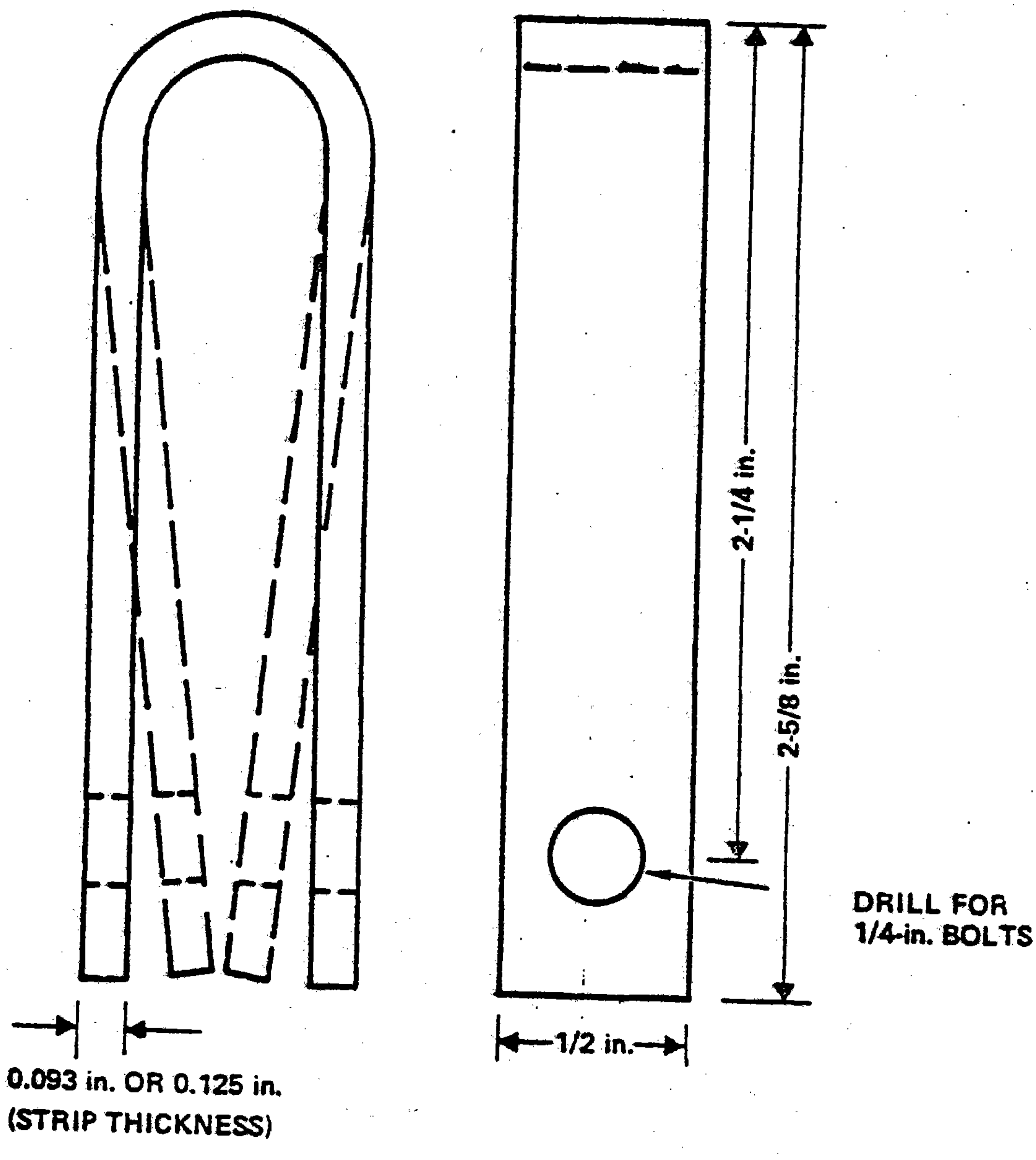
8X

SHOT-PEENED

Figure 86c

Boiling MgCl2 Sol'n

STRESS CORROSION TEST
U-BEND SPECIMEN



71-014-59-8

Figure 86b

STRESS CORROSION

9-N7-129-27

SENSITIZATION

SENSITIZATION

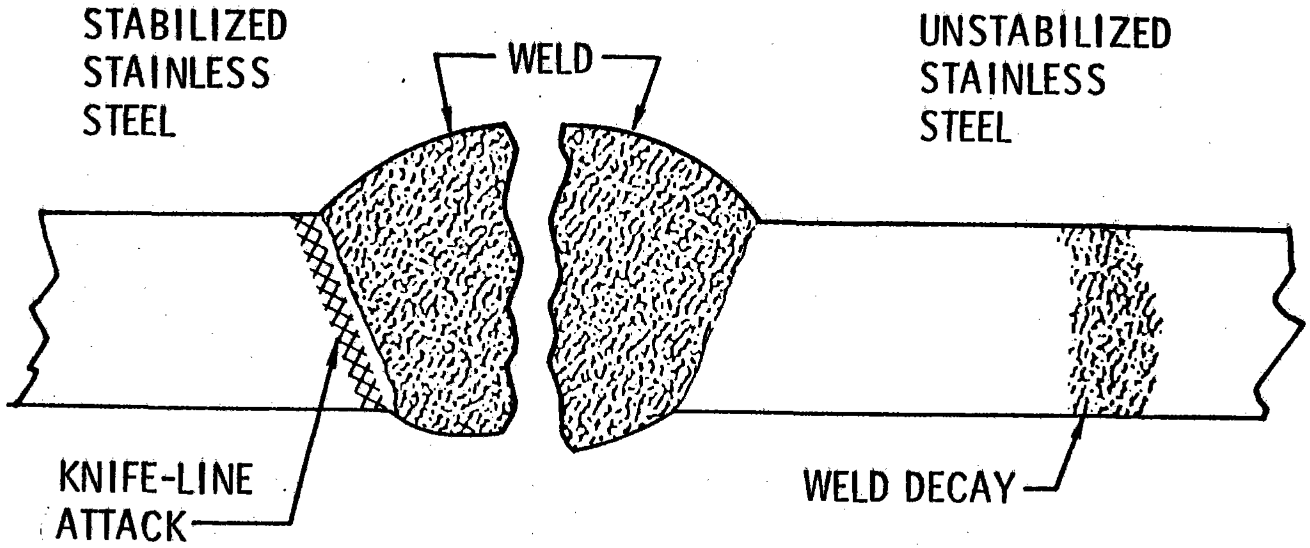
- HAS NO EFFECT ON STRENGTH
- HAS NEGLIGIBLE EFFECT ON DUCTILITY
- HAS MINOR EFFECT ON IMPACT STRENGTH AT LOW TEMPERATURES
- HAS NO EFFECT ON OXIDATION RESISTANCE
- HAS NO EFFECT ON SODIUM COMPATIBILITY

9-N7-129-26

TO RESIST SENSITIZATION:

- OPERATE ABOVE 1200°F
- SOLUTION ANNEAL AND OPERATE BELOW 800°F
- REDUCE CARBON (e.g. 304L) — LOSE STRENGTH
- ADD STRONG CARBIDE-FORMERS SUCH AS Ti(321) OR Cb(347) —
    - LESS WELDABLE
    - SUBJECT TO KNIFE-LINE ATTACK
    - WILL SENSITIZE EVENTUALLY

9-N7-129-24



NARROW REGION
(2000 to 2600^{0}F)

Nb, Ti CARBIDES
DISSOLVED; DID
NOT PRECIPITATE
ON REHEATING

WIDER REGION
(900 to 1400^{0}F)

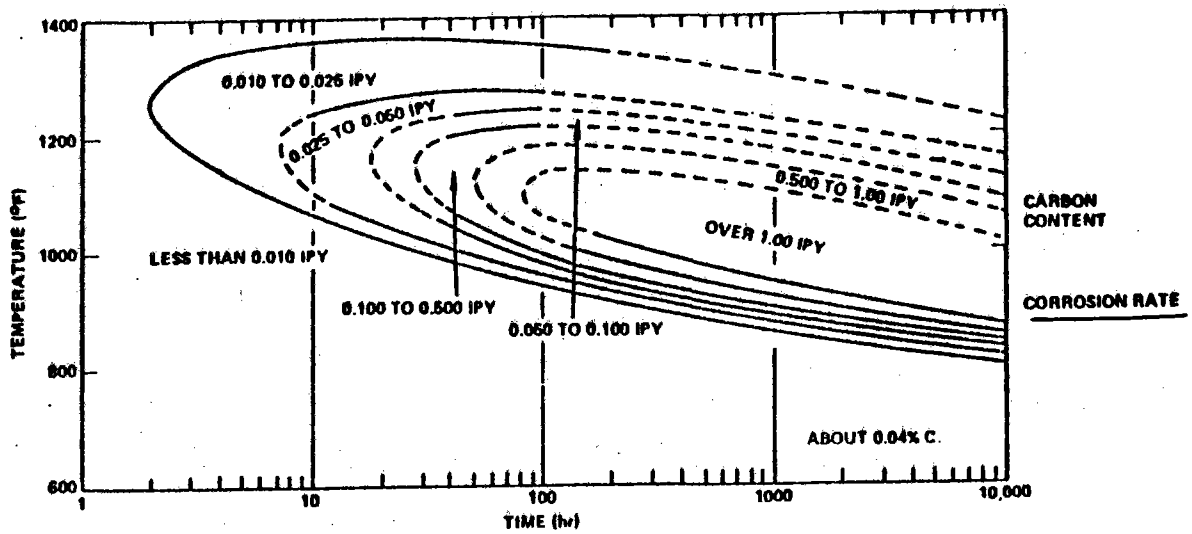
CHROMIUM CARBIDE
PRECIPITATES:

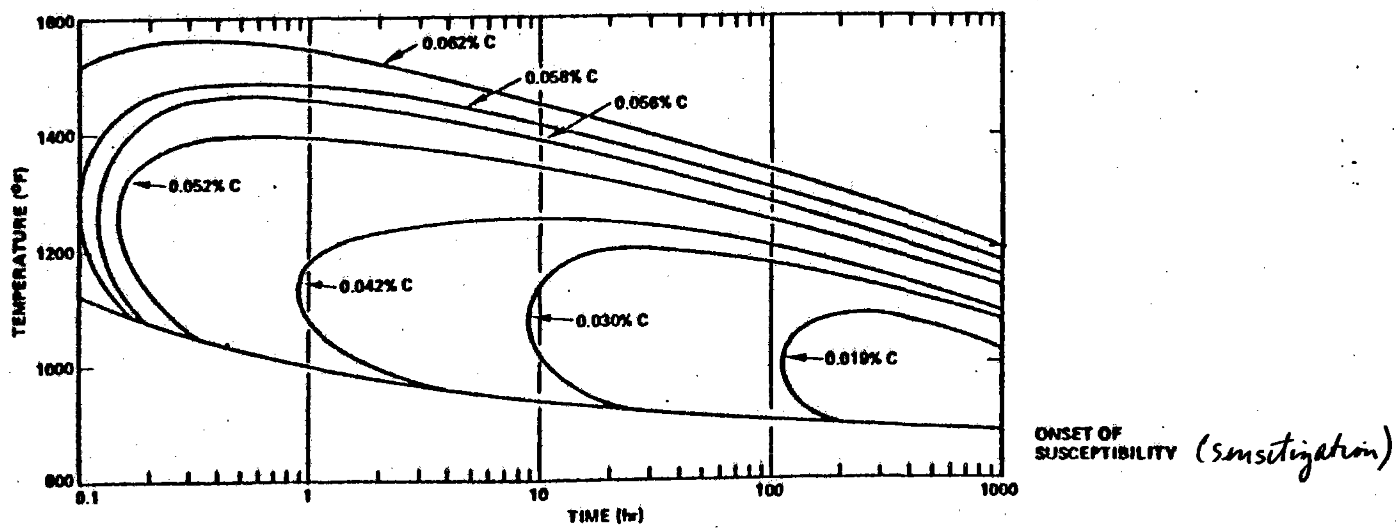
STEEL IS SENSITIZED

70-MA1-48-359

Mo provides pitting resistance
stabilization doesn't help much if operate in water at hi T.

TIME-TEMPERATURE-SENSITIZATION DIAGRAMS FOR AUSTENITIC STAINLESS STEEL





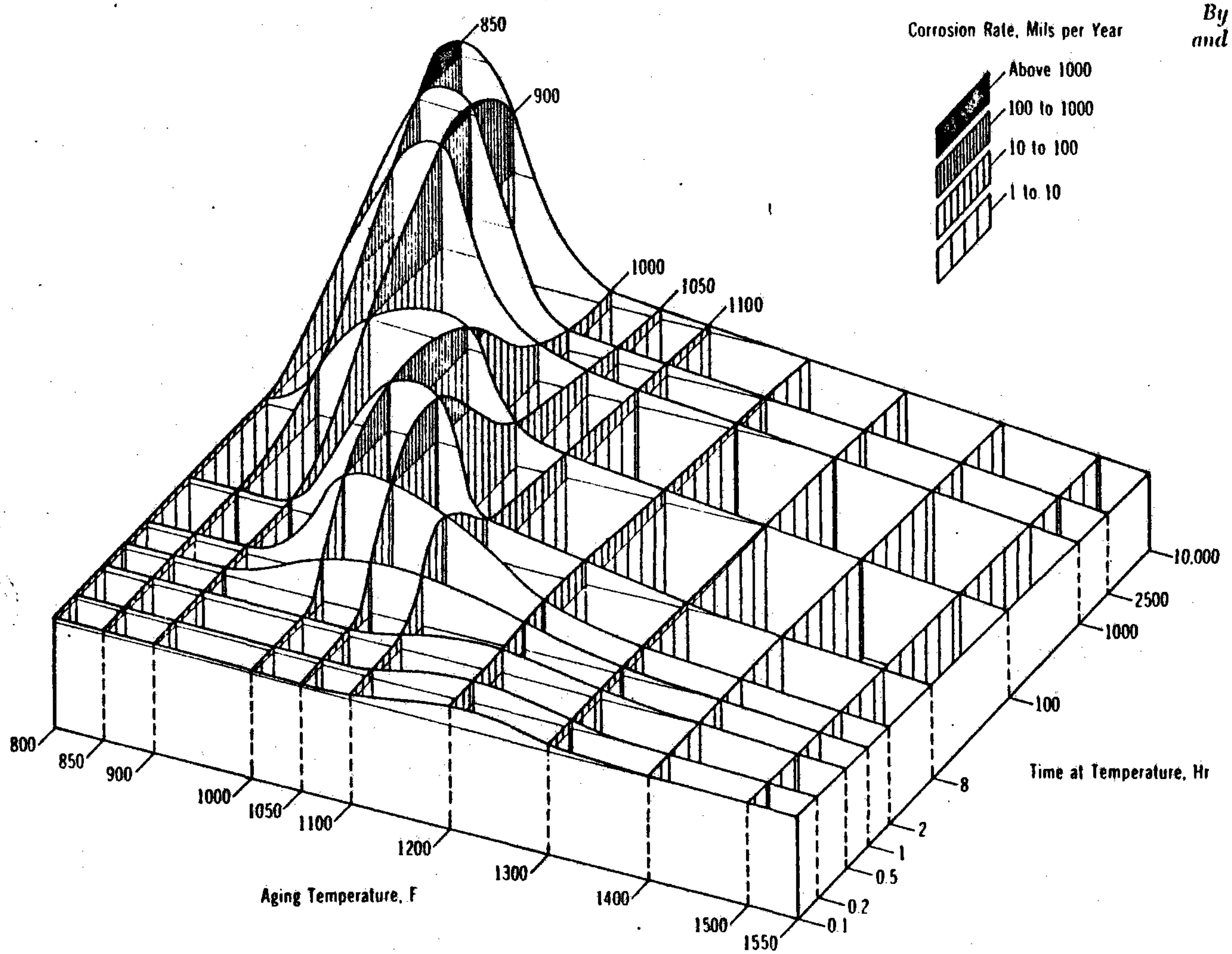
70(724)48-374A

low-C steels thus used
bec. can weld on Fab.

347 SS.

How Sensitization Affects the Corrosion of Stainless Weld Metal

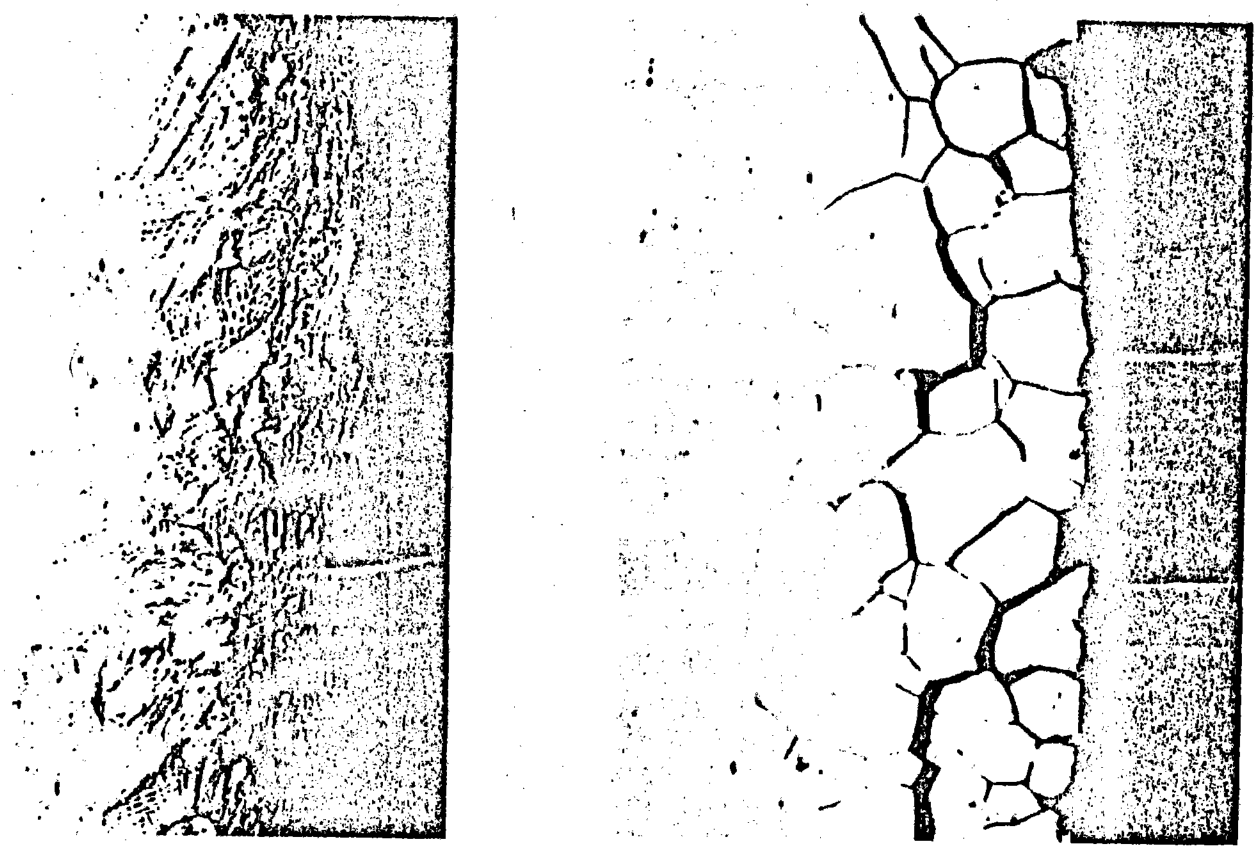
By RUSSELL B. GUNIA
and THOMAS J. MOORE*



This three-dimensional drawing illustrates the time-temperature-sensitization relationship for 18-8 weld metal (0.036% C) which was aged in the as-welded condition before being corrosion tested in boiling nitric acid. (The vertical scale is logarithmic with the same base as the time scale.)

*Mr. Gunia is manager, stainless steel metallurgy, United States Steel Corp., Pittsburgh, and Mr. Moore is assistant director of research, Arcos Corp., Philadelphia.

PEENED AND UNPEENED TYPE 304 SS AFTER SENSITIZING (1 hr AT 1200°F), AND TESTING FOR INTERGRANULAR CORROSION IN HNO_3-HF



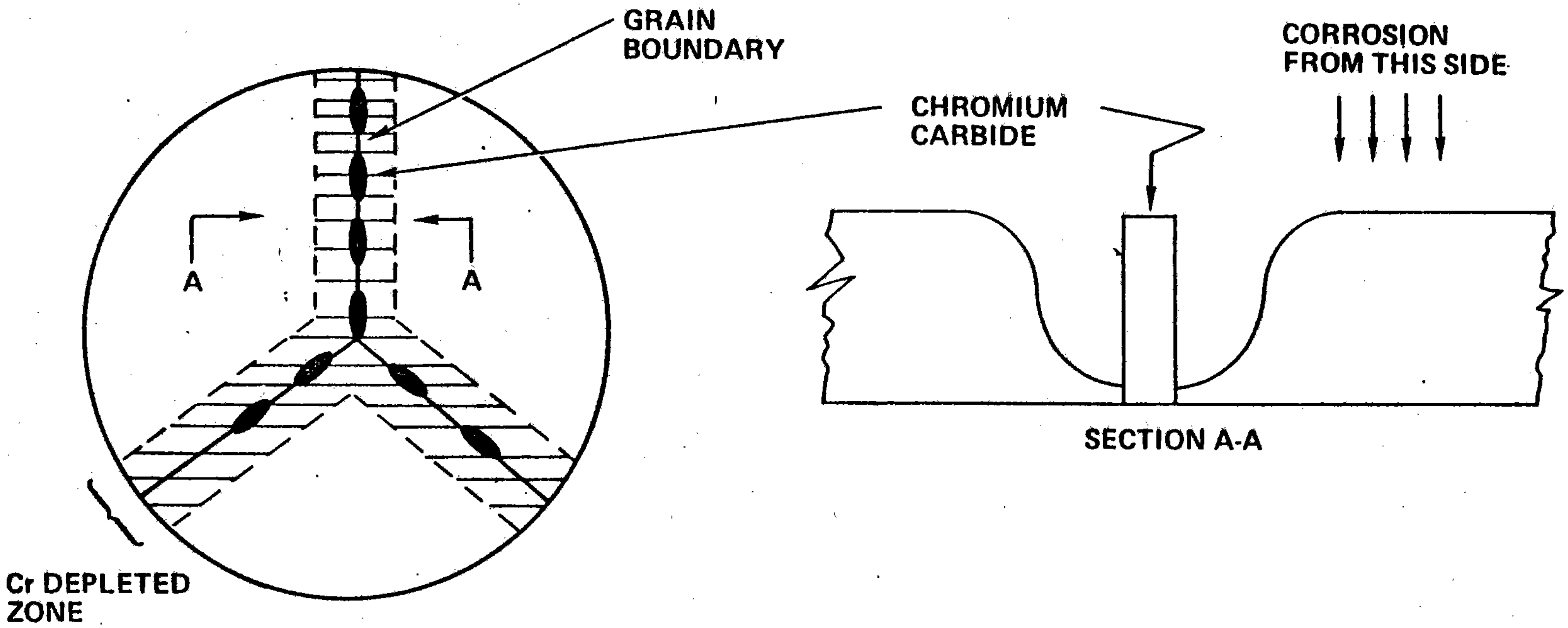
a. Peened

b. Unpeened

41000-1274

NOTE INTERGRANULAR ATTACK IN UNPEENED SURFACE AND ABSENCE OF CORROSION IN THE COLD WORKED SURFACE OF THE PEENED SECTION (250X)

SENSITIZATION



9-N7-129-22

SENSITIZATION

SECTION III-C

MATERIALS AND SODIUM

SODIUM "CORROSION" EFFECTS

A. SOLUTION MASS TRANSFER

AKA TEMPERATURE GRADIENT MASS TRANSFER

- ESSENTIALLY INSIGNIFICANT IN NON-RADIOACTIVE SYSTEMS

B. INTERSTITIAL MASS TRANSFER

AKA DISSIMILAR METAL MASS TRANSFER

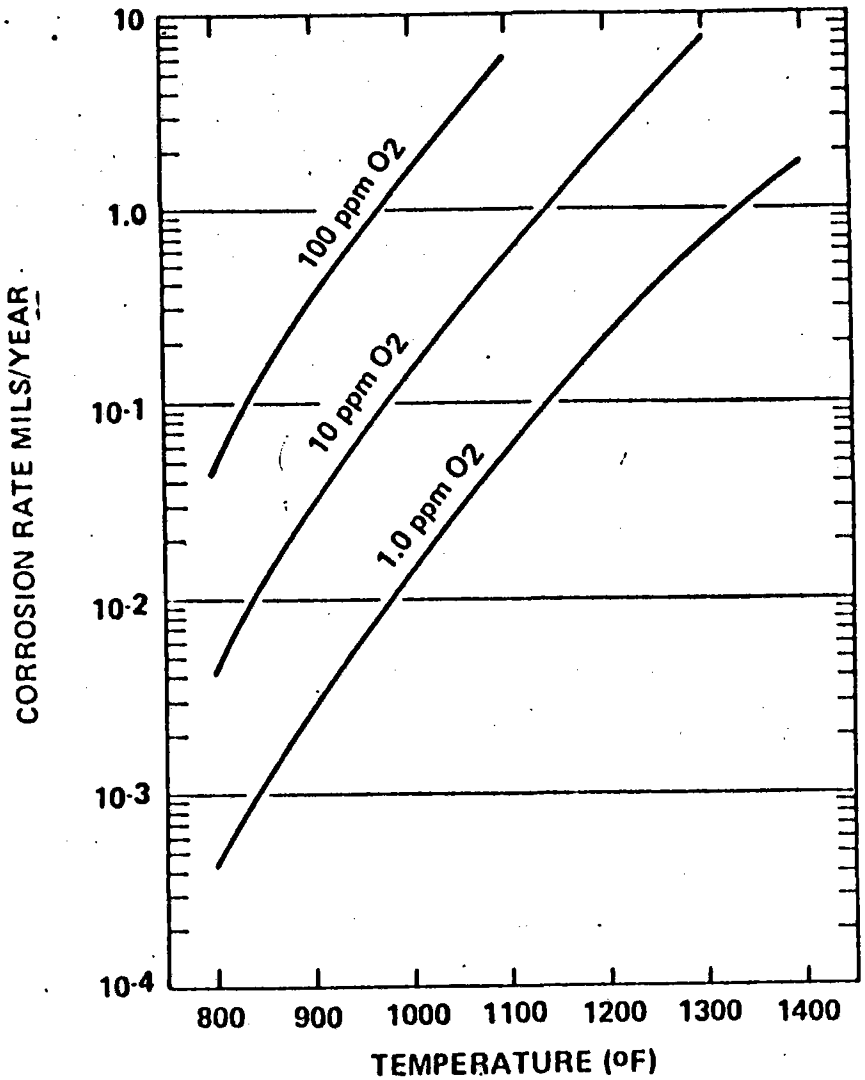
AKA CARBON TRANSFER

- ESSENTIALLY INSIGNIFICANT BELOW 700^{O}F
- PREDICTABLE ABOVE 700^{O}F

C. DISSOLUTION OF EXPOSED INCLUSIONS

- EASILY AVOIDED BY GRAIN FLOW CONTROL OR PURE METALS

CORROSION OF 316 STAINLESS STEEL BY FLOWING SODIUM



NOTES

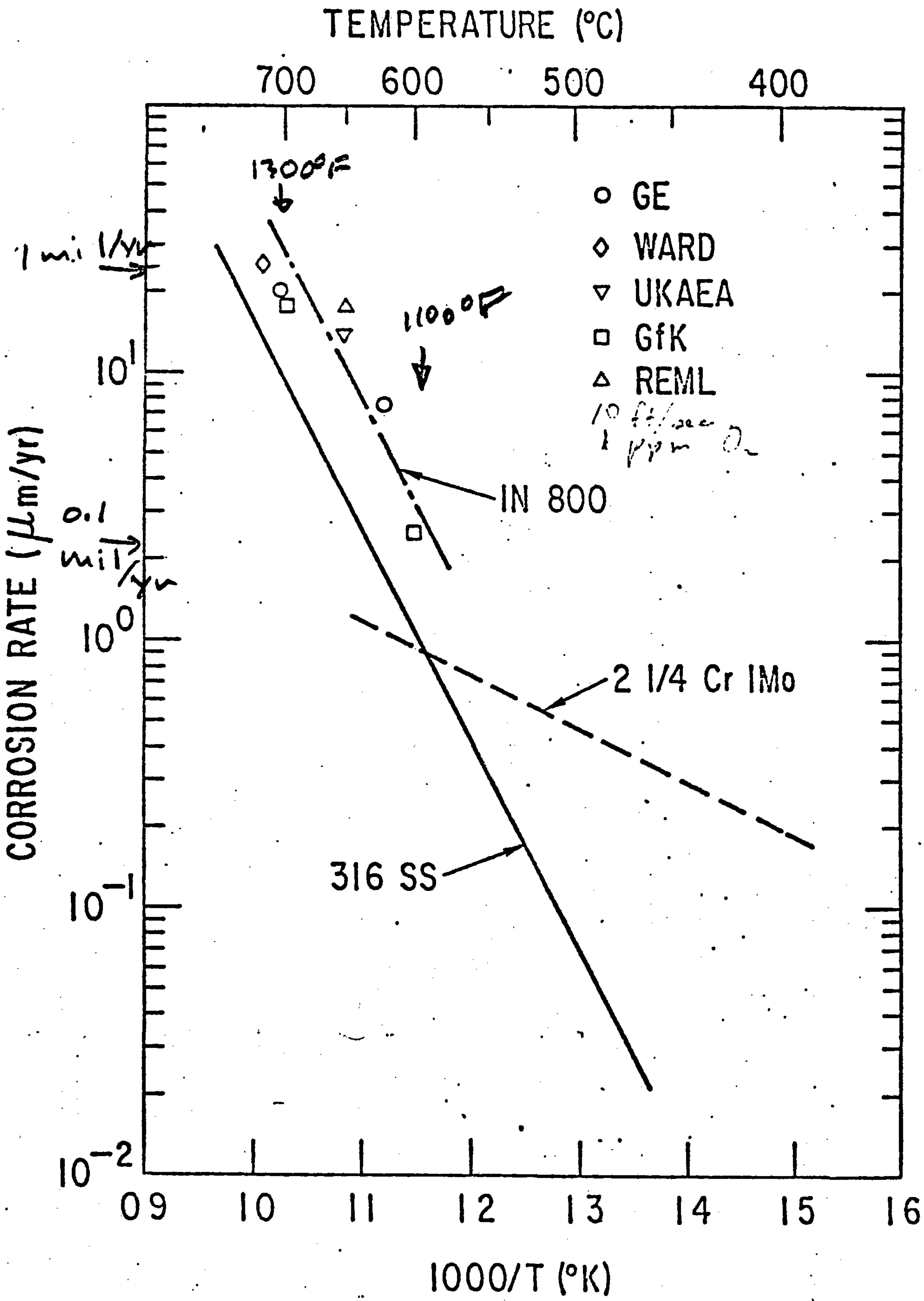
1) FOR SODIUM VELOCITY >10 ft/s, LOWER CORROSION AT LOWER FLOW
2) OXYGEN ANALYZED BY VANADIUM WIRE; USUALLY 1/10 OF RESULTS BY OTHER METHODS
3) MULTIPLY BY 2 FOR HIGH $dT/d\ell$ (i.e. CORE)

REFERENCE: <u>NUCLEAR SYSTEMS MATERIALS HANDBOOK</u>

Rockwell International

Atomics International Division

76-S29-66-24



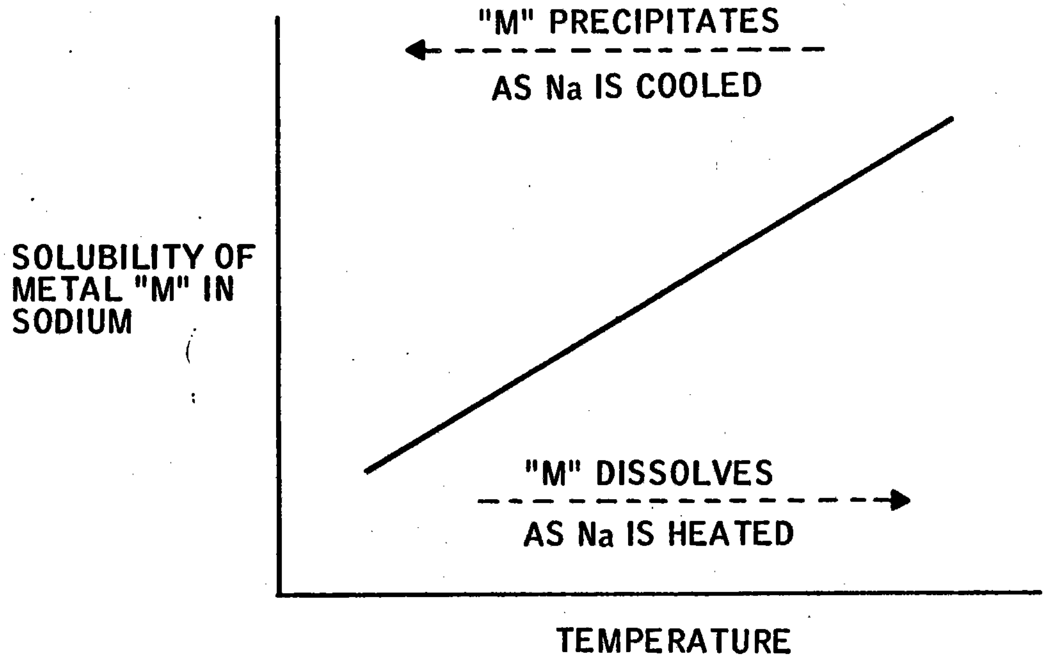
TEMPERATURE (°C)
700
600
500
400
1300°F
1100°F
1 mil 1/yr
0.1 mil/yr
GE
WARD
UKAEA
GfK
REML
10 ft/sec
1 ppm O2
IN 800
2 1/4 Cr IMo
316 SS
CORROSION RATE (μm/yr)
10^1
10^0
10^-1
10^-2
09
10
11
12
13
14
15
16
1000/T (°K)

ALL COMMERCIAL ALLOYS
USED IN HIGH-TEMPERATURE
STRUCTURAL APPLICATIONS:

(IRON-CHROMIUM
AND
IRON-NICKEL-CHROMIUM)

ARE COMPATIBLE WITH SODIUM

EFFECT OF TEMPERATURE ON SOLUBILITY

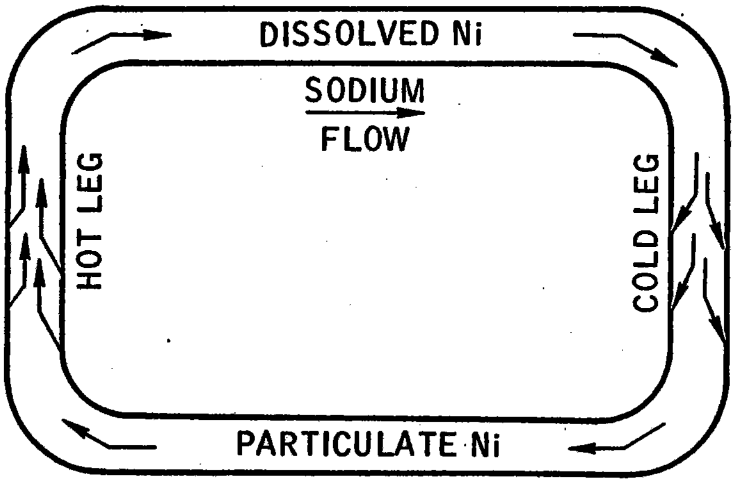


9-010-116-21

SOLUBILITY - GRADIENT MASS TRANSFER

CASE "A" - TRANSFER OF ELEMENT - (e.g. Ni)

NICKEL DIFFUSES TO SURFACE AND DISSOLVES



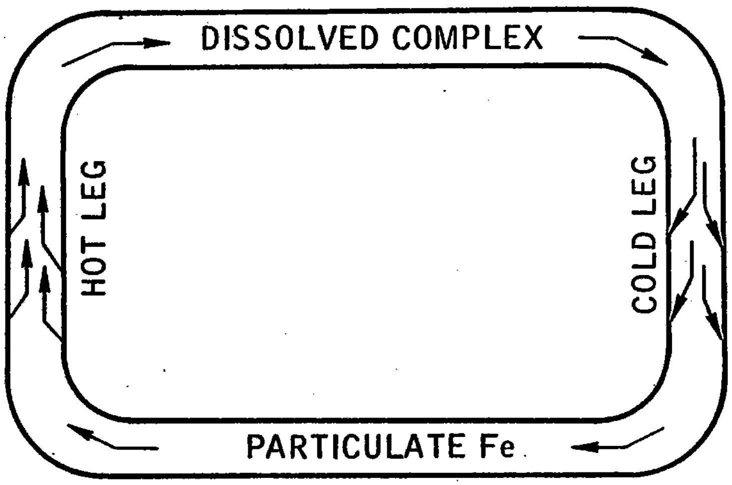
NICKEL PRECIPITATES AND ADHERES OR IS TRAPPED OR RETURNS TO HOT LEG

7-A15-184-11

SOLUBILITY - GRADIENT MASS TRANSFER

CASE "B" - TRANSFER OF COMPLEX - e.g. $Na_2O \cdot FeO$

IRON REACTS TO FORM COMPLEX WHICH DISSOLVES



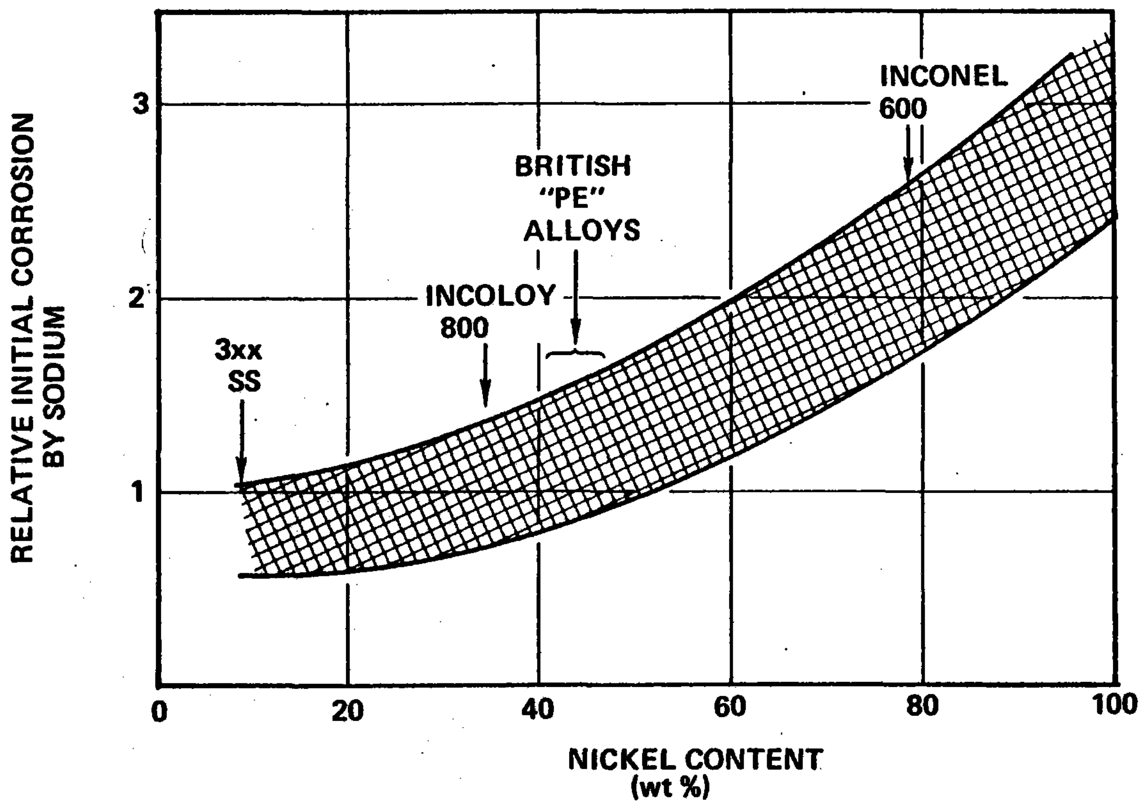
COMPLEX DECOMPOSES, YIELDING FREE IRON

$$\text{REACTION: } 3\,Na_2O + Fe \underset{\text{COLD}}{\overset{\text{HOT}}{\rightleftharpoons}} \underbrace{2\,Na_2O \cdot FeO + 2Na}_{\text{COMPLEX}}$$

7-A15-184-10

Fe, Cr go through complex formation
Ni general solution

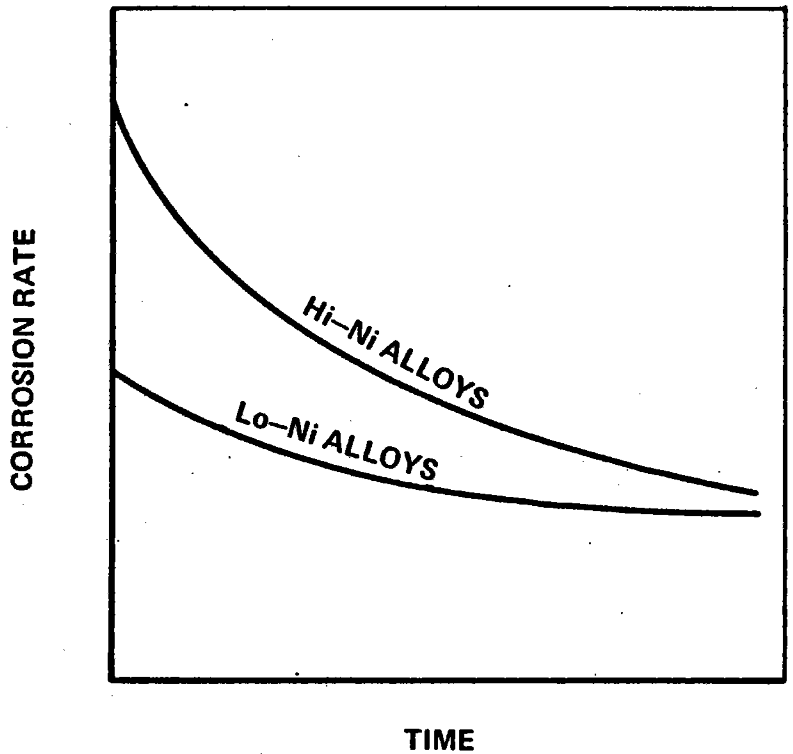
INITIAL CORROSION OF IRON-CHROME-NICKEL ALLOYS



9-O10-116-16

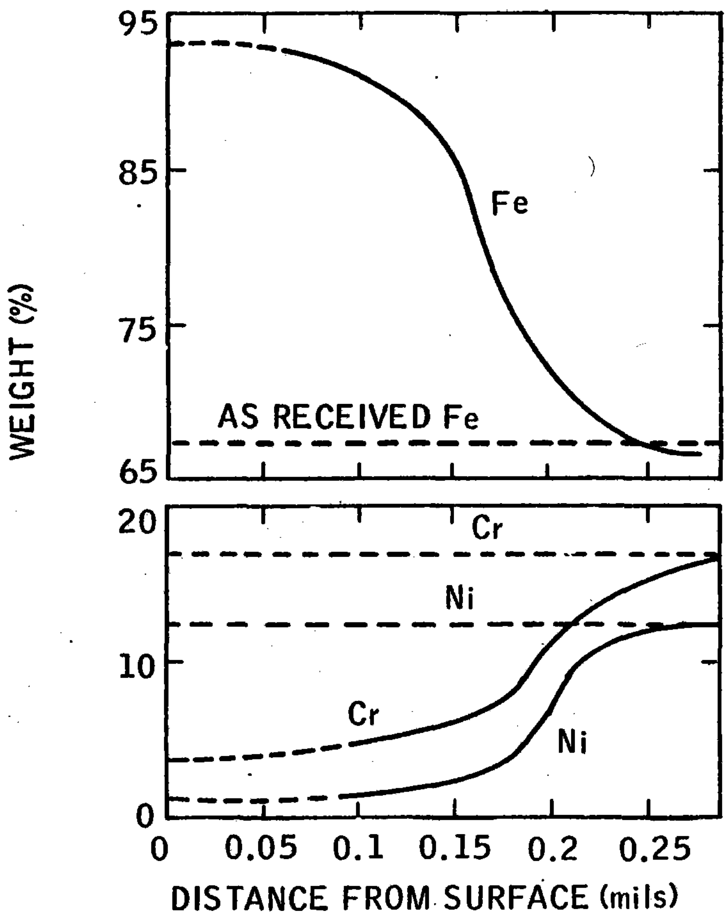
INFERRED Data

EFFECT OF TIME ON SODIUM CORROSION OF IRON-CHROME-NICKEL ALLOYS



9-O10-116-18

COMPOSITIONAL CHANGE IN SS ASSOCIATED WITH ELEMENTAL LEACHING IN Na

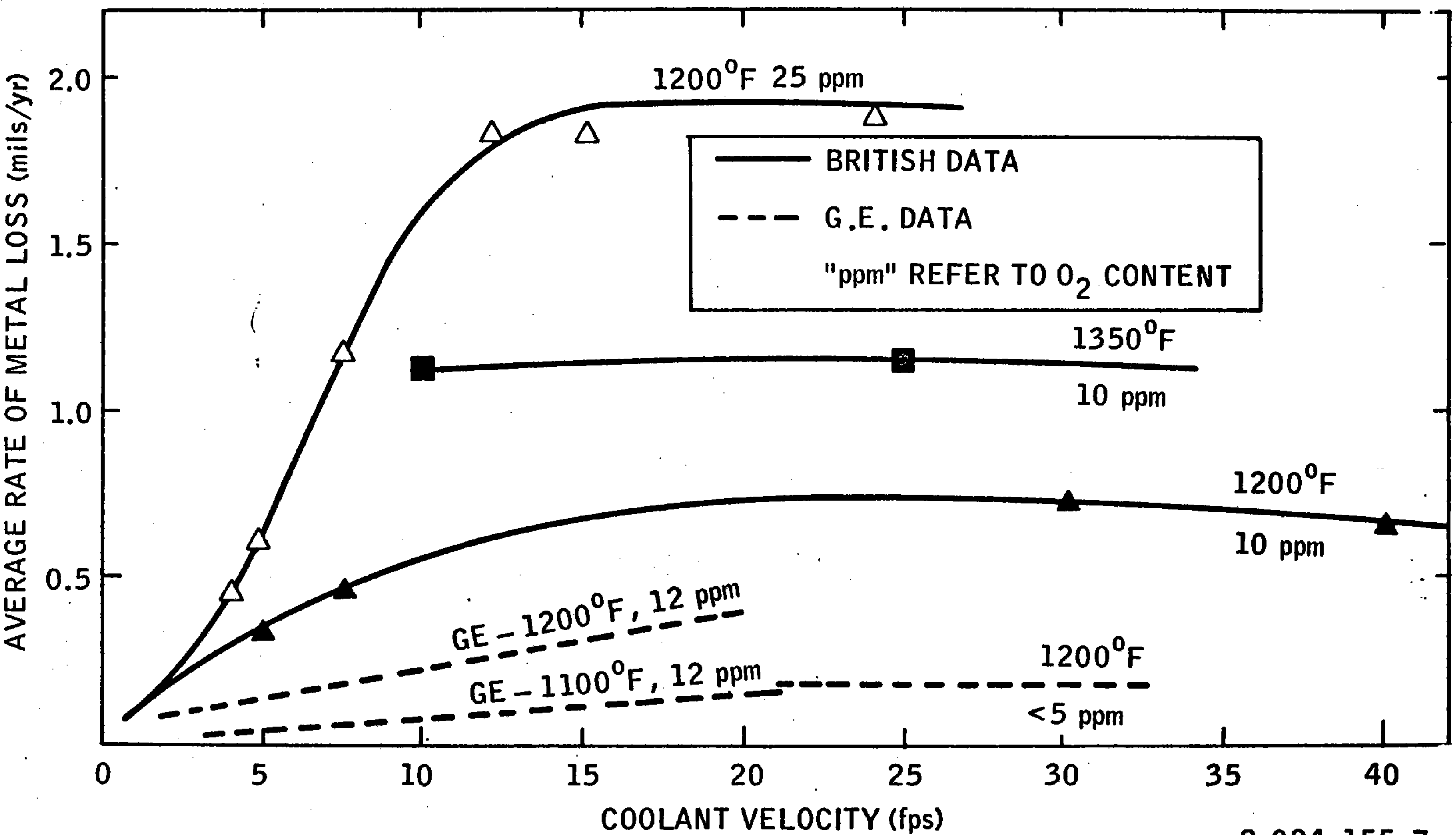


"Ferrite layer" basis

Time = ?

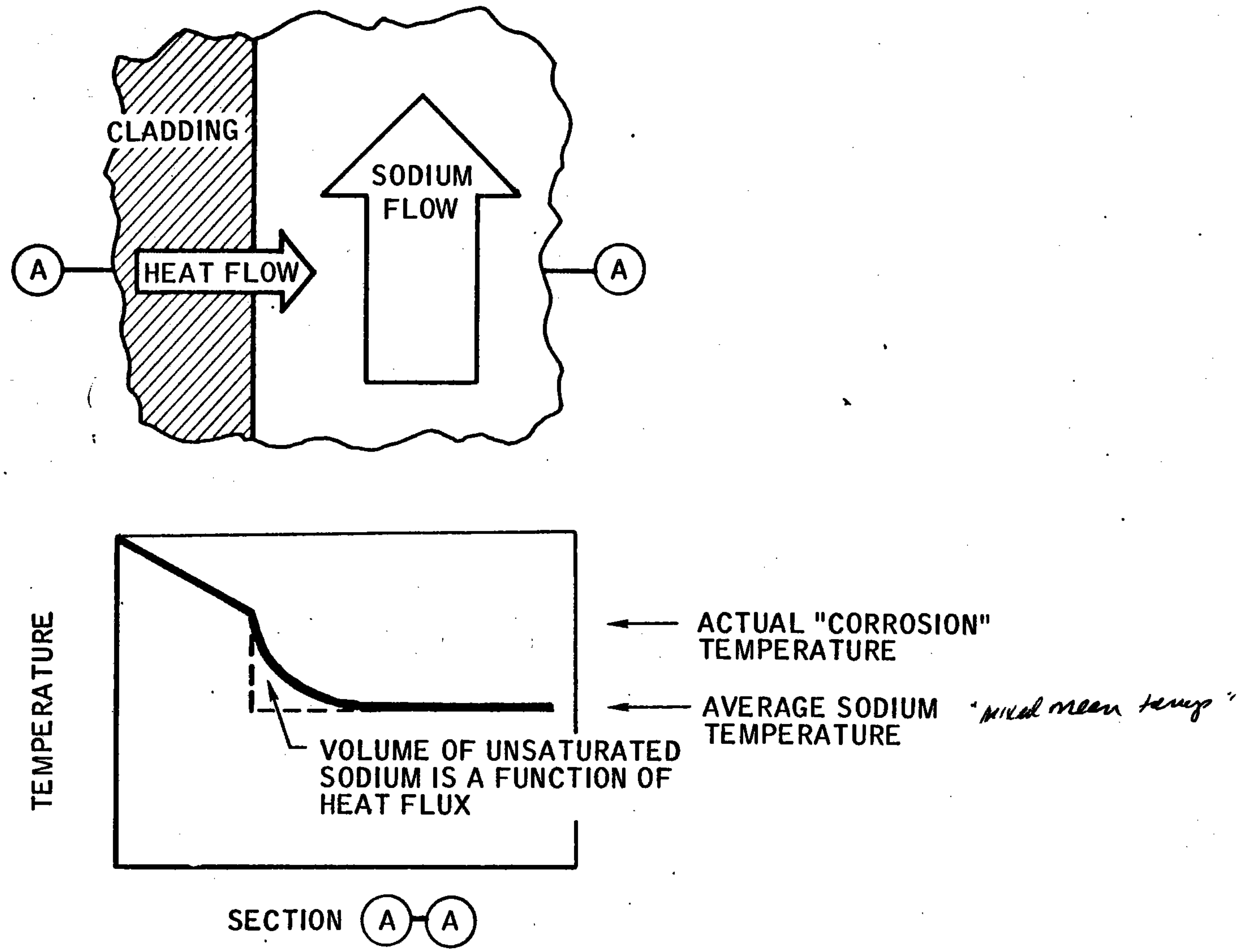
9-010-116-23

ENVIRONMENTAL EFFECTS ON CLADDING CORROSION



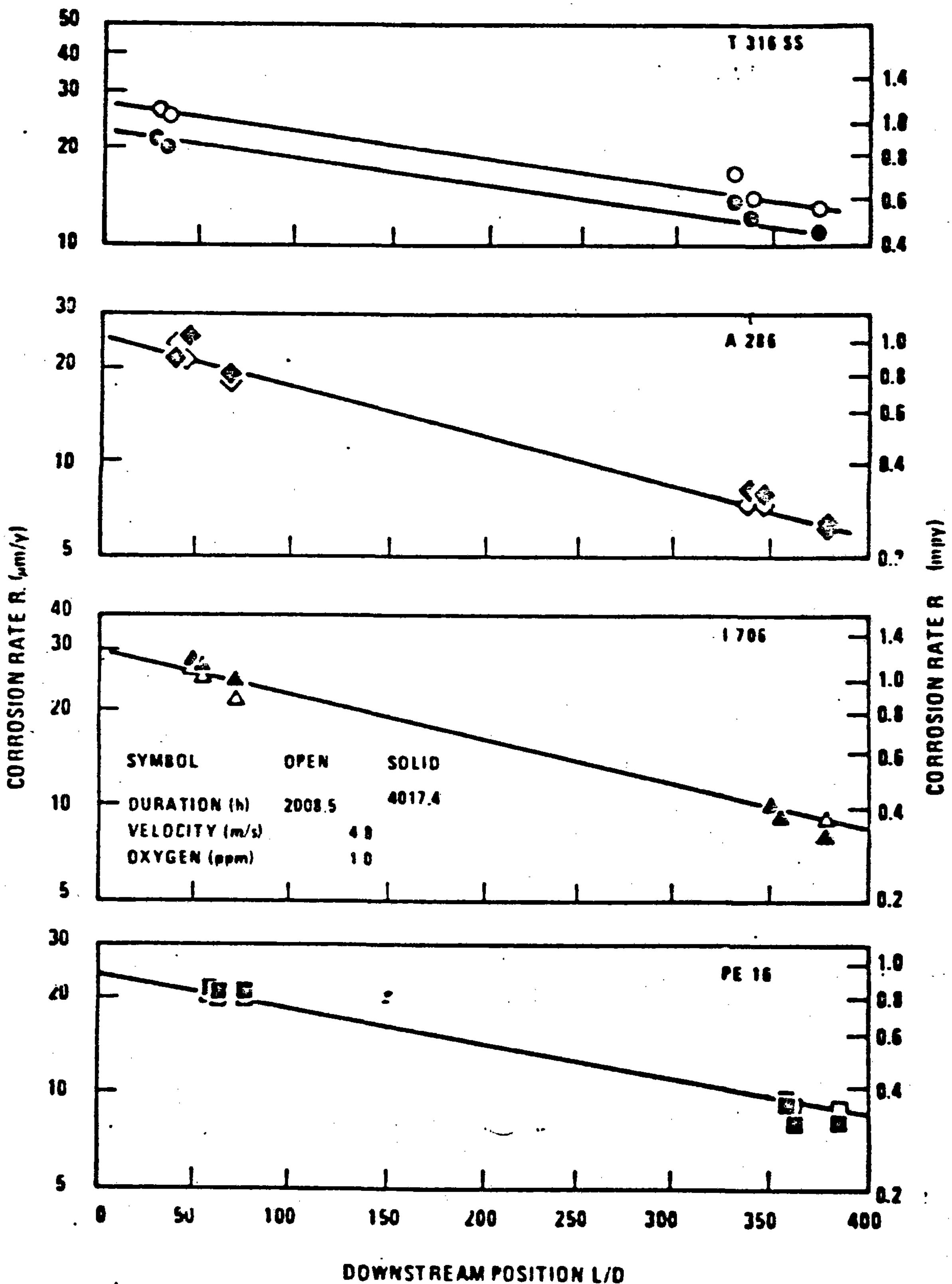
8-024-155-7

THE "HEAT FLUX EFFECT"



9-010-116-22

Fluid is becoming saturated as move down to lower temp.

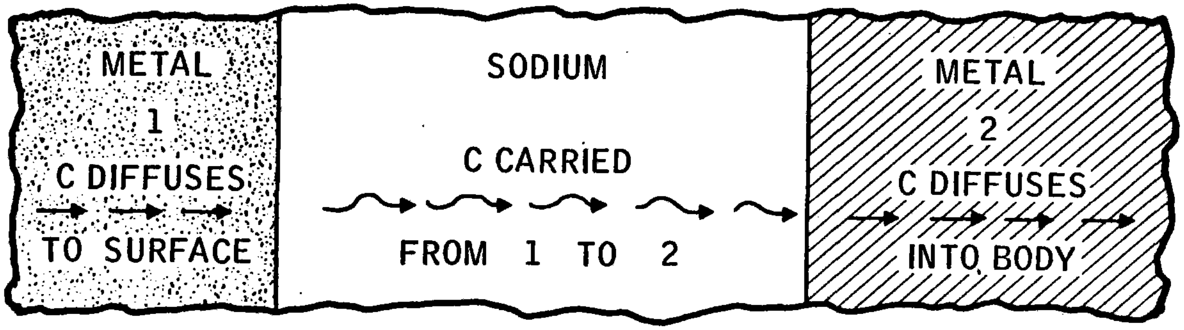


"Downstream Effect in ITF." 700°C

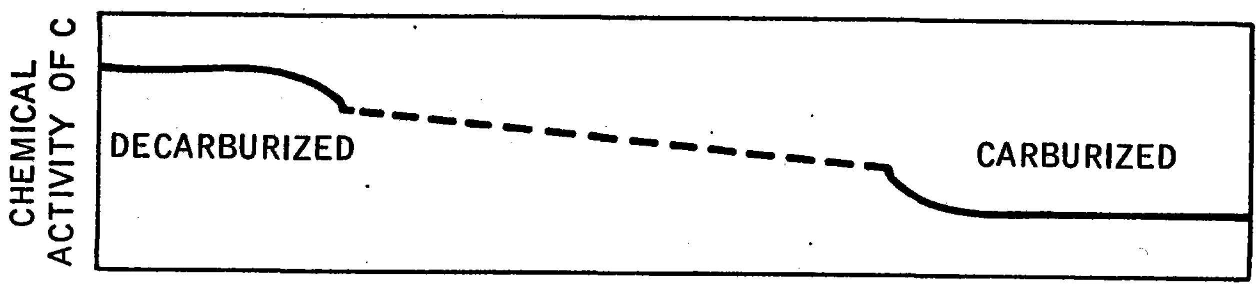
ACTIVITY - GRADIENT MASS TRANSFER (e.g. CARBON TRANSPORT)

INTERSTITIAL EFFECT

ENTROPY DRIVEN



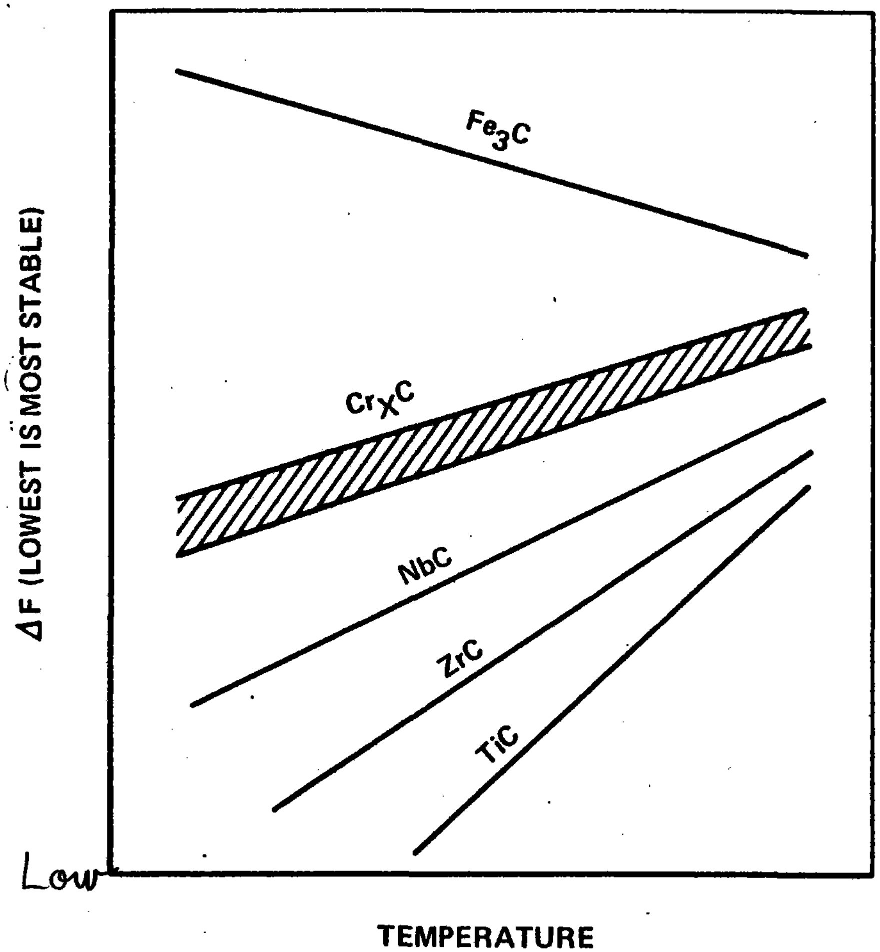
PHYSICAL REPRESENTATION



ACTIVITY PROFILE

7-A15-184 6

ACTIVITY OF CARBON FOR SEVERAL METAL CARBIDES

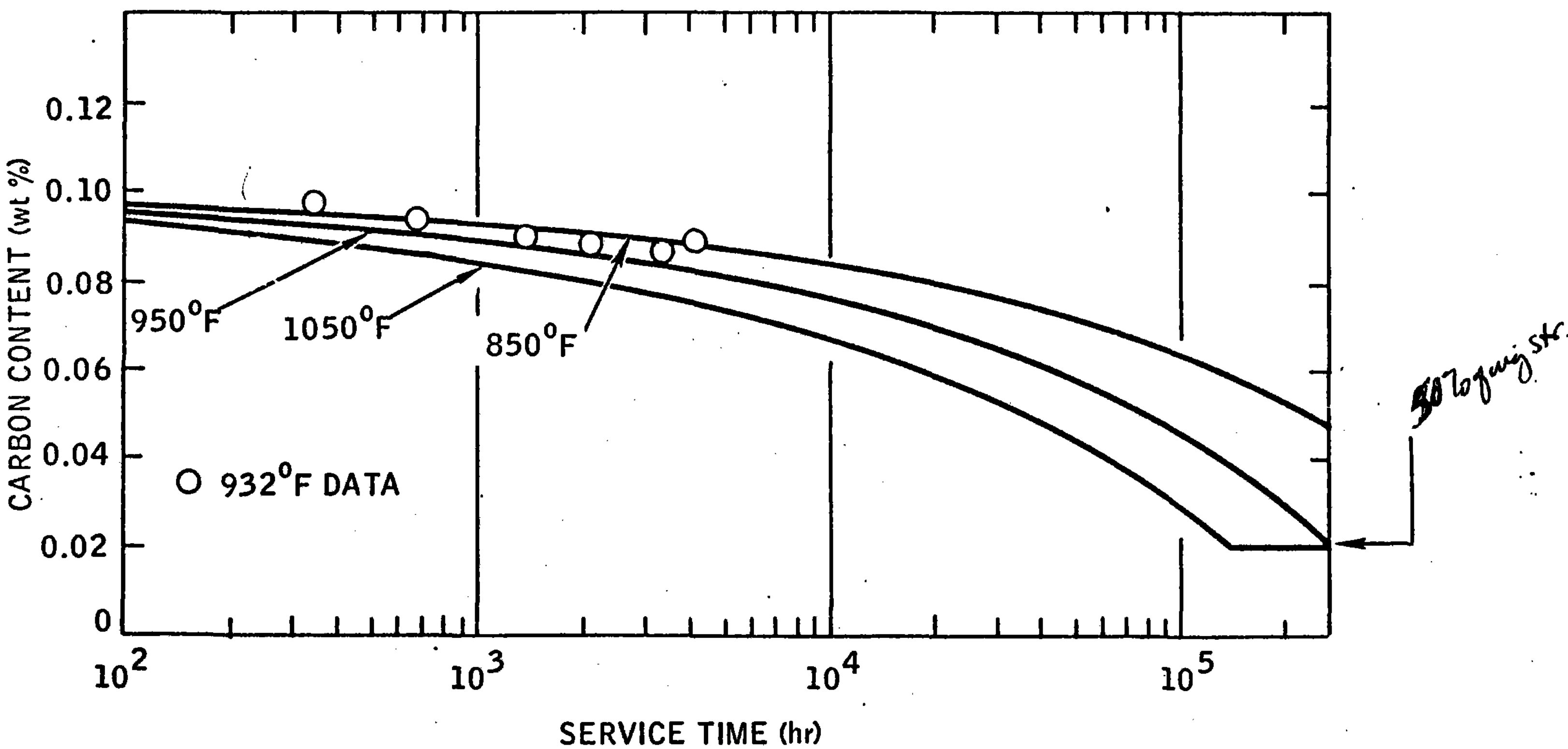


Stainless will decarburize C-steel

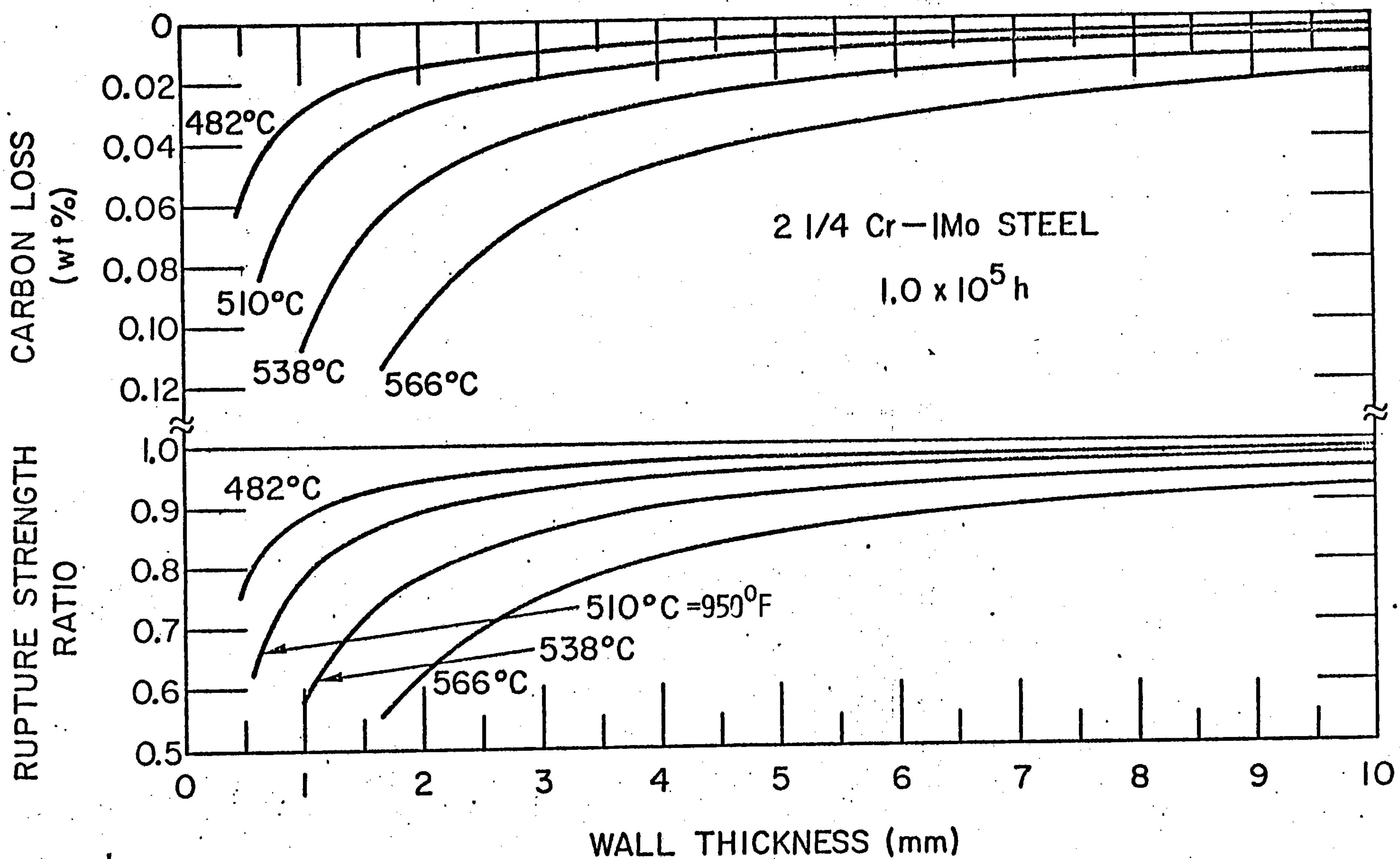
9-010-116-20

(2.4 MM)

DECARBURIZATION OF 0.095-in. THICK 2¼Cr-1Mo STEEL BY SODIUM (ONE SIDE)



8-09-144-48



EFFECT OF DECARBURIZATION ON RUPTURE STRENGTH OF 2-1/4 Cr - 1 Mo STEEL STRUCTURES

G.E. design Formula

Explains 9Cr reluctance

STRENGTH DEGRADATION ALLOWANCES
(2¼ Cr - 1 Mo)

- REDUCTION IN MAXIMUM ALLOWABLE STRESS INTENSITY (S_o)

EQUATION:

$$S_o^f = \frac{3.53 \times 10^5 \times t^{1/2} \times \exp\left(-\frac{13336}{T}\right)}{S_o\, d}$$

S_o^f : % REDUCTION OF S_o TO BE APPLIED

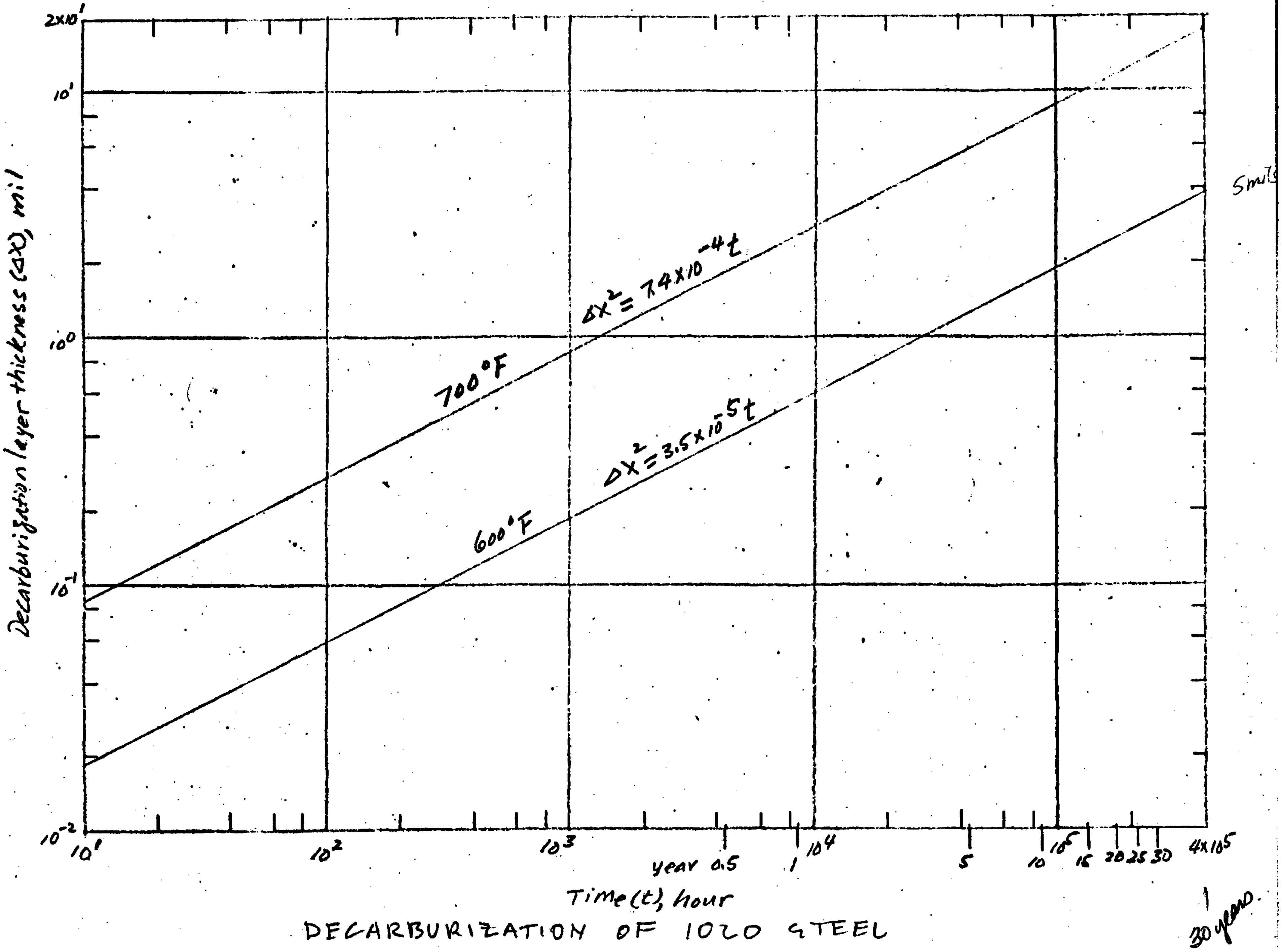
S_o : ALLOWABLE STRESS INTENSITY, ksi (TABLE I-14.2 ; N-47)

t : TIME OF EXPOSURE AT TEMPERATURE, hrs (2.5×10^5)

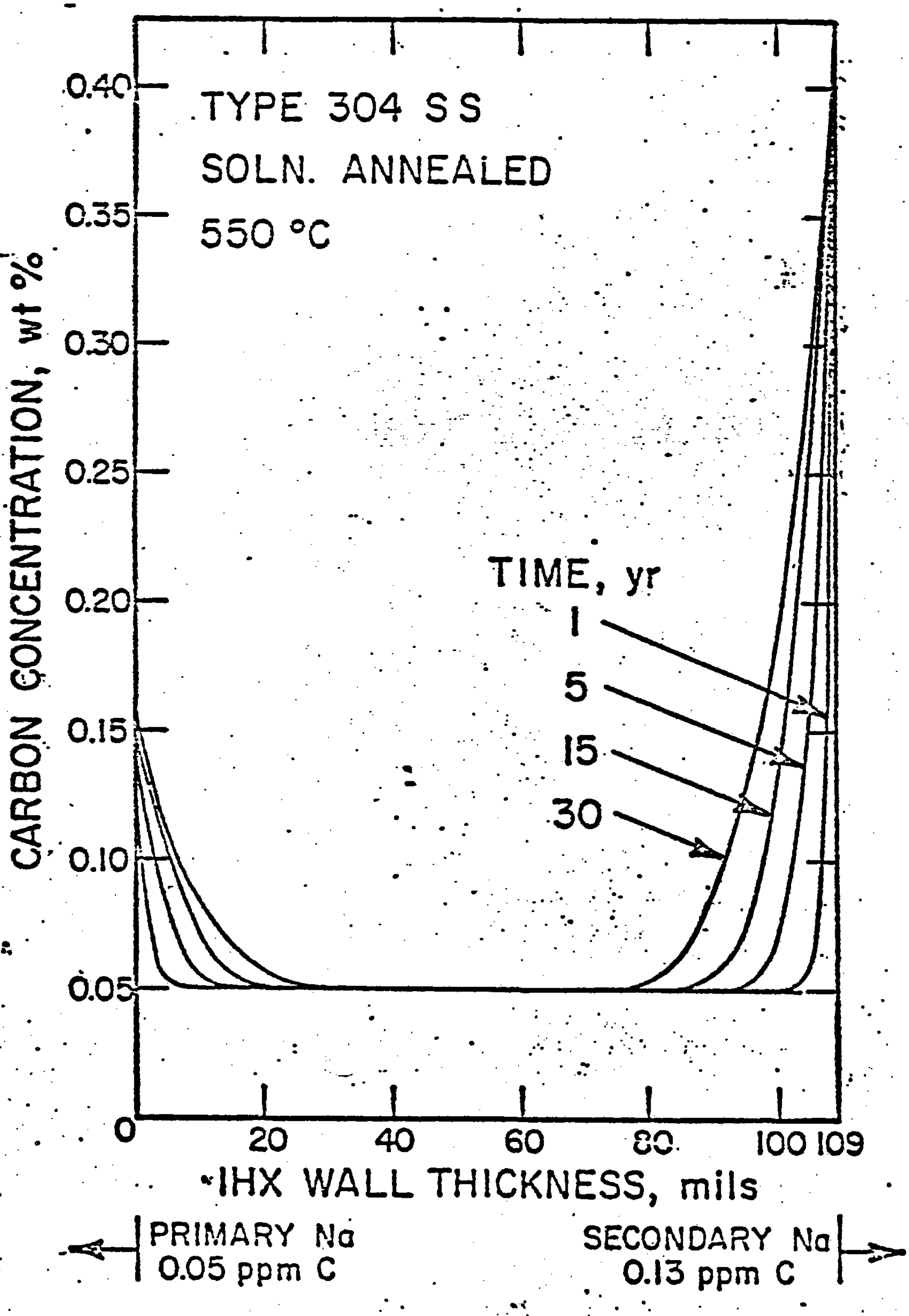
T : TEMPERATURE, °K

d : THICKNESS OF FLAT MEMBER EXPOSED TO SODIUM, in.

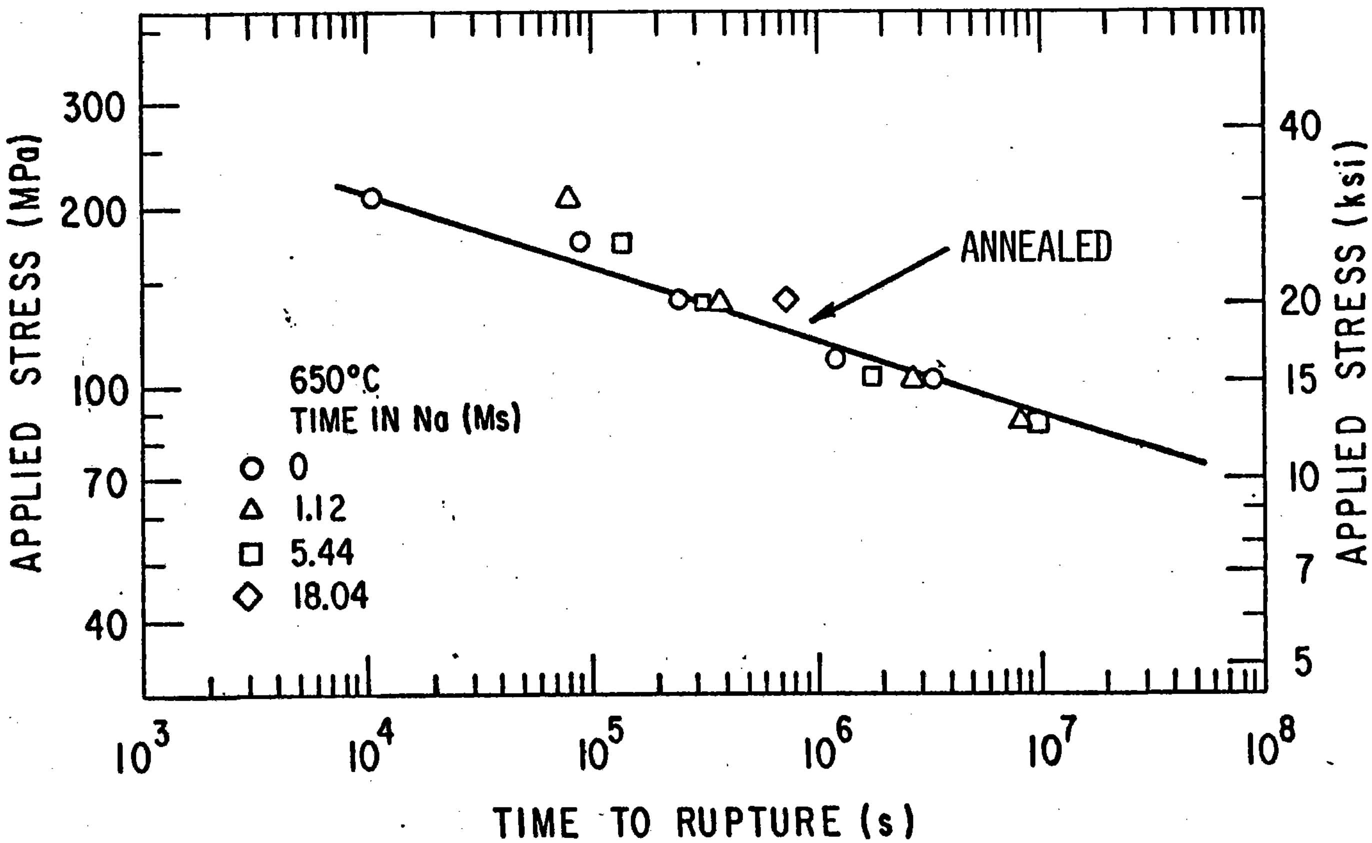
T (°F)	S_o (ksi)	S_o^f inches d=0.1	d=0.25	d=0.5
600	15.0	0.017	0.007	0.0034
700	15.0	0.120	0.048	0.024
800	15.0	0.557	0.223	0.111
900	13.1	2.886	1.554	0.577
950	11.0	6.418	2.567	1.284
1000	7.8	16.27	6.51	3.255
1100	4.2	86.57	34.63	17.32



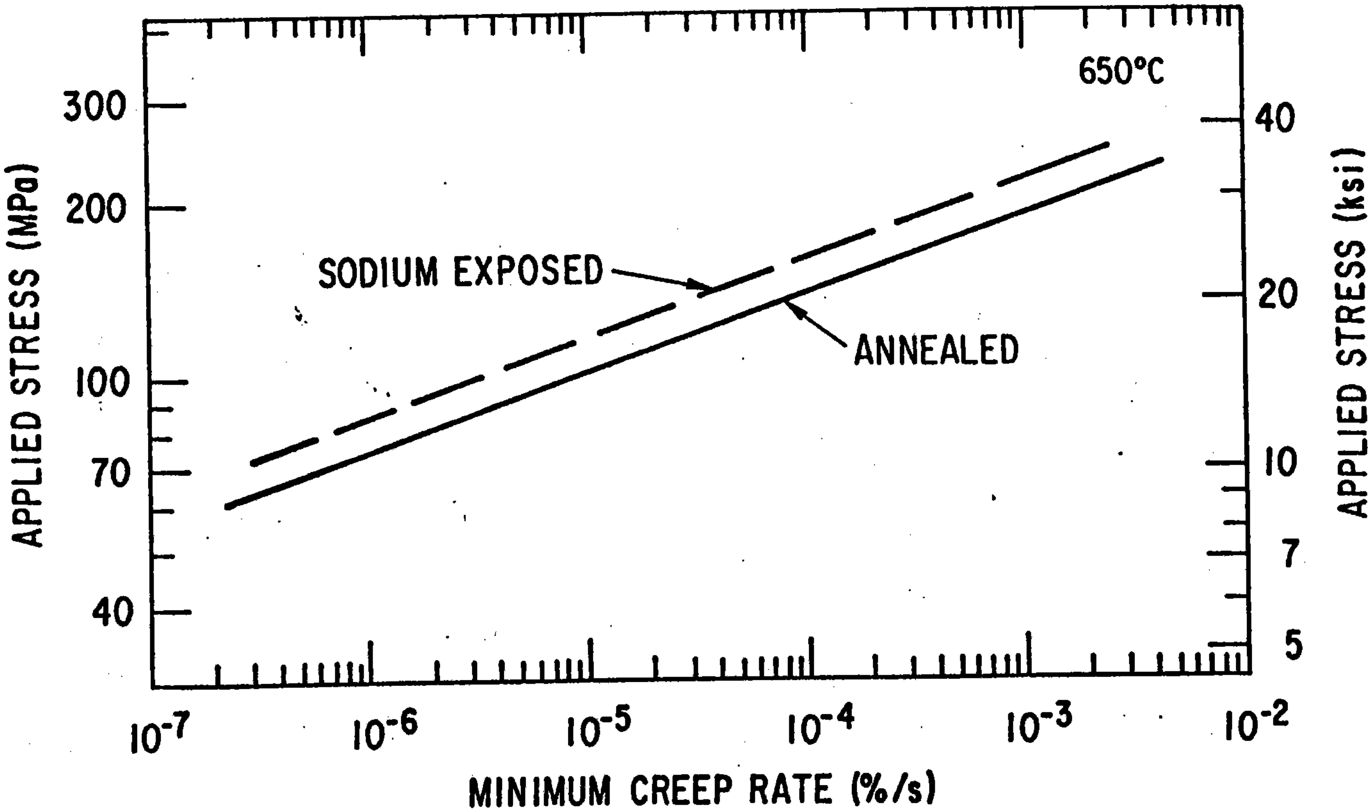
DECARBURIZATION OF 1020 STEEL



FROM ANL PRESENTATION @ SLL

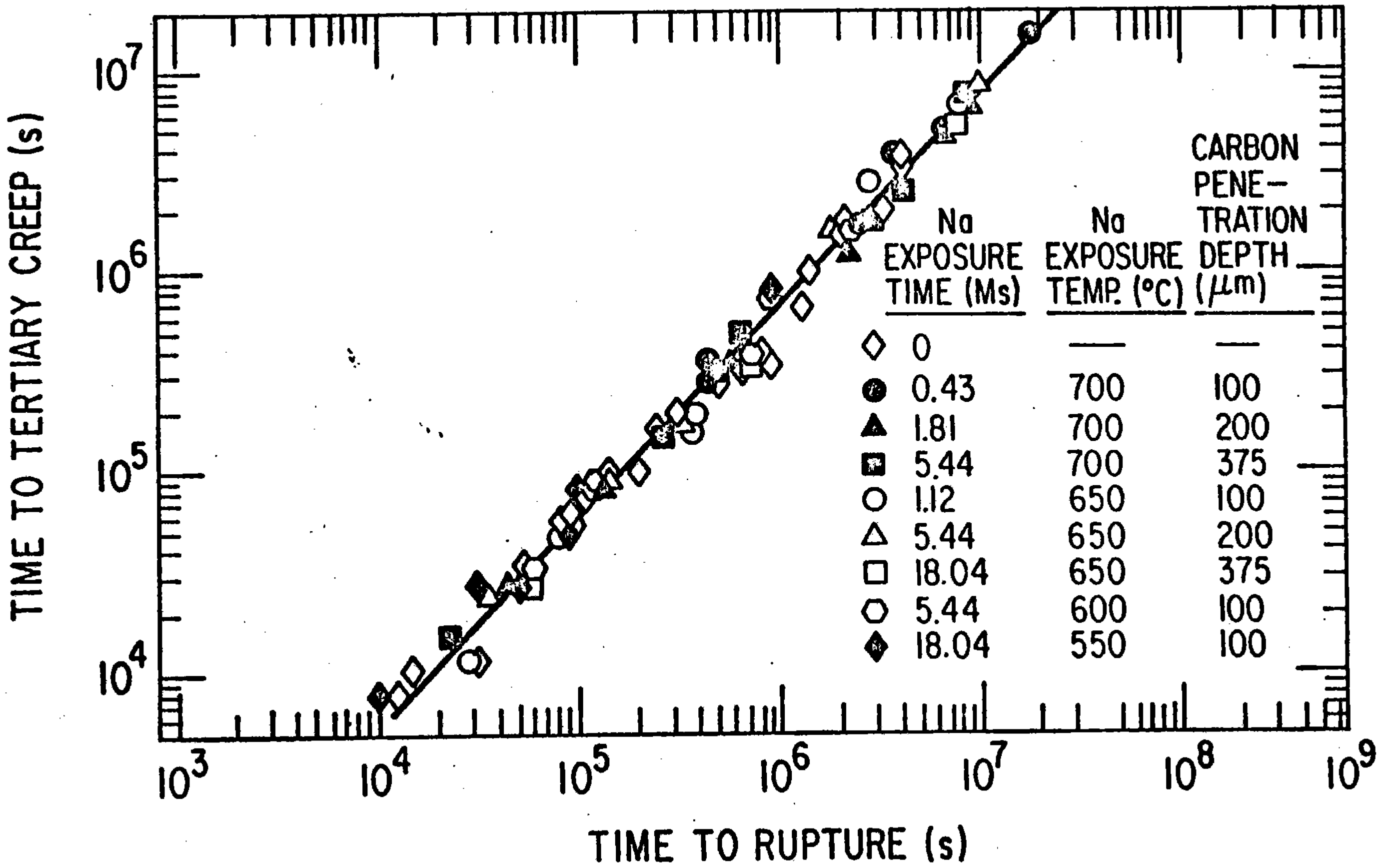


NOTE: The data are applicable for oxygen and carbon concentrations in sodium of ~1 and 0.3 to 0.6 wppm, respectively.



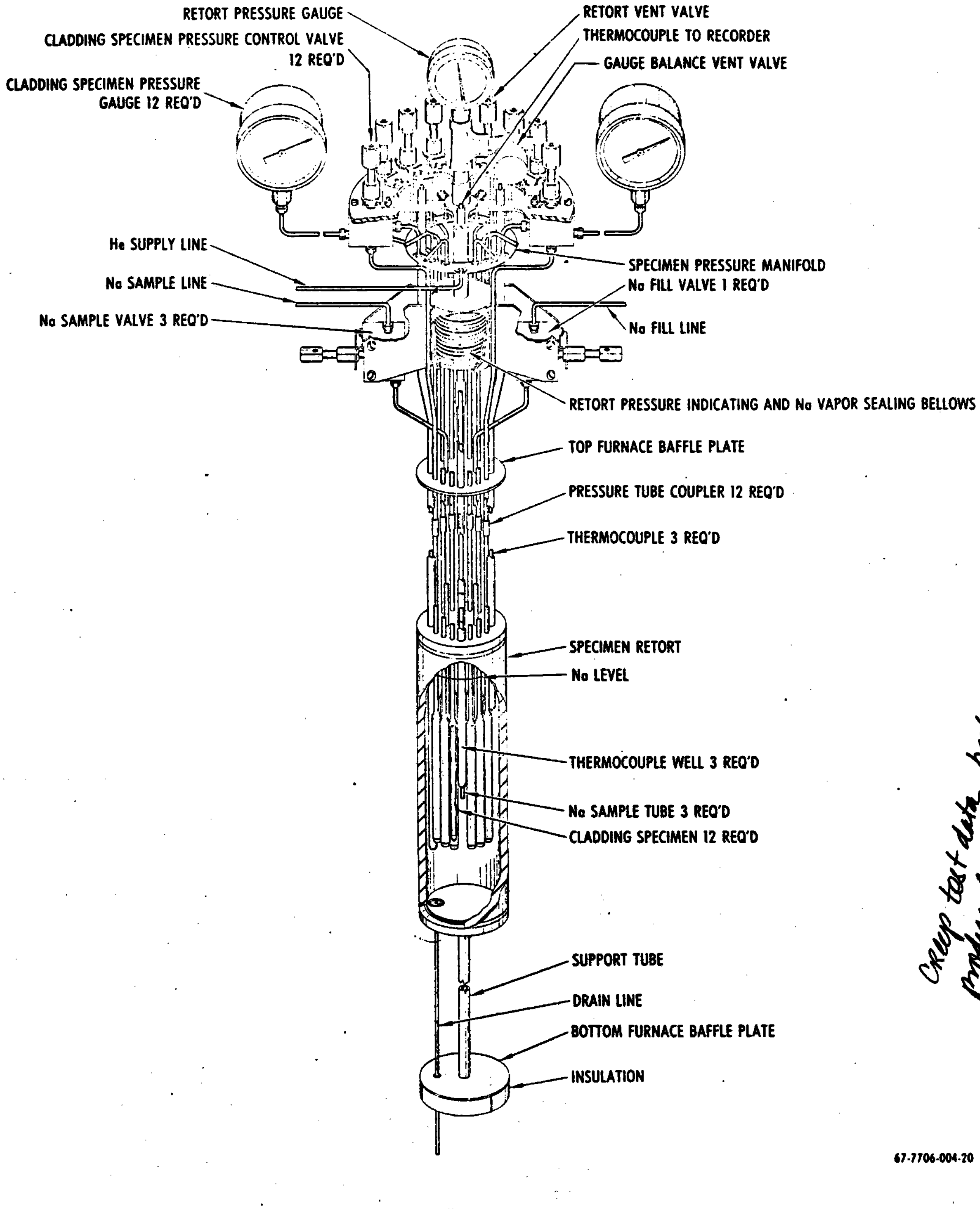
NOTE: The data are applicable for carbon concentration in sodium in the range 0.3 to 0.6 wppm. FAIRLY CARBURIZING.

PART I - STRUCTURAL MATERIALS	GROUP 1 - HIGH ALLOY STEELS	SECTION 2 - 304 SS, SODIUM EXPOSED
REVISION: 0, 11-28-78		TIME TO TERTIARY CREEP, SODIUM EXPOSED



NOTE: The data are applicable for oxygen and carbon concentrations in sodium of ~1 and 0.3 to 0.6 wppm, respectively.

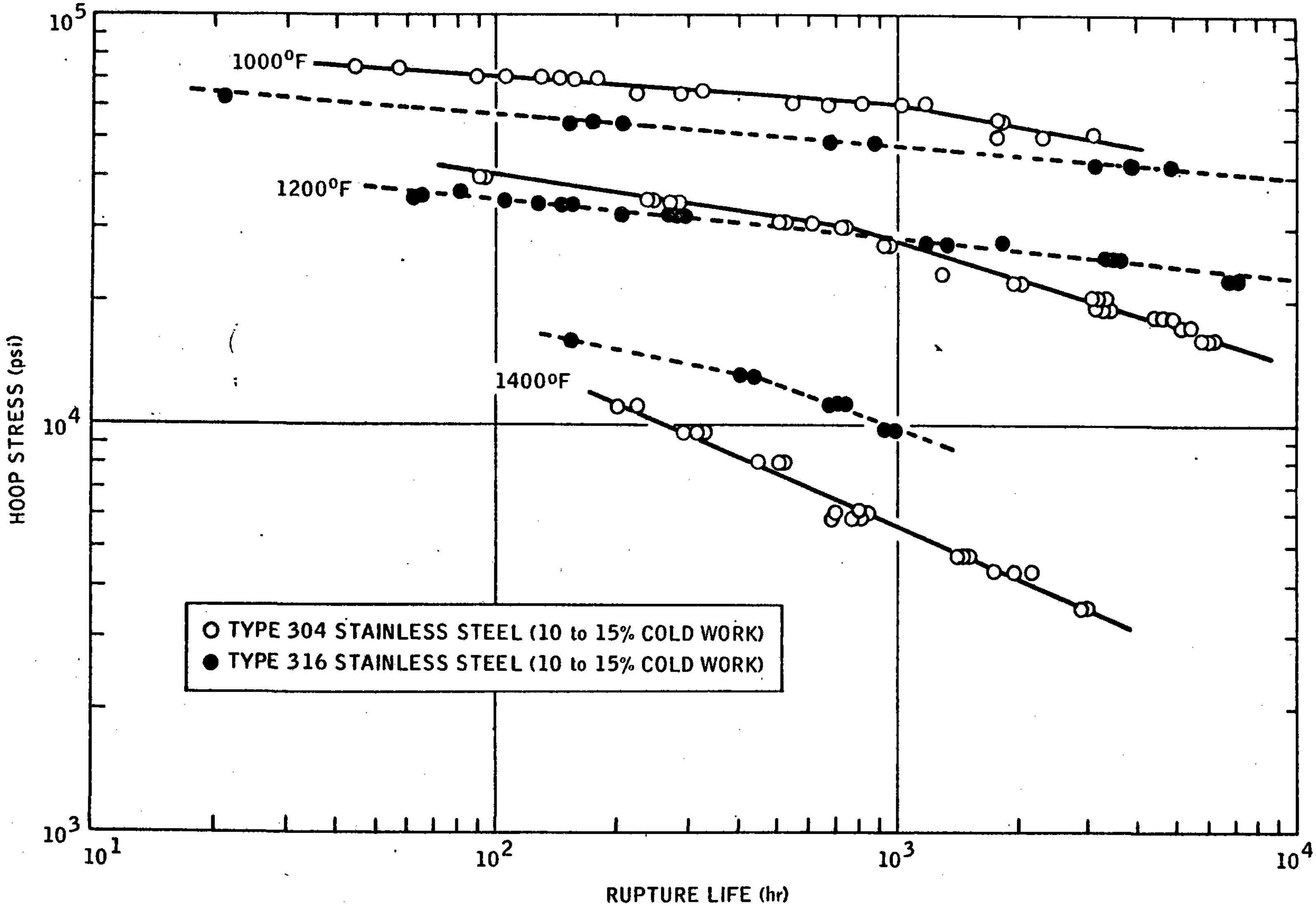
12 PIN BIAXIAL CLADDING TEST RETORT FOR LMFBR



Creep test data best ever produced, no Na effects clean, highly isothermal

67-7706-004-20

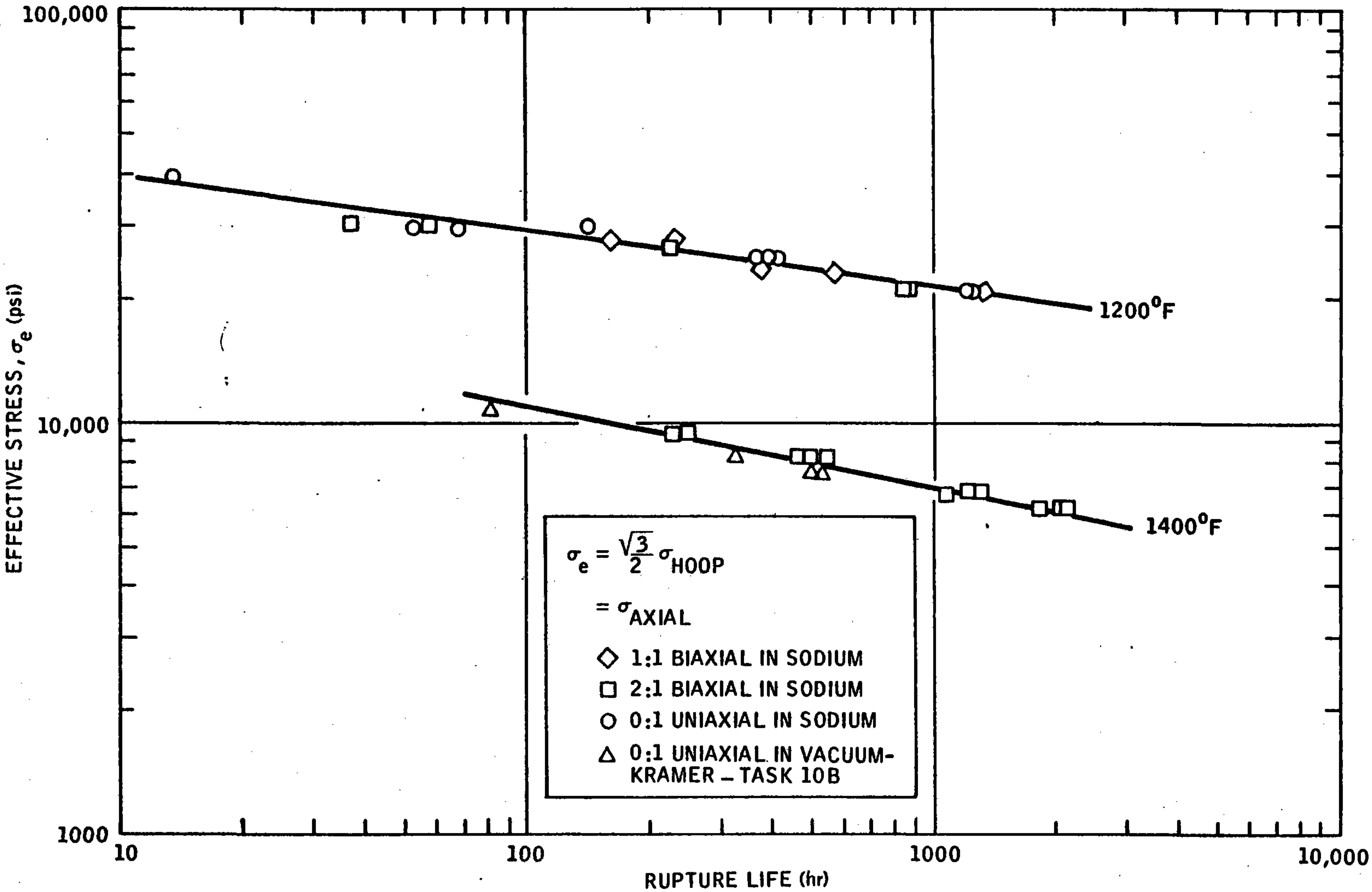
BIAXIAL STRESS-RUPTURE BEHAVIOR OF COLD WORKED TUBES OF 304 AND 316 SS IN STATIC SODIUM



in 316, Mo prevents breaking observed in 304 curve.

8-025-157-2A

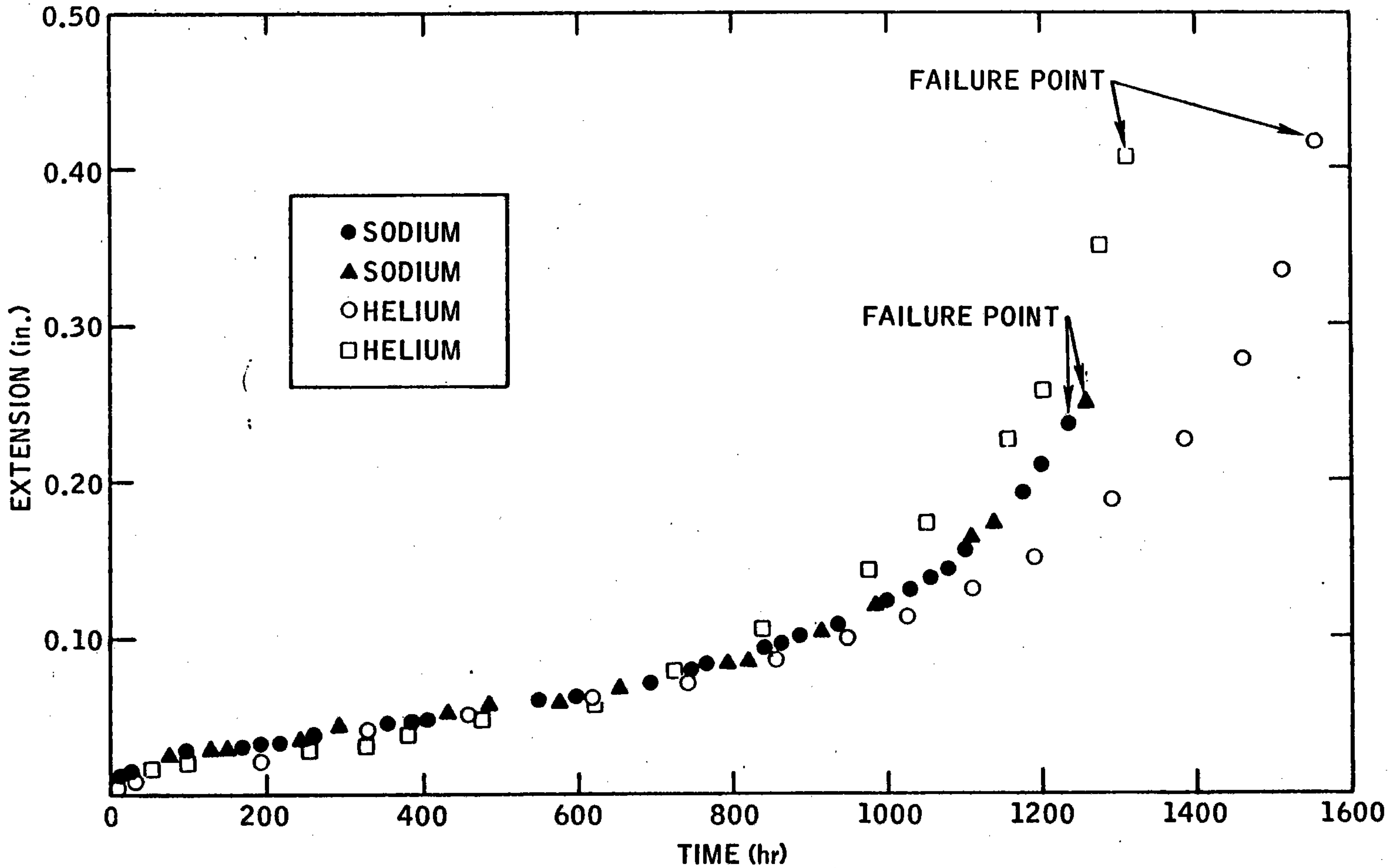
CORRELATION OF STRESS STATE WITH RUPTURE LIFE USING VON MISES' YIELD THEORY-ANNEALED 304 STAINLESS STEEL



9-JY24-085-23

UNIAXIAL CREEP OF ANNEALED TYPE 304 STAINLESS STEEL IN 1200°F SODIUM AND HELIUM ENVIRONMENTS–21,000 psi STRESS

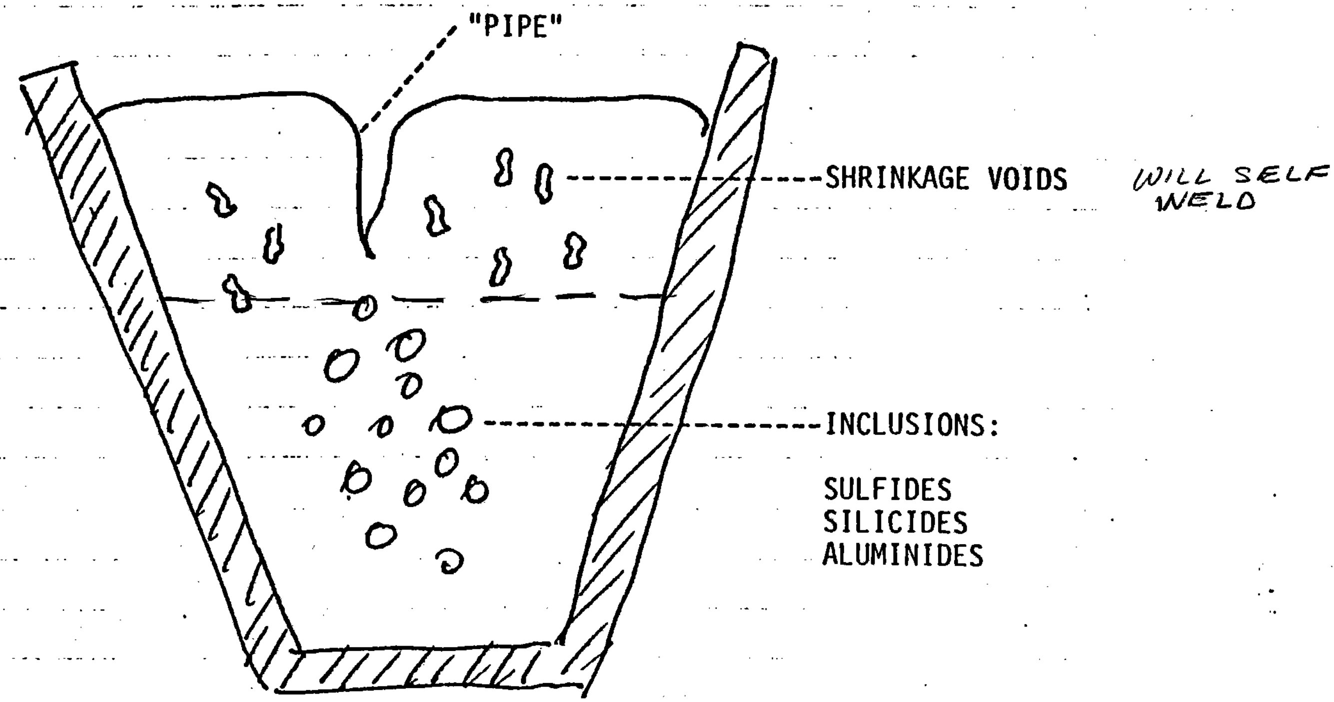
3RD STAGE CREEP



9-AU12-091-15

CORRSION OF

NON METALLIC INCLUSIONS



STEEL CASTING

- CASTING IS CROPPED TO REMOVE "PIPE"
- CASTING IS HOT-WORKED

  CLOSES "VOIDS"
- INCLUSIONS WHICH HAVE HIGH MELTING POINTS
  - ALUMINIDES

  FRAGMENT & SEAL
- INCLUSIONS WITH LOW M.P. MAINTAIN AREA RELATIONSHIP - STAY AS STRINGERS

- STRINGERS RUN PARALLEL TO GRAIN FLOW
- NON-METALLIC STRINGERS ARE SUSCEPTIBLE TO Na CORROSION

LIQUID METAL CONTAINERS

3. DESIGN CONSIDERATIONS (CONT)

3.2.5 All material selections for liquid metal containers shall be approved by the M&P Coordinator or assigned M&P Engineer.

3.2.6 Where grain direction is critical for designs utilizing bar, forgings, sheet or plate, it shall be indicated by a two-directional arrow and the word GRAIN on the field of the drawing.

3.2.6.1 Designs involving machining which leaves thin sections (1/8 inch or less) normal to the grain should be avoided. When this condition is unavoidable, adequate precautions should be taken to assure that the material does not contain laminations, stringers, or other flaws running parallel to the grain. Some appropriate precautions which may be specified include, but are not limited to:

A) Surface etch followed by dye penetrant inspection.
B) A thin specimen cut from surface and inspected for flaws.

3.2.6.2 In welded design the heat of welding may increase the size of internal flaws. For critical applications, forging or forming should be considered to avoid machining, as illustrated in Fig. 3.2.6.2.

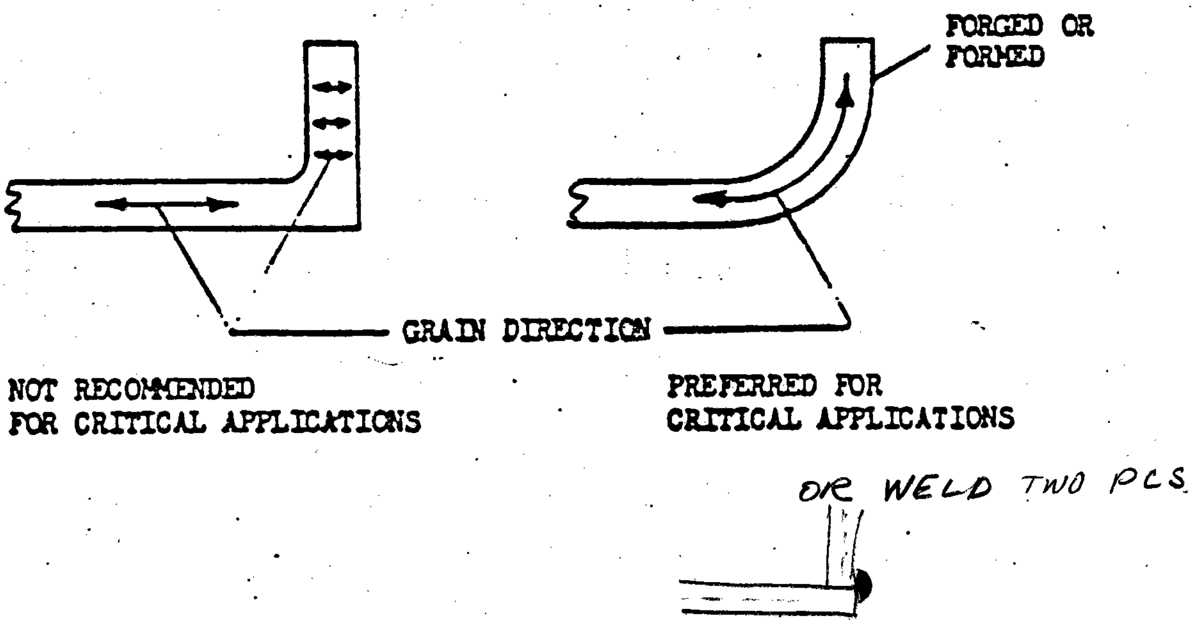


Fig. 3.2.6.2

SELECTED MATERIALS BY COMPONENT

SOLAR CENTRAL RECEIVER
HYBRID POWER SYSTEM

MATERIALS SELECTION

Rockwell International
Energy Systems Group

JCS:65

HYBRID POWER SYSTEM COMPONENTS

RECEIVER
FOSSIL FIRED HEATER
RISER
DOWNCOMER
STORAGE
STEAM GENERATOR COMPLEX
PUMPS
VALVES
TRANSITION POINTS
HORIZONTAL PIPING

RECEIVER

PANELS AND HIGH-TEMPERATURE HEADERS - 304 SS
LOW-TEMPERATURE HEADERS AND VALVES - MILD STEEL -
PANEL COATING PYROMARK

Rockwell International
Energy Systems Group

FOSSIL-FIRED HEATER MATERIALS

FURNACE MEMBRANE WALLS - 2 1/4 Cr - 1 Mo
HIGH-TEMPERATURE CONVECTION - 304 SS
LOW-TEMPERATURE CONVECTION - MILD STEEL

NO real SPACE relative to interior.

MEMBRANE WALL CONSTRUCTION

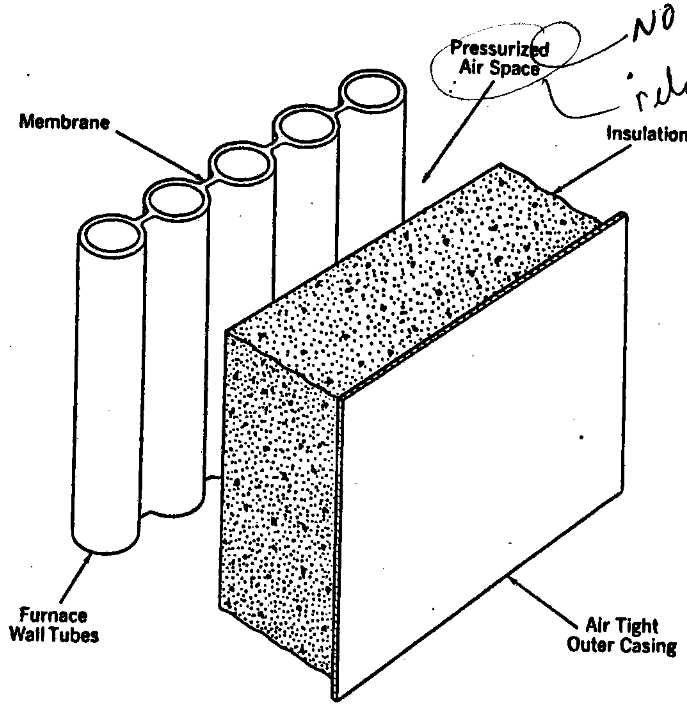


Fig. 19 Typical section through furnace wall (membrane design).

Rockwell International
Energy Systems Group

RISER AND DOWNCOMER MATERIALS

RISER - MILD STEEL
DOWNCOMER - 304 SS

Rockwell International
Energy Systems Group

JCS:65

STORAGE SUBSYSTEM MATERIALS

COLD TANK - MILD STEEL
HOT TANK - 304 SS

Rockwell International
Energy Systems Group

STEAM GENERATOR COMPLEX MATERIALS

EVAPORATOR AND SEPARATOR - 2 1/4 Cr - 1 Mo
SUPERHEATER AND REHEATER - 304 SS

Rockwell International
Energy Systems Group

PUMP MATERIALS

Common practice ~~to~~ to practice

FFTF PUMPS FOR 1050 °F SERVICE
USE THIS CONSTRUCTION

CASE AND IMPELLER - 316 SS
BEARINGS - STELLITE 6, 6B

VALVE MATERIALS

BODY - LOW TEMPERATURE; MILD STEEL
       HIGH TEMPERATURE; 304 SS
HARD FACING - STELLITE

TRANSITION MATERIALS

INCO 82 WELD MATERIAL

Rockwell International
Energy Systems Group

JCS:65

HORIZONTAL PIPING

HIGH TEMPERATURE - 304 SS
LOW TEMPERATURE - MILD STEEL

Rockwell International
Energy Systems Group

BASIS OF MATERIAL SELECTION

MATERIAL SELECTION

FOR

COAL-FIRED SODIUM HEATER

MATERIAL SELECTION

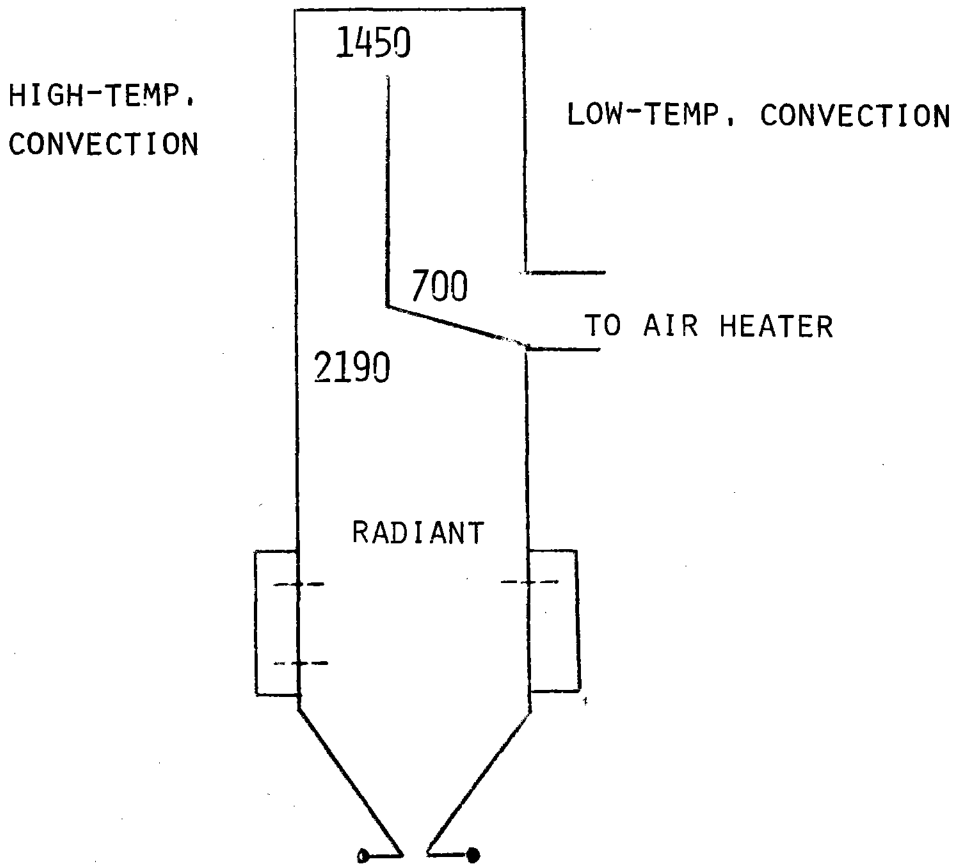
LOW-TEMP. CONVECTION SURFACE	- CARBON STEEL
FURNACE TUBES	- 2-1/4 Cr - 1 Mo
HIGH-TEMP. CONVECTION SURFACE	- TP304 SS*

*Acceptable alternate - 9Cr - 1 Mo

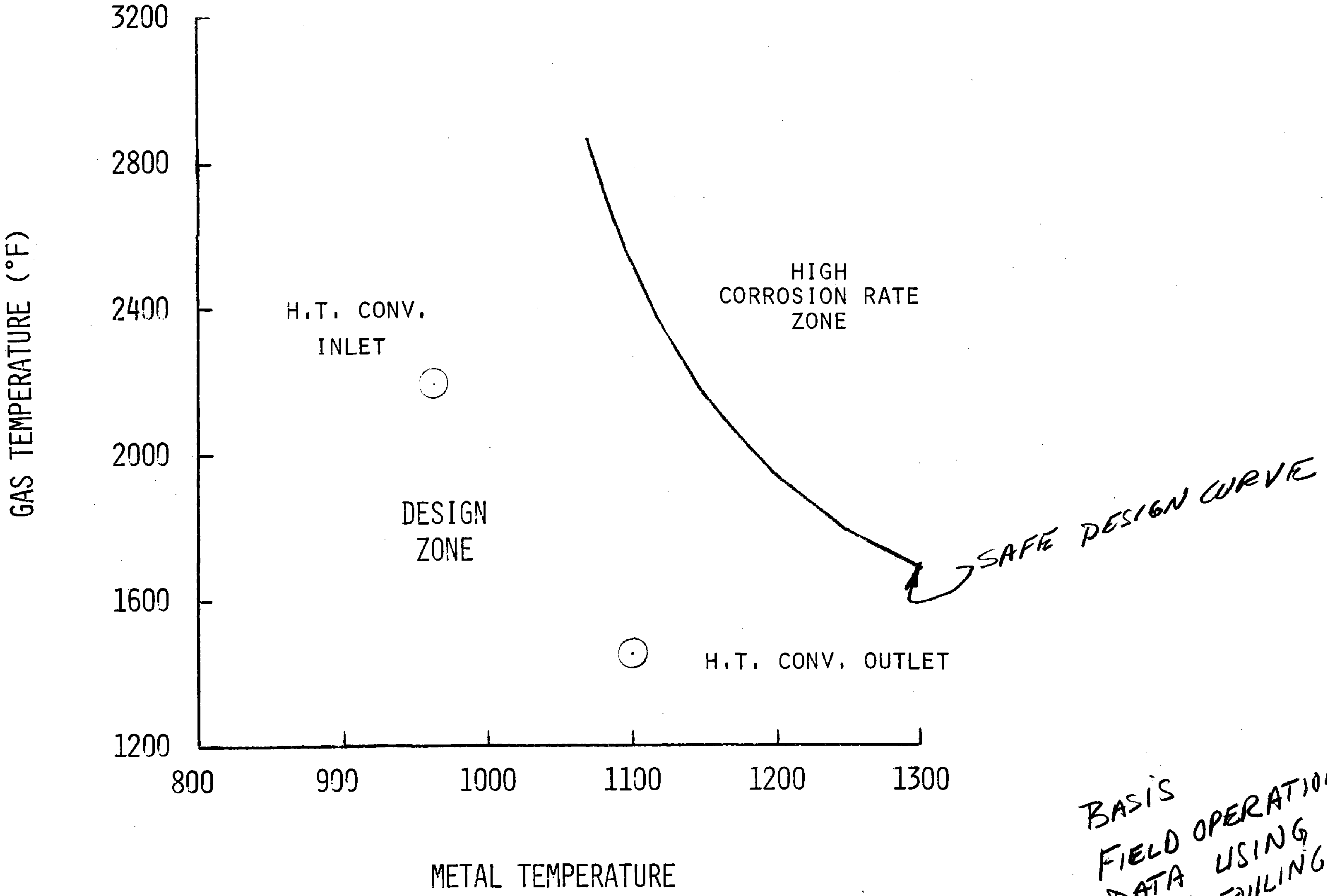
MATERIAL SELECTION - CONSIDERATIONS

- GAS-SIDE CORROSION
- SODIUM-SIDE DECARBURIZATION
- MECHANICAL STRENGTH — SIZED ON STRUCTURAL SUPPORT BASIS
- FABRICABILITY
- ECONOMICS

FLUE GAS TEMPERATURES



GAS-SIDE CORROSION



BASIS
FIELD OPERATION
DATA USING
HIGH FOULING
FUEL

SODIUM TEMPERATURE

	100%	20% HEATER LOAD
L.T. CONV. SURFACE	550-678°F	550-685°F
FURNACE	678-963	685-1050* 1000°F
H.T. CONV. SURFACE	963-1100	1050-1100

*BASED ON NO FLUE GAS RECIRCULATION

① top burners
② FLUE GAS RECIRCULATION

CONCERN: $2\frac{1}{4}$ Cr - 1 Mo

AT LOW LOADS, MORE OF THE TOTAL ABSORPTION OCCURS IN THE FURNACE

RESULTING IN HIGHER TUBE METAL TEMPERATURES

ACTION:

CONTROL TEMPERATURE AT LOW LOAD BY:

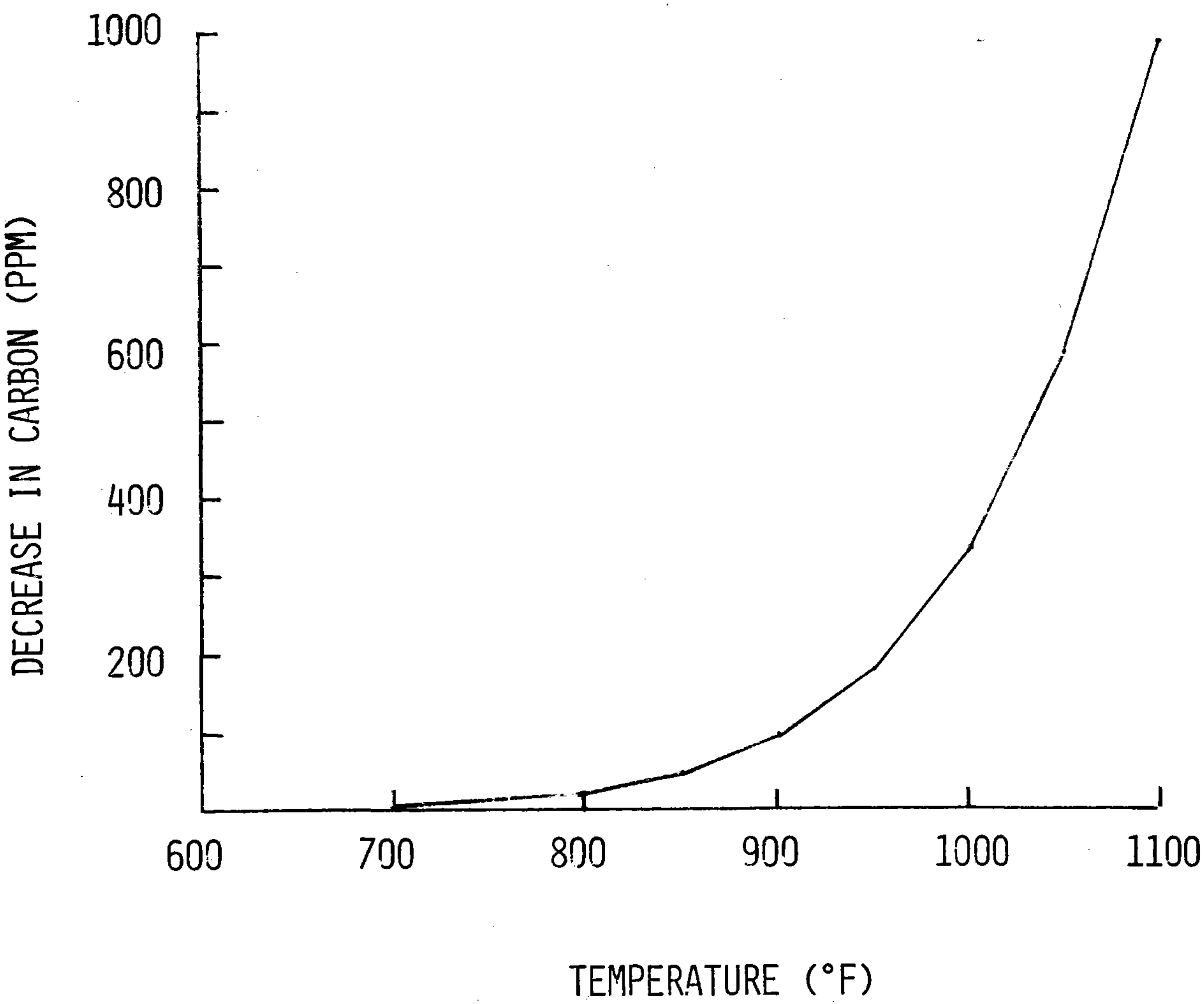
- FLUE GAS RECIRCULATION
- HIGHER EXCESS AIR TO BURNERS (STILL BEING EVALUATED)
- FIRING ONLY THE TOP ROW OF BURNERS

TO REDUCE GAS TEMPERATURE IN BURNER ZONE AND EFFECTIVELY REDUCE SIZE OF FURNACE

DECARBURIZATION IN SODIUM

2-1/4 Cr - 1 Mo FURNACE TUBE

30 YEARS



MEMBRANE PANEL FABRICATION

B&W HAS MANUFACTURED MEMBRANE PANELS OF 2-1/4 CR - 1 MO ALLOY

- DEVELOPMENT PROGRAM ~ 1974
- USED IN COAL GASIFICATION UNIT

TRANSITION MATERIALS

- 2-1/4 Cr - 1 Mo/TP304 SS - INCONEL 600
- 2-1/4 Cr - 1 Mo/CARBON STEEL - NONE REQ'D

SECTION V-B

BALANCE OF PLANT

BALANCE-OF-PLANT MATERIALS

SELECTION SUMMARY

A. HIGH TEMPERATURE REGION (~$1100^{\circ}F$)

COMPONENT	MATERIAL	DISCUSSION	BACK-UP
RECEIVER DOWNCOMER HOT STORAGE TANK HOT VALVE BODIES	304 SS	ADEQUATE STRENGTH BEST WELDABILITY WASH MUCH RESEARCH MUCH EXPERIENCE LOWEST 3XXSS COST 1592	avoid inelastic analysis 316 SS (LOCAL, HIGHER STRENGTH) INCONEL 718 (LOCAL, MUCH HIGHER STRENGTH)
SUPERHEATER REHEATER	304 SS	ALSO: NO DECARB BUT: KEEP DRY	ALLOY 800 Super. 9 CR - 1 Mo
PUMP IMPELLER PUMP CASE	CF8M (CAST 316 SS) 316 SS	CURRENT PRACTICE	NONE NEEDED
VALVE HARDFACING PUMP BEARING	STELLITE	ADEQUATE MUCH EXPERIENCE	NONE NEEDED

BALANCE-OF-PLANT MATERIALS
SELECTION SUMMARY

B. INTERMEDIATE TEMPERATURE REGION (700 - 1000^{o}F)

COMPONENT	MATERIAL	DISCUSSION	BACK-UP
EVAPORATOR SEPARATOR	2-1/4 Cr-1 Mo	No Cl-SCC MUCH EXPERIENCE STRENGTH OK DECARB OK COST OK	NONE NEEDED

C. LOW TEMPERATURE REGION (< 700^{o}F)

COMPONENT	MATERIAL	DISCUSSION	BACK-UP
RECEIVER HEADERS RISER COLD STORAGE TANK VALVE BODIES	CARBON STEEL	MUCH EXPERIENCE STRENGTH OK DECARB OK LOW COST	NONE NEEDED
PUMP IMPELLER PUMP CASE	CF8M (CAST 316 SS) 316 SS	CURRENT PRACTICE	NONE NEEDED
VALVE HARDFACING PUMP BEARING	STELLITE	MUCH EXPERIENCE	NONE NEEDED

BALANCE-OF-PLANT MATERIALS
SELECTION SUMMARY

D. TRANSITION JOINTS

COMPONENT	MATERIAL	DISCUSSION	BACK-UP
INTERMEDIATE TEMP. (< 1000°F)	INCO 82	INTENSIVE LMFBR R&D	16-8-2/ I-800/ INCO 82
LOW TEMP.	INCO 82	EXPERIENCE	NONE NEEDED

STRENGTH DEGRADATION ALLOWANCES
($2\frac{1}{4}$ Cr - 1 Mo)

- REDUCTION IN MAXIMUM ALLOWABLE STRESS INTENSITY (S_o)

EQUATION :

$$S_o^f = \frac{3.53\times10^5 \times t^{1/2} \times \exp\left(-\frac{13336}{T}\right)}{S_o\, d}$$ 2124

S_o^f : % REDUCTION OF S_o TO BE APPLIED

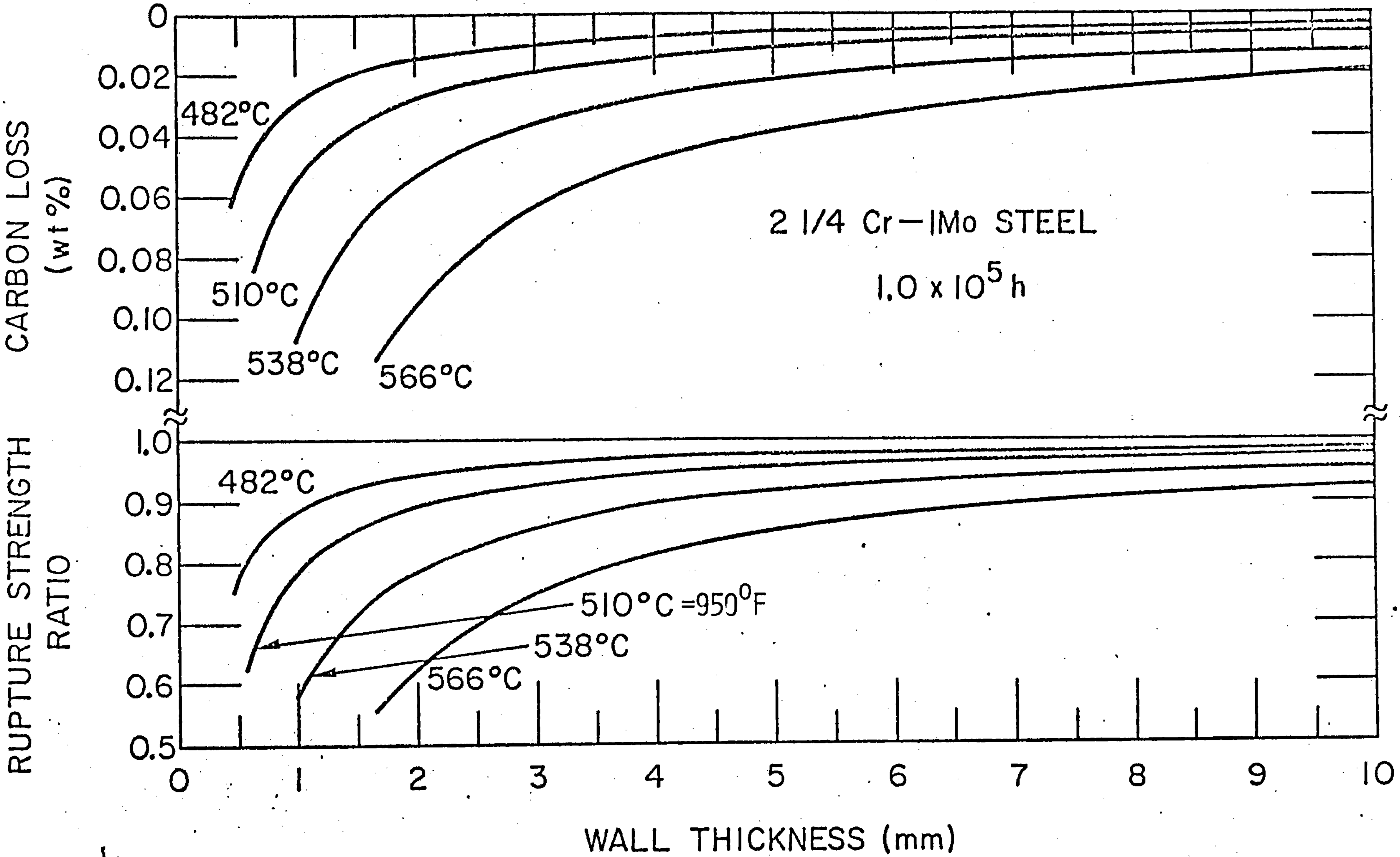
S_o : ALLOWABLE STRESS INTENSITY, ksi (TABLE I-14.2 ; N-47)

t : TIME OF EXPOSURE AT TEMPERATURE, hrs (2.5×10^5) $t^{1/2}$ = 500

T TEMPERATURE, °K

d : THICKNESS OF FLAT MEMBER EXPOSED TO SODIUM, in

T (°F)	S_o (ksi)	S_o^f d=0.1	S_o^f d=0.25	S_o^f d=0.5
600	15.0	0.017	0.007	0.0034
700	15.0	0.120	0.048	0.024
800	15.0	0.557	0.223	0.111
900	13.1	2.886	1.554	0.577
950	11.0	6.418	2.567	1.284
1000 811K	7.8	16.27	6.51	3.255
1050 839K	5.8	37.3	14.9	7.46
1100	4.2	86.57	34.63	17.32



EFFECT OF DECARBURIZATION ON RUPTURE STRENGTH OF 2-1/4 Cr - 1 Mo STEEL STRUCTURES

STRESS CORROSION CRACKING
IN 304 SS PWR STEAM GENERATORS

REACTOR	EQUIVALENT FULL-POWER DAYS	CUMULATIVE DEFECTS
DRESDEN-1	2963	161
INDIAN PT-1	1750	265
KRB	2651	364
KWL LINGEN	1739	112
MZFR	2134	-0-
N-REACTOR		27
SENA (CHOOZ)	1956	20
TARAPUR-1	1317	2
TARAPUR-2	1304	143
TRINO	2428	-0-
YANKEE ROWE	4144	65

THRU DEC 31, 1976

Chalk River Review

EXPERIENCE WITH TUBE MATERIALS
TO DECEMBER 31, 1976

TUBE MATERIAL	NUMBER OF REACTORS	NUMBER OF TUBES	NUMBER OF TUBE FAILURES	TUBE FAILURE RATE	FAILURE MECHANISM
TYPE 304 SS	11	58 547	1159	2.0%	A,B
INCONEL-600	42	526 886	11 867	2.0%	A,B,C,D,E
MONEL-400	8	167 700	232	0.14%	A,D
INCOLOY-800		36 558	0	0	--

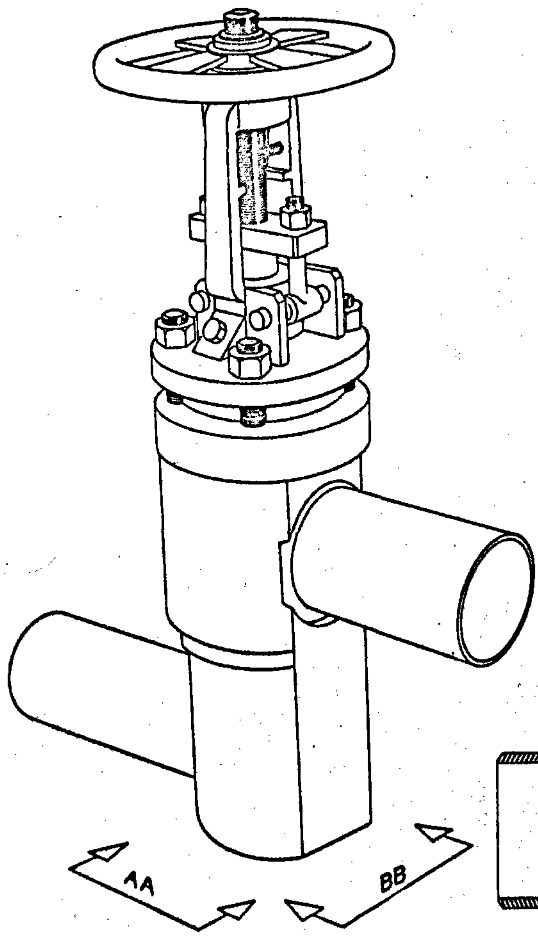
Water (Shell) side

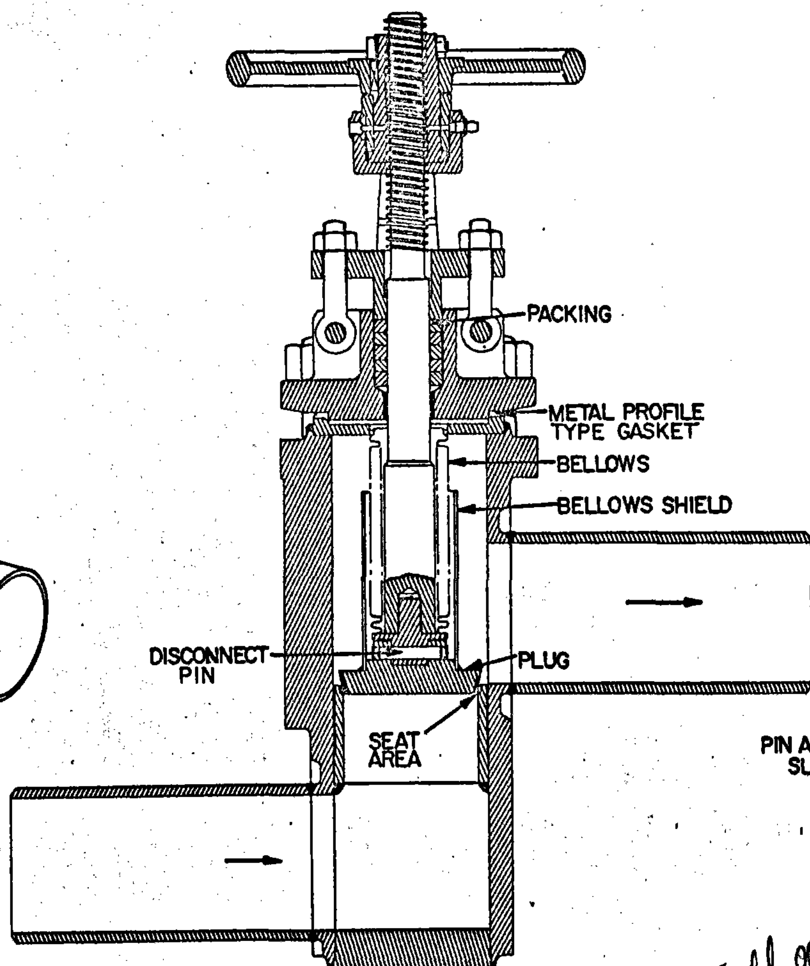
A SCC
B Phosphate Wastage
C Denting
D Fretting
E Fatigue

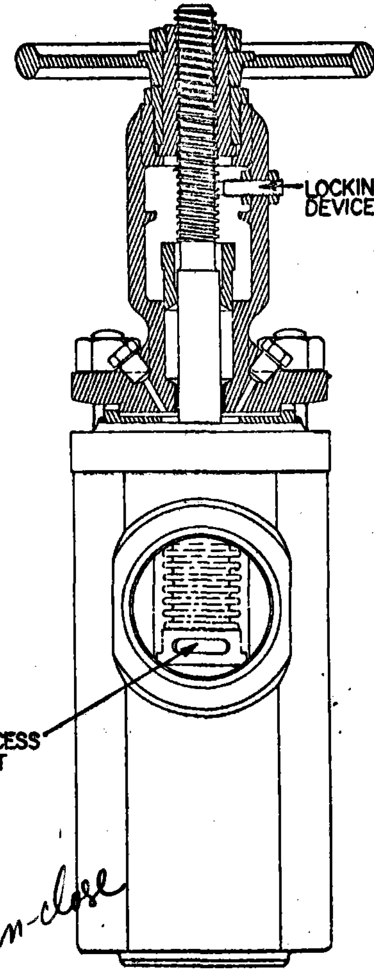
No evidence of corrosion on Na side

DESIGN FEATURES TO ACCOMMODATE THE MATERIAL

BELLOWS SEAL VALVES

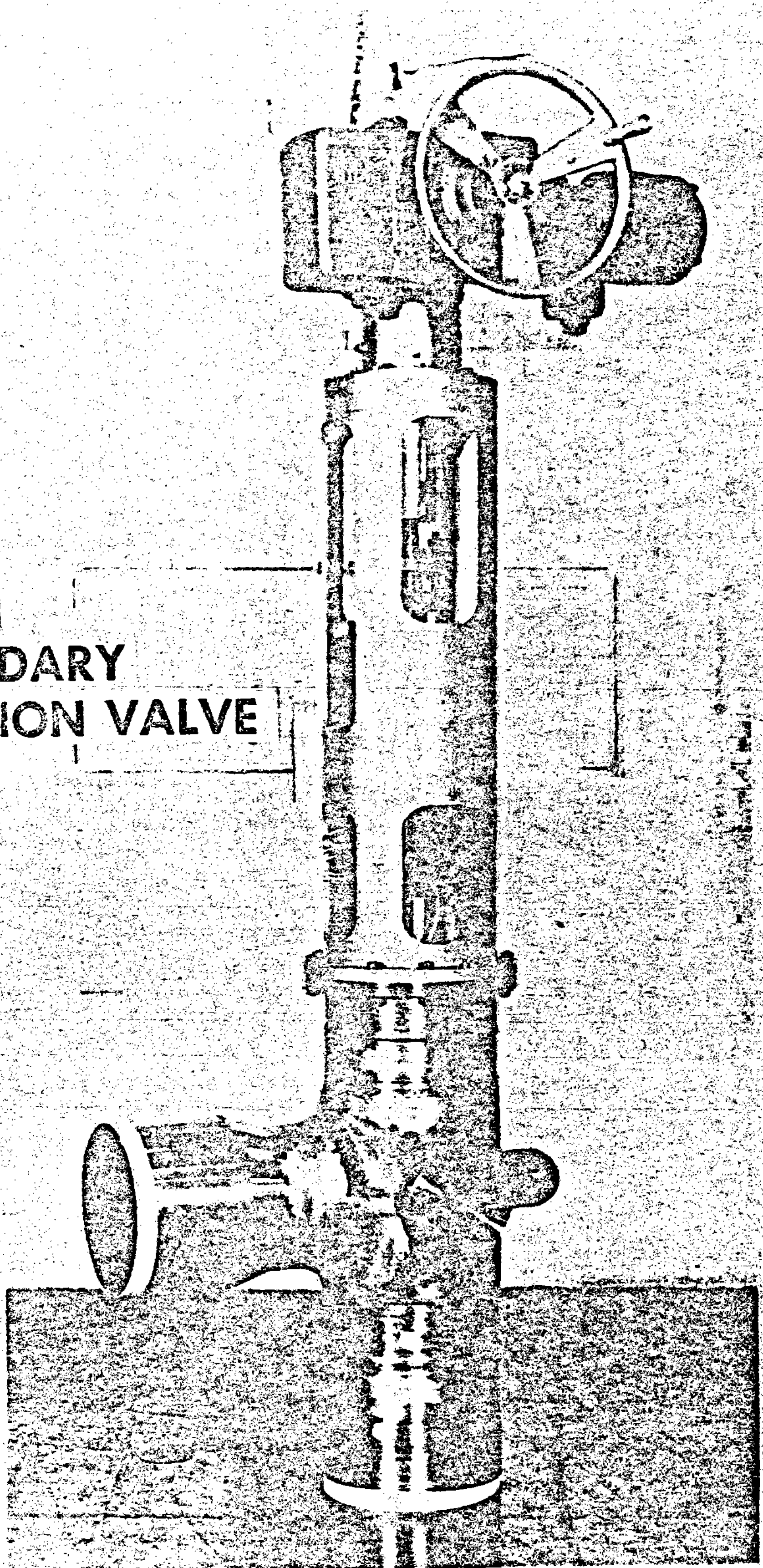






2000 ~ Full open-close
~ 10000 ~ 15-50% open

66-3623-107-2

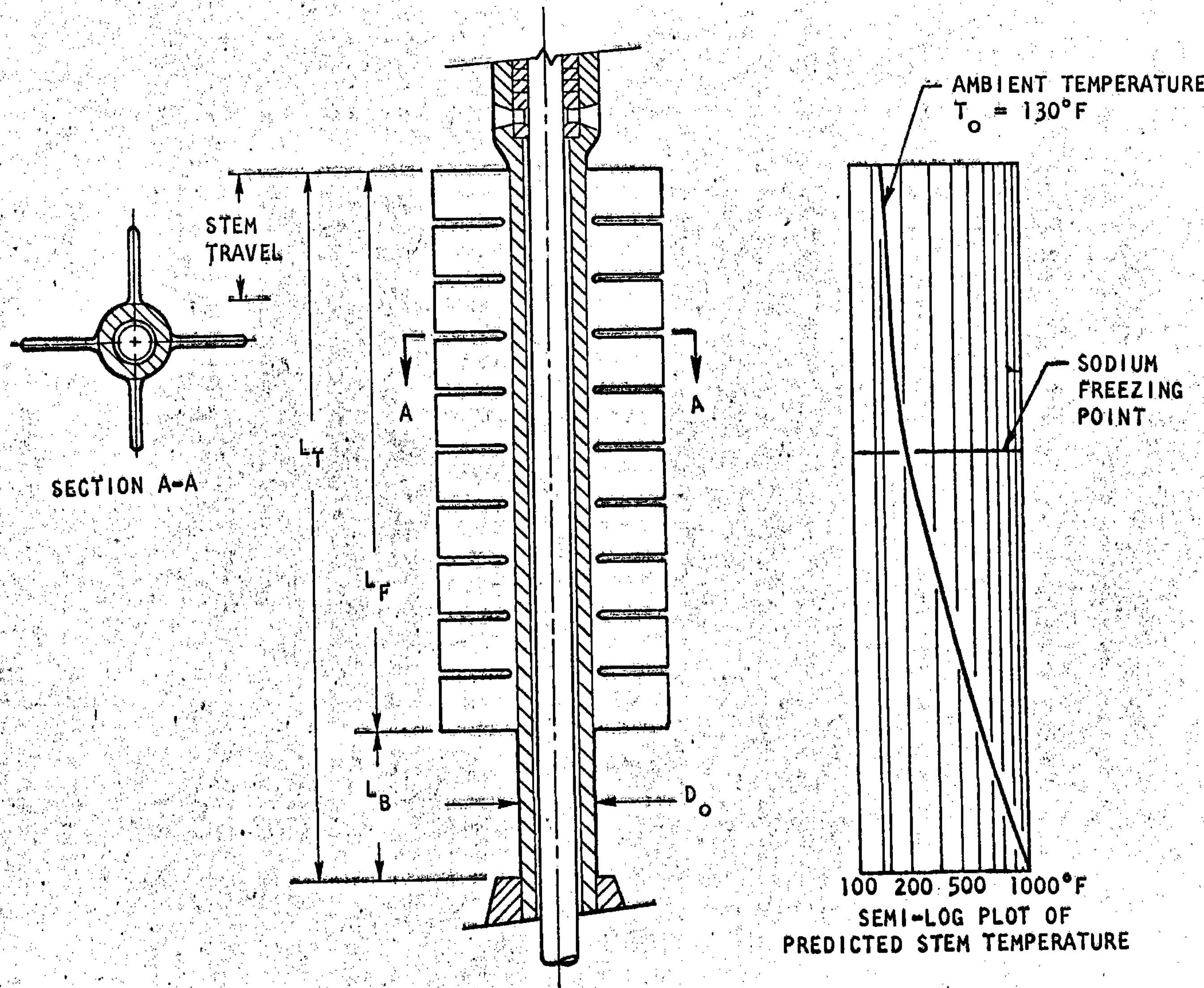


8-INCH
SECONDARY
ISOLATION VALVE

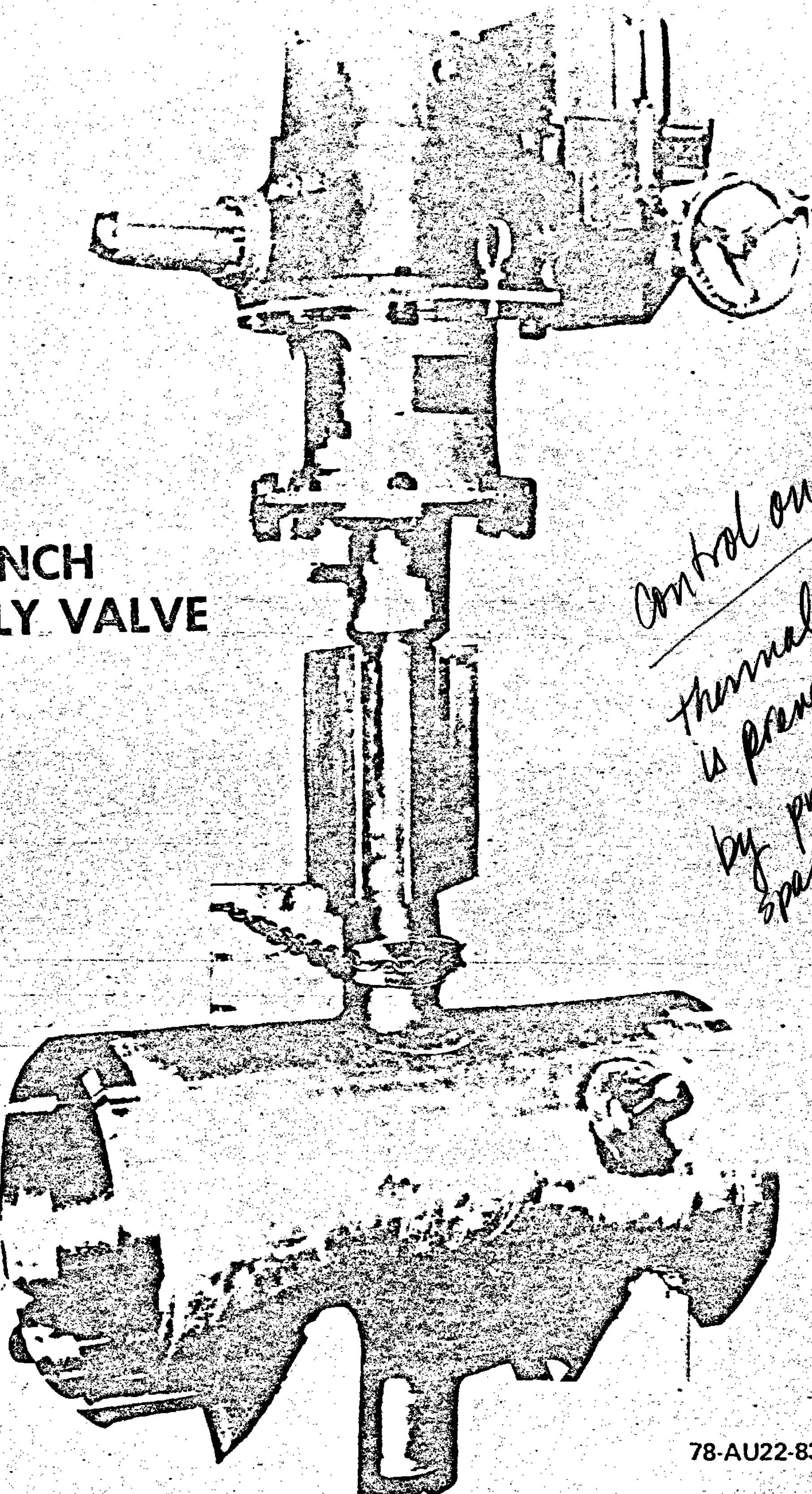
78-AU22-83-9

T. S.

FREEZE SEAL TEMPERATURE PROFILE



70-MA1-48-242



18-INCH BUTTERFLY VALVE

control on rec'r

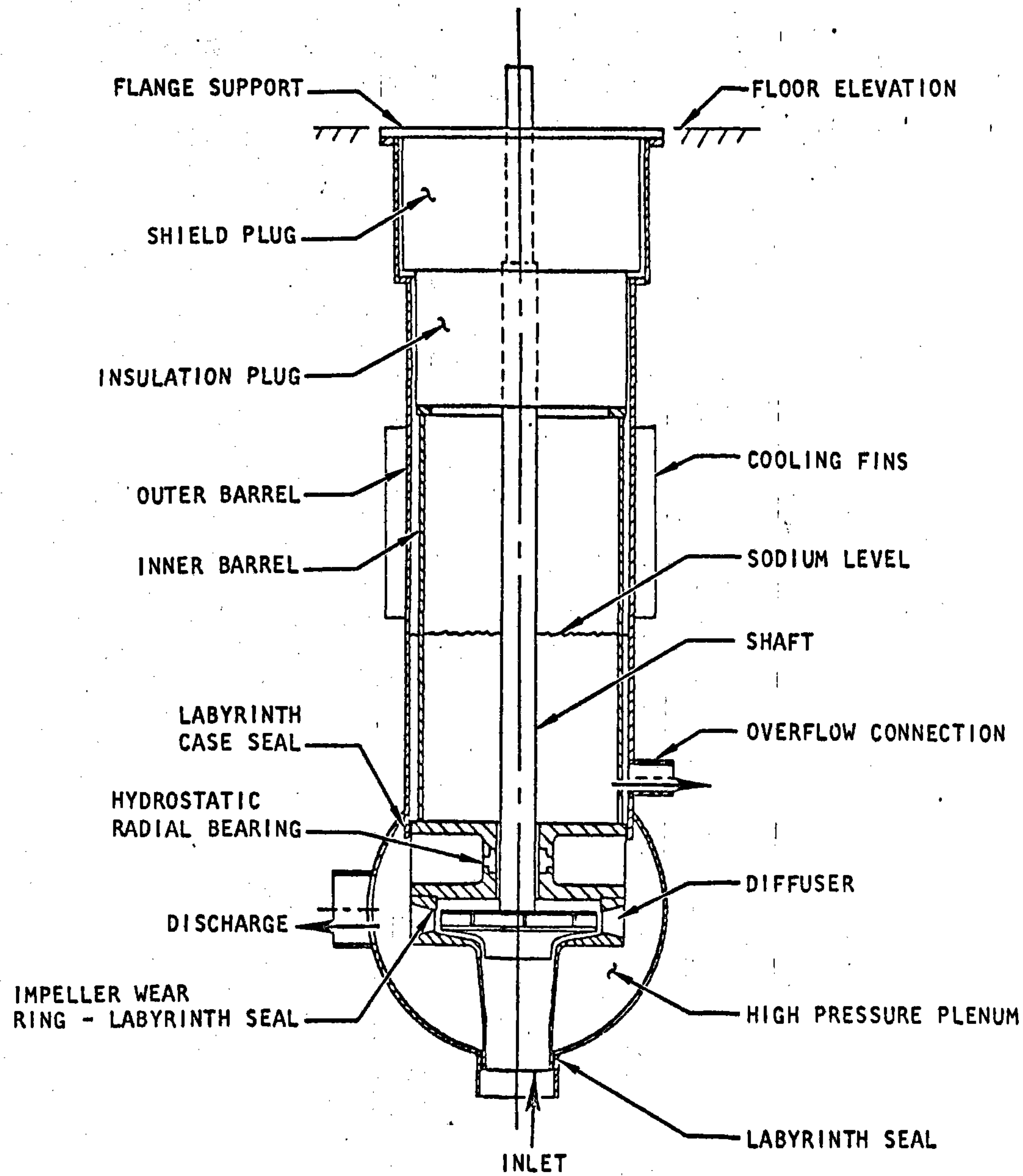
thermal striping is prevented by proper valve spacing

78-AU22-83-8

T. J.

SC 8

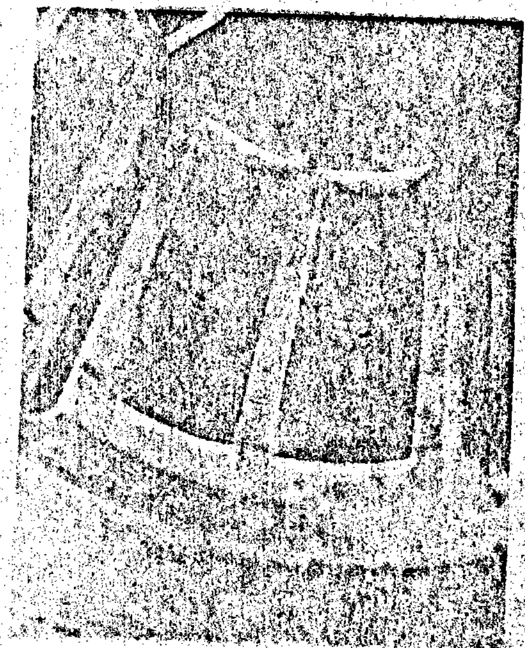
HNPF TYPE PUMP

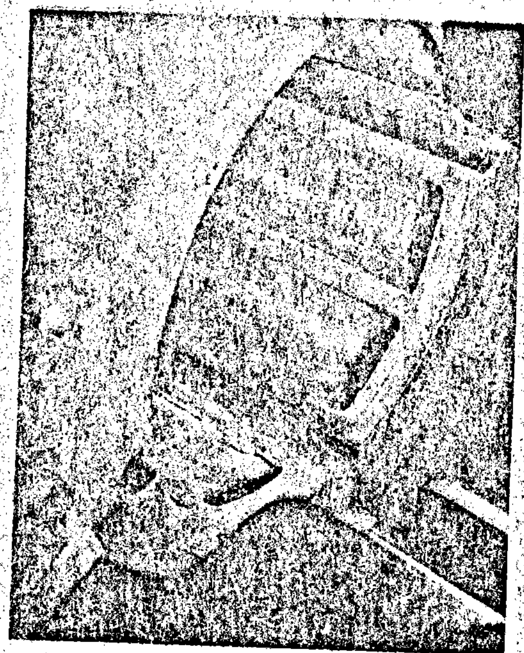


Bearings:
Hard faced +
pump will have pressurized at start up due to Na head in tower.
Hydrostatic bearing will be functioning

70-MA1-48-203

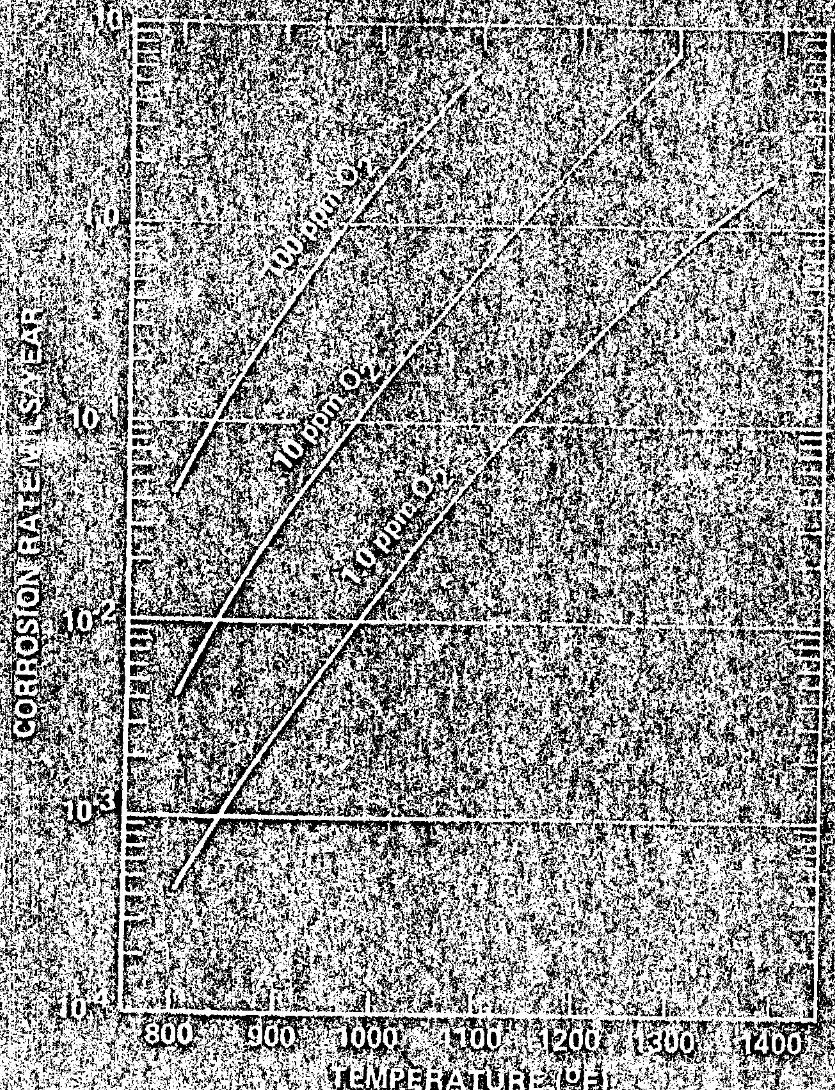
HNPF PUMP BEARING





Atomics International
North American Rockwell

CORROSION OF 316 STAINLESS STEEL BY FLOWING SODIUM



NOTES:

1) FOR SODIUM VELOCITY ~10 ft/s, LOWER CORROSION AT LOWER FLOW

2) OXYGEN ANALYZED BY VANADIUM WIRE, USUALLY 1/10 OF RESULTS BY OTHER METHODS

3) MULTIPLY BY 2 FOR HIGH dT/dZ (i.e. HEAT FLUX)

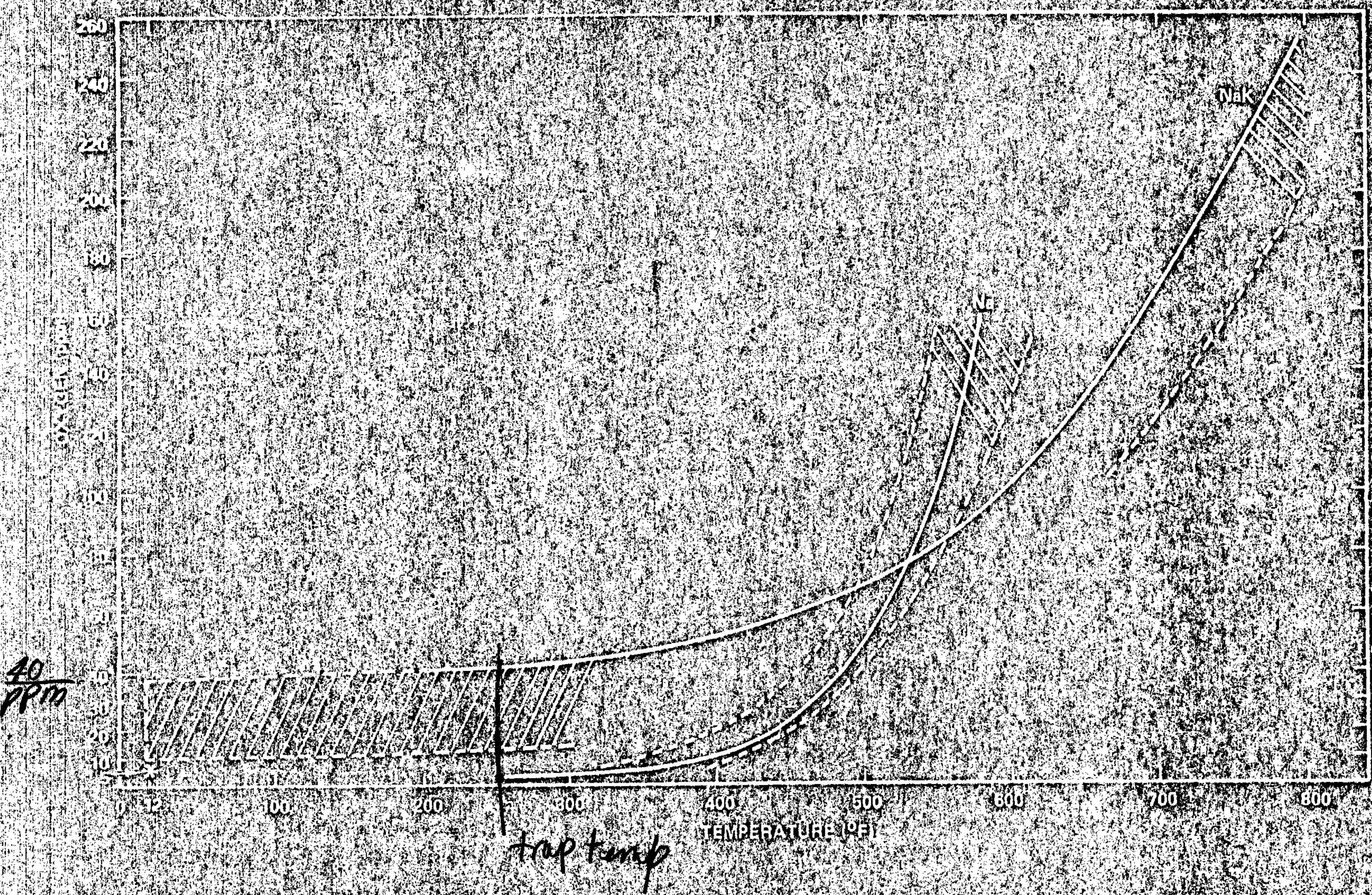
REFERENCE: NUCLEAR SYSTEMS MATERIALS HANDBOOK

Rockwell International
Energy Systems Group

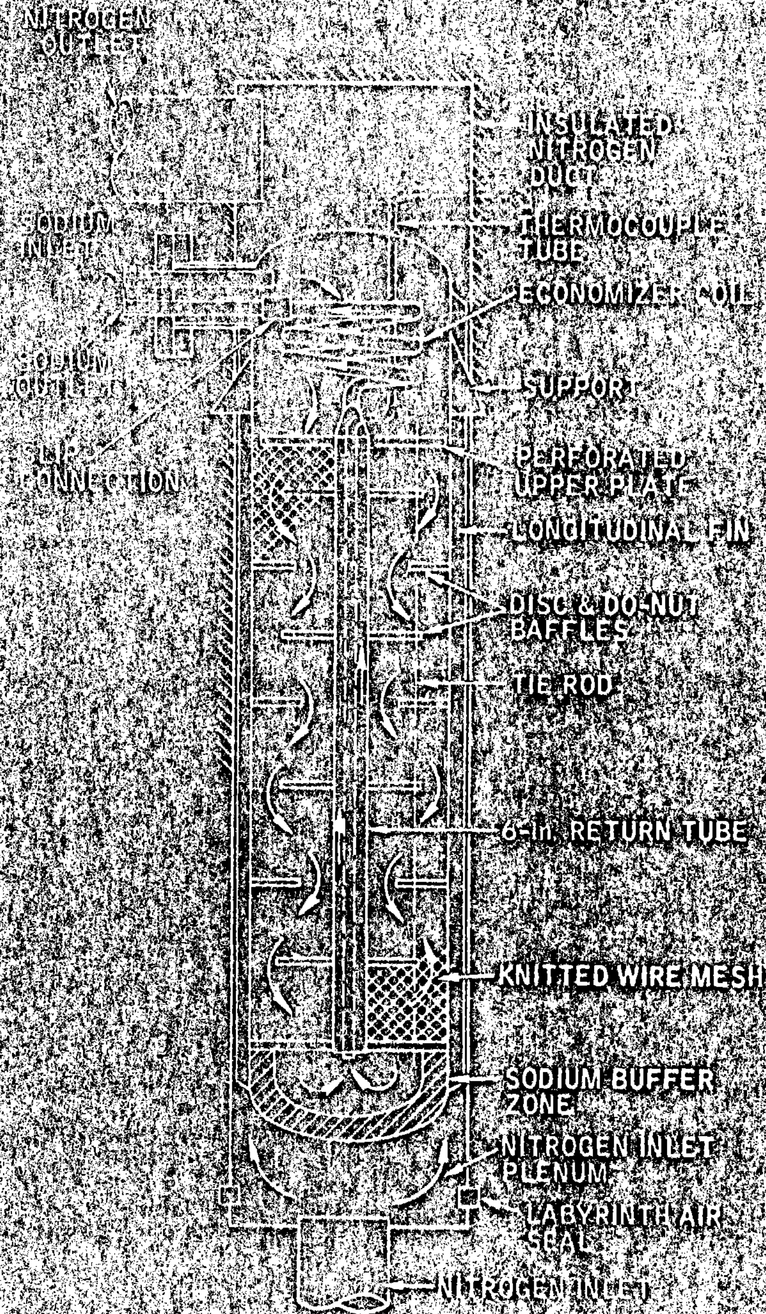
78-D1-133-3

70-S2-04B-384

SATURATION CONCENTRATION FOR OXYGEN IN NaK AND SODIUM



SODIUM COLD TRAP



filter 30gpm
plant 12,000 gpm
40 days to clean up

CONCLUSION:

THE MATERIAL ENGINEERING FOR HIGH TEMPERATURE SODIUM SYSTEMS HAS BEEN COMPLETED AND FIELD TESTED.

REACTOR AND TEST LOOP EXPERIENCE

SODIUM HEATER EXPERIENCE

SODIUM HEATER EXPERIENCE

- SODIUM COMPONENT TEST INSTALLATION
  1. TWO HEATERS
  2. 35 MWT EACH
- H-1
  1. BUILT 1954
  2. 50,000 HOURS AT 700°F OR GREATER
- H-2
  1. BUILT 1975
  2. INSTALLATED AND OPERATING

Rockwell International
Energy Systems Group

BJM:1101

SCTI H-1 HEATER SPECIFICATION

GOVERNING SPECIFICATIONS

Knolls Atomic Power Laboratory Specification No. CTU-1 Revision 2, dated October 29, 1953.

DESIGN CONDITIONS

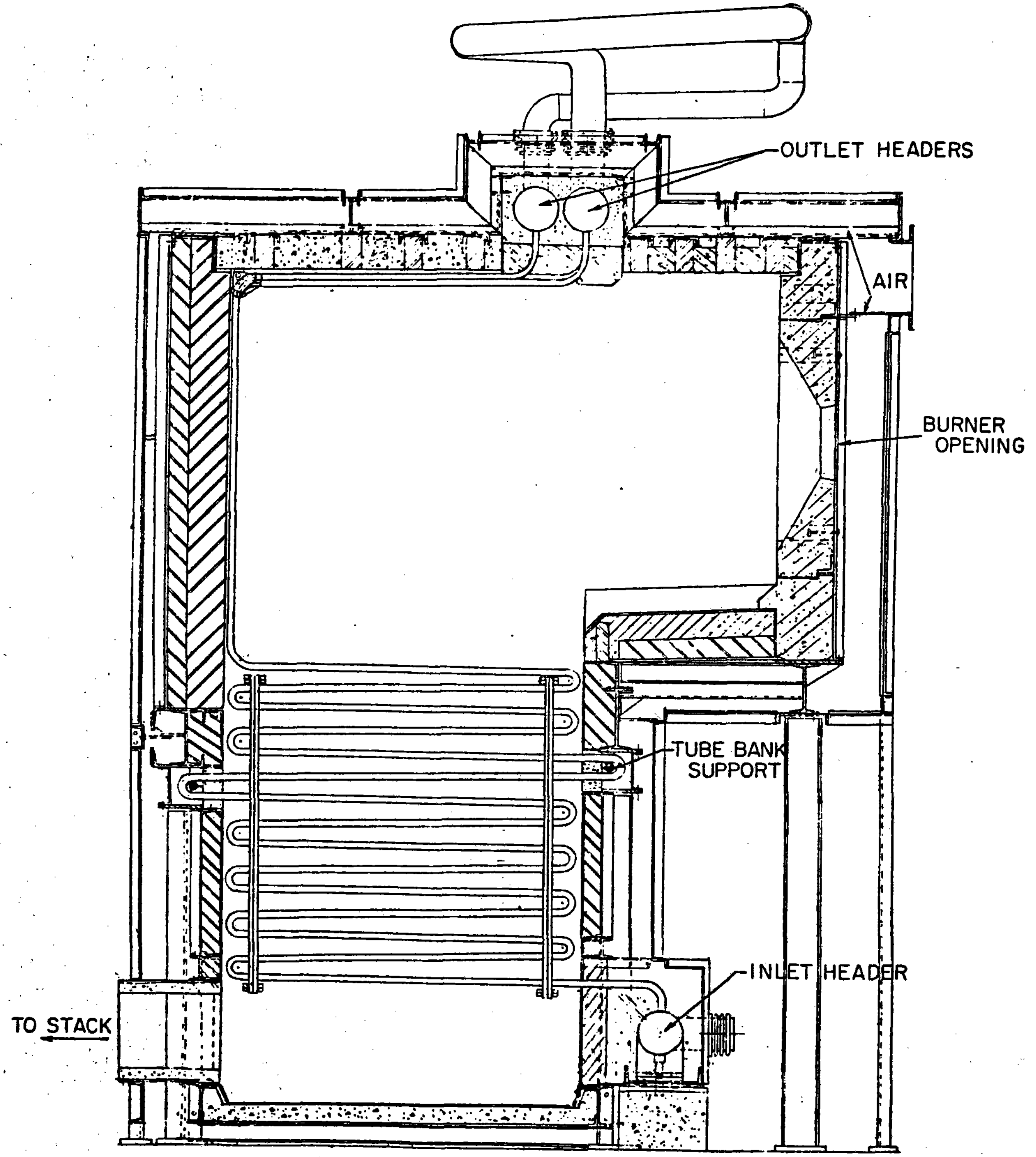
		Operating Load		
		5%	100%	125%
Heat output	Btu/hr	5,000,000	100,000,000	125,000,000
Sodium outlet temperature	^oF	740	850	1,200
Sodium inlet temperature	^oF	470	580	870
Sodium Pressure Drop				
Tubes	psi	--	6.3	6.8
Inlet to outlet	psi	--	8.0	8.7
Fuel rate	gpm	.75	17.4	23.9
Excess Air leaving heater	%	25	25	25
Air Inlet Temperature	^oF	80	80	80
Gas temperature leaving heater	^oF	510	1,000	1,250
Wet gas flow	lb/hr	6,240	146,500	201,000
Air flow to burners	lb/hr	5,900	138,500	190,000
Furnace liberation	B/hr ft^3	2,620	61,400	84,100
Dry gas loss	%	9.7	20.7	26.3
Water from AF fuel loss	%	6.3	7.5	8.1
Moisture in Air loss	%	0.2	0.5	0.7
Unburned combustion loss	%	0.0	0.0	0.0
Radiation loss	%	2.3	1.6	1.2
Unaccounted for loss	%	1.5	1.5	1.5
Total losses	%	20.0	31.8	37.8
Efficiency	%	80.0	68.2	62.2

SCTI H-1 HEATER

GENERAL HEATER DATA

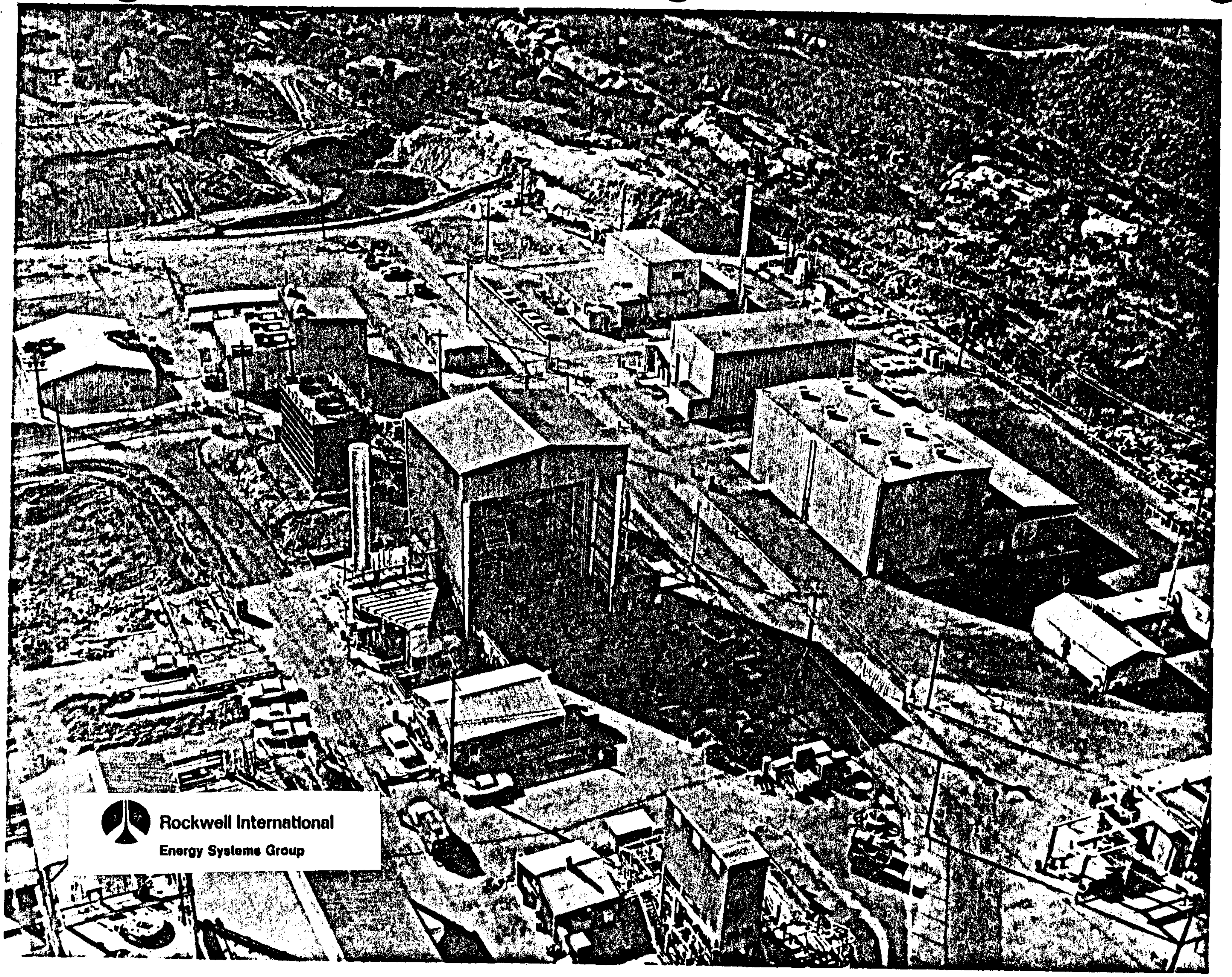
Weight of Heater	295,000 lbs
Volume	2,200 cu ft
Volume of Sodium (in heater)	168 cu ft
Convection Volume	1,890 cu ft
Tubes	1¼ OD x 0.095 thick minimum wall
Heating Surface	7,344 sq ft
Header Design Pressure	200 psi
Casing Design Pressure	18 in H_2O

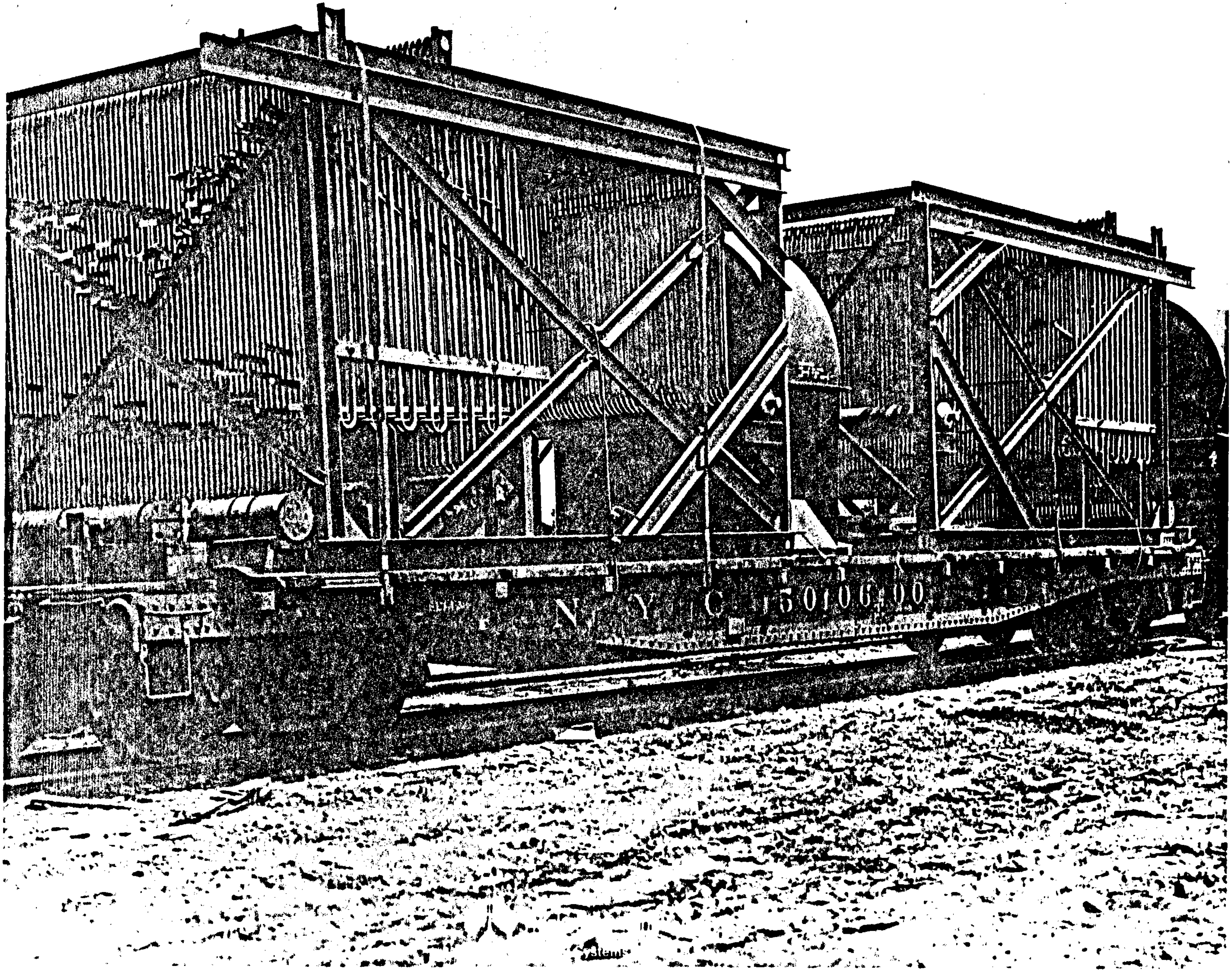
Rockwell International
Energy Systems Group

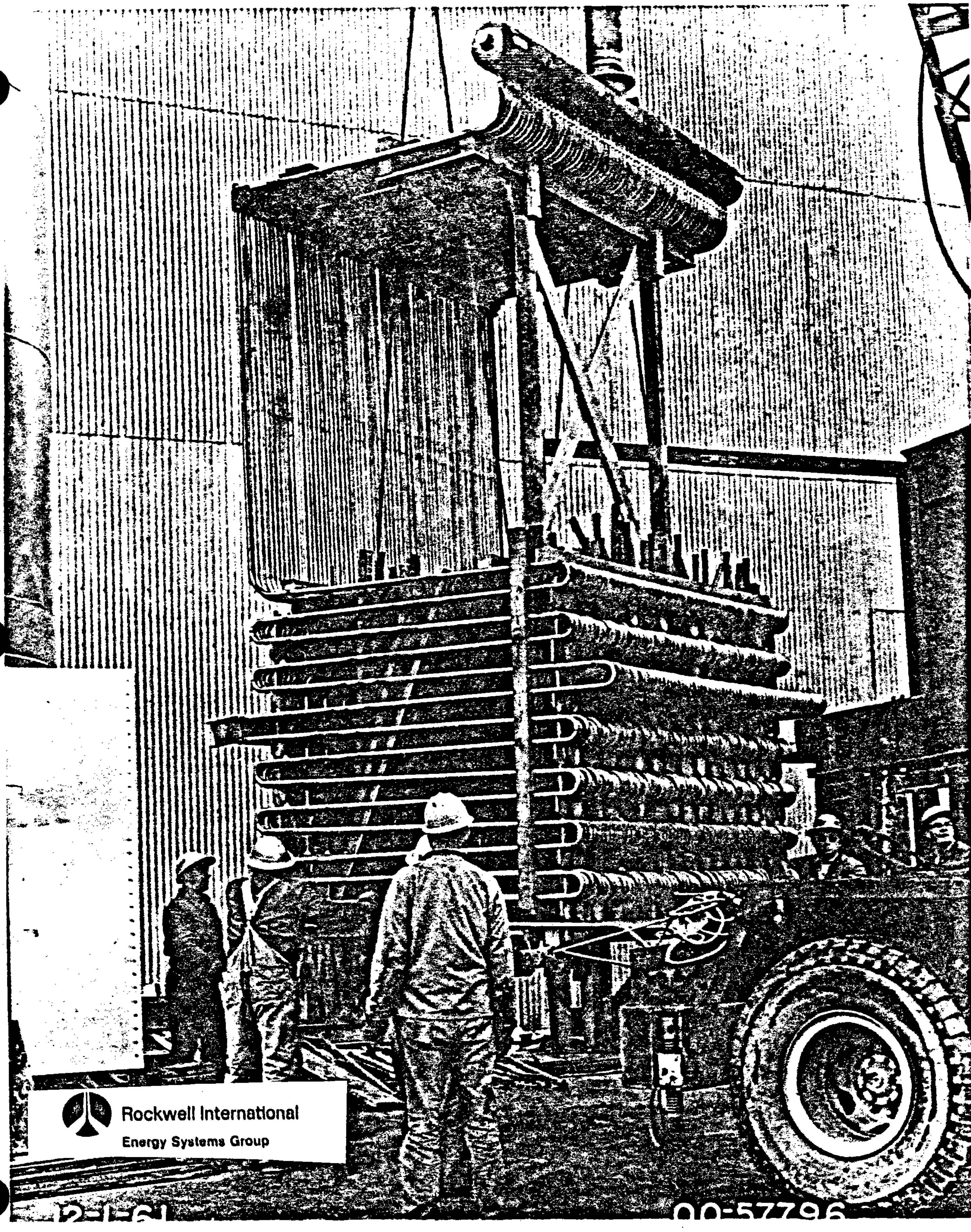


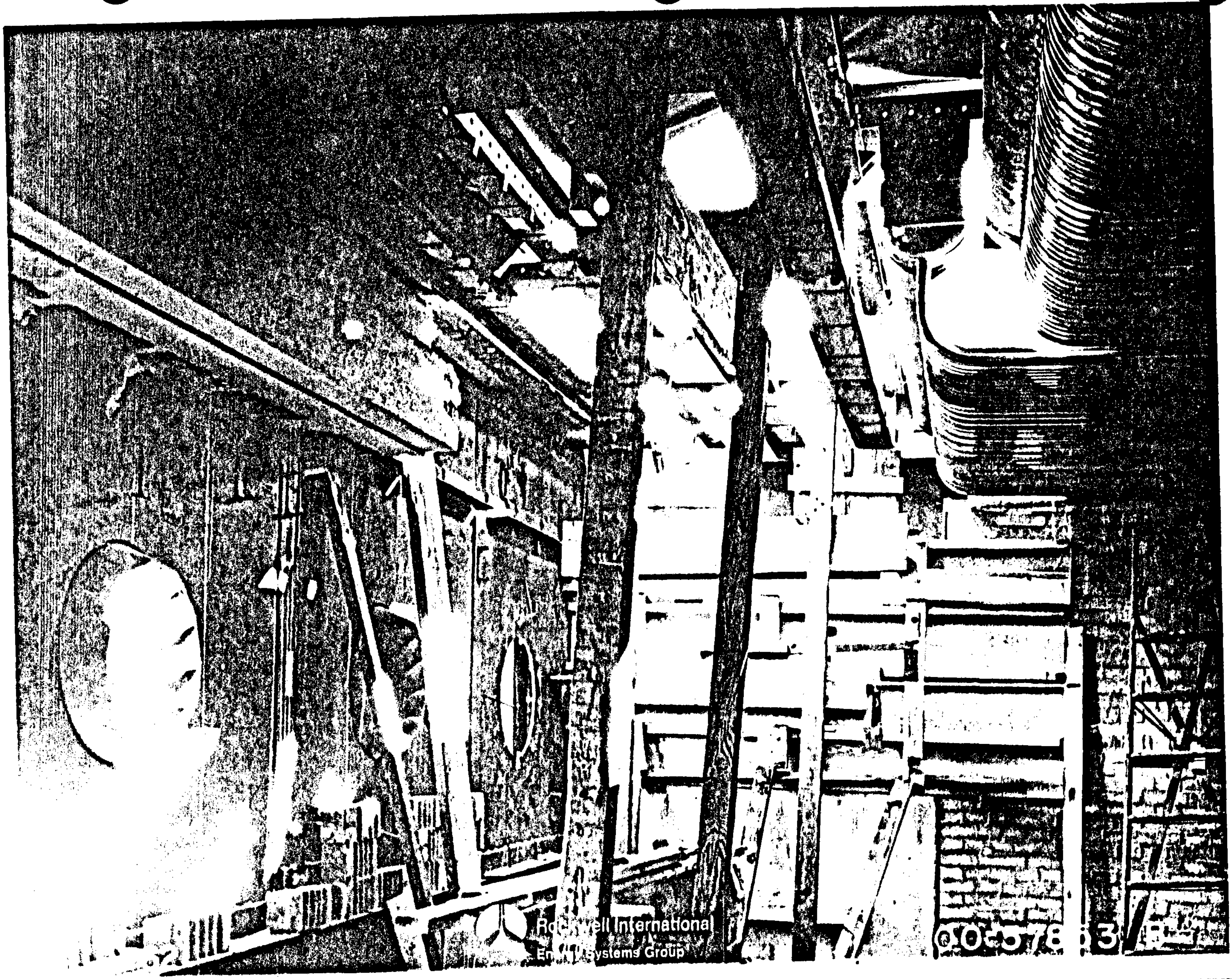
SCTI H-1 SODIUM HEATER

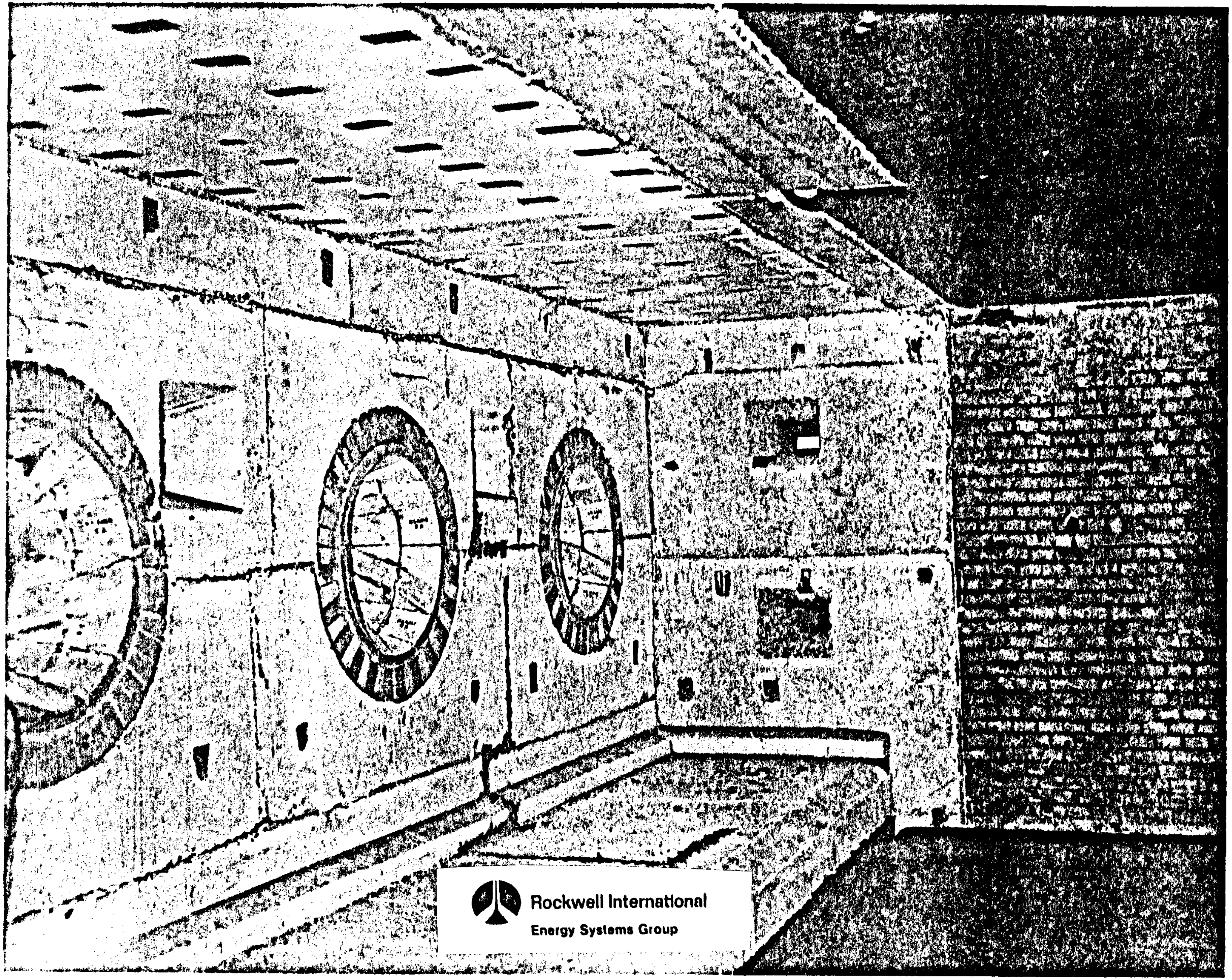
Rockwell International
Energy Systems Group

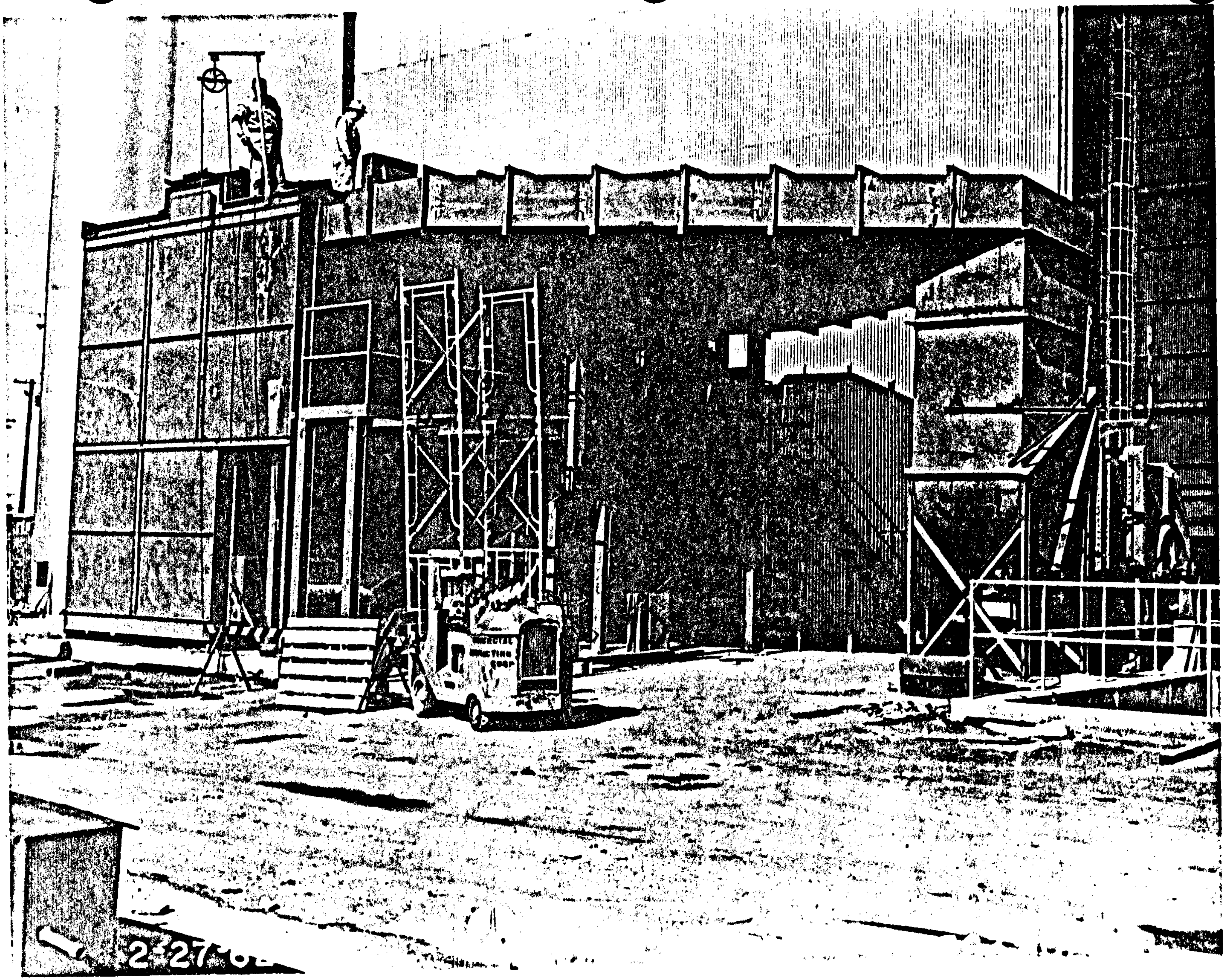

Rockwell International
Energy Systems Group

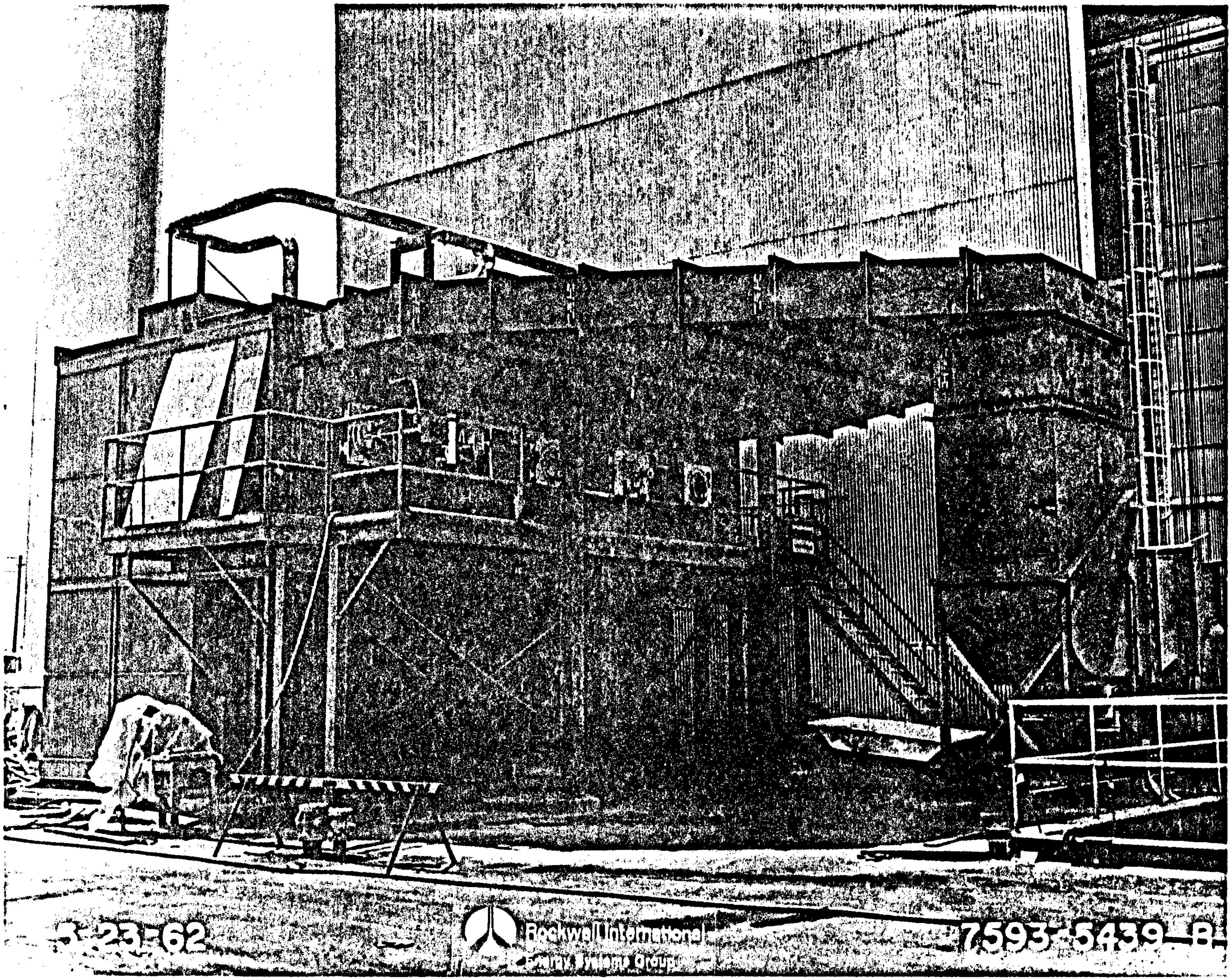

N Y C

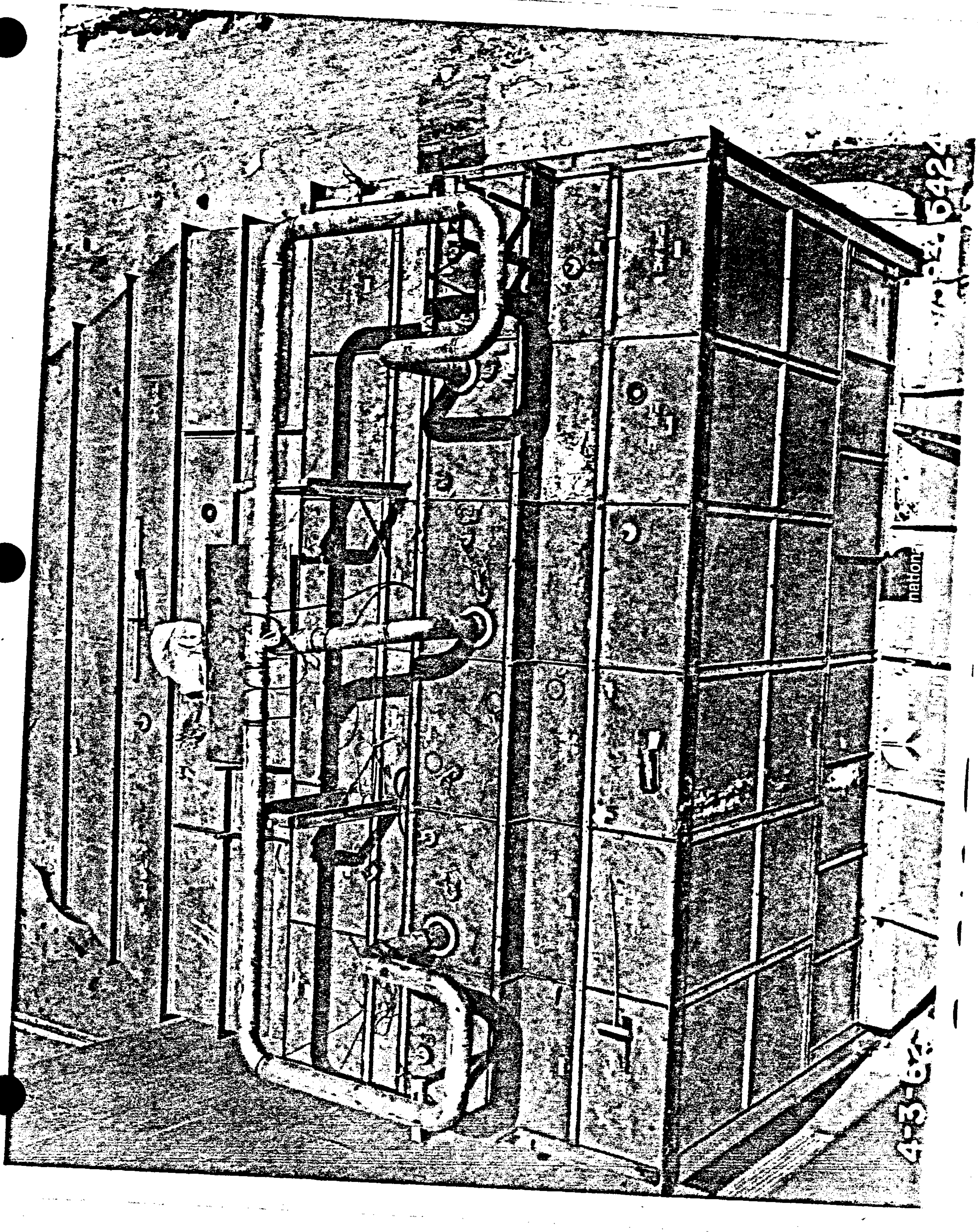

Rockwell International
Energy Systems Group
2-1-61
00-57796

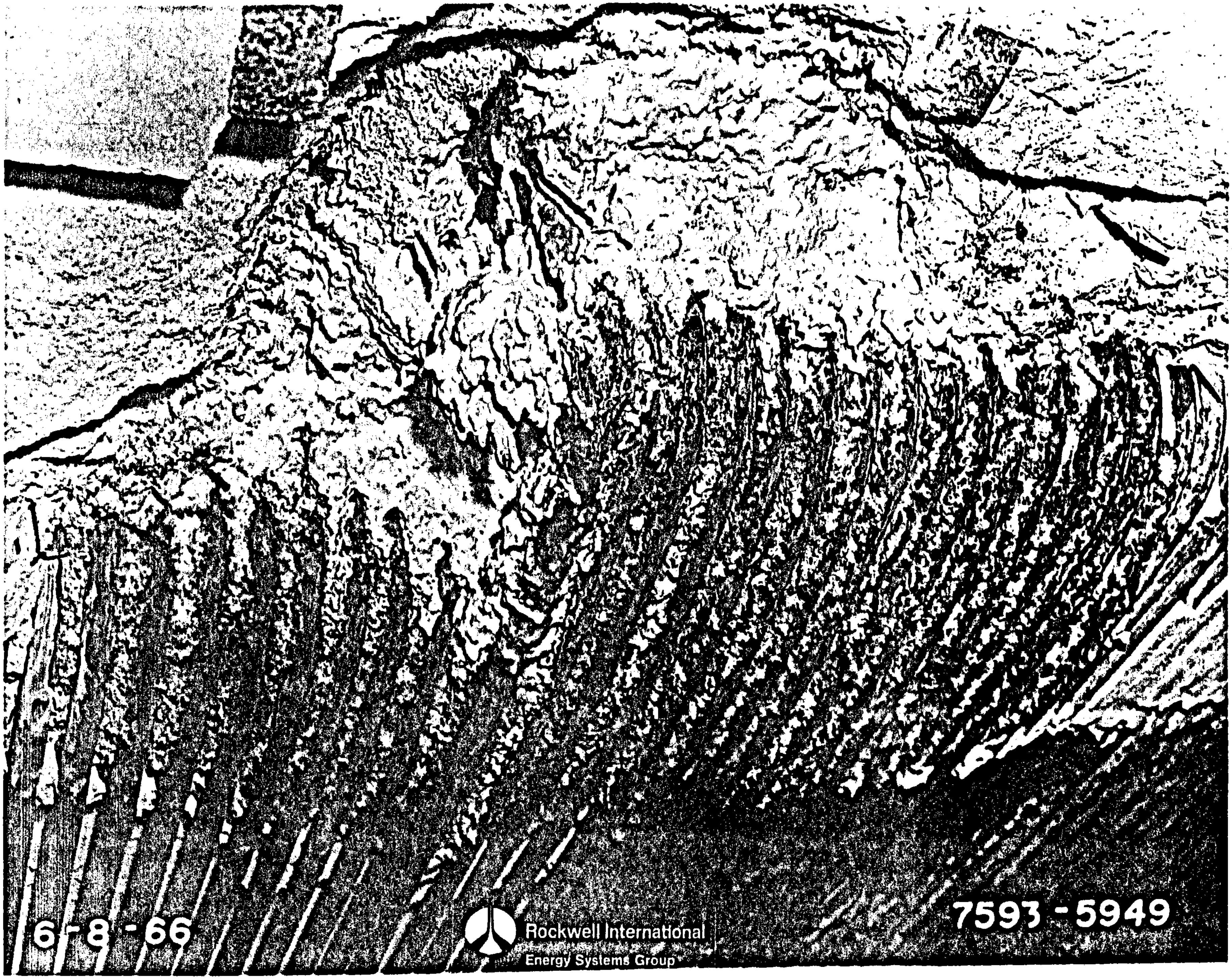

Rockwell International
Energy Systems Group


Rockwell International
Energy Systems Group



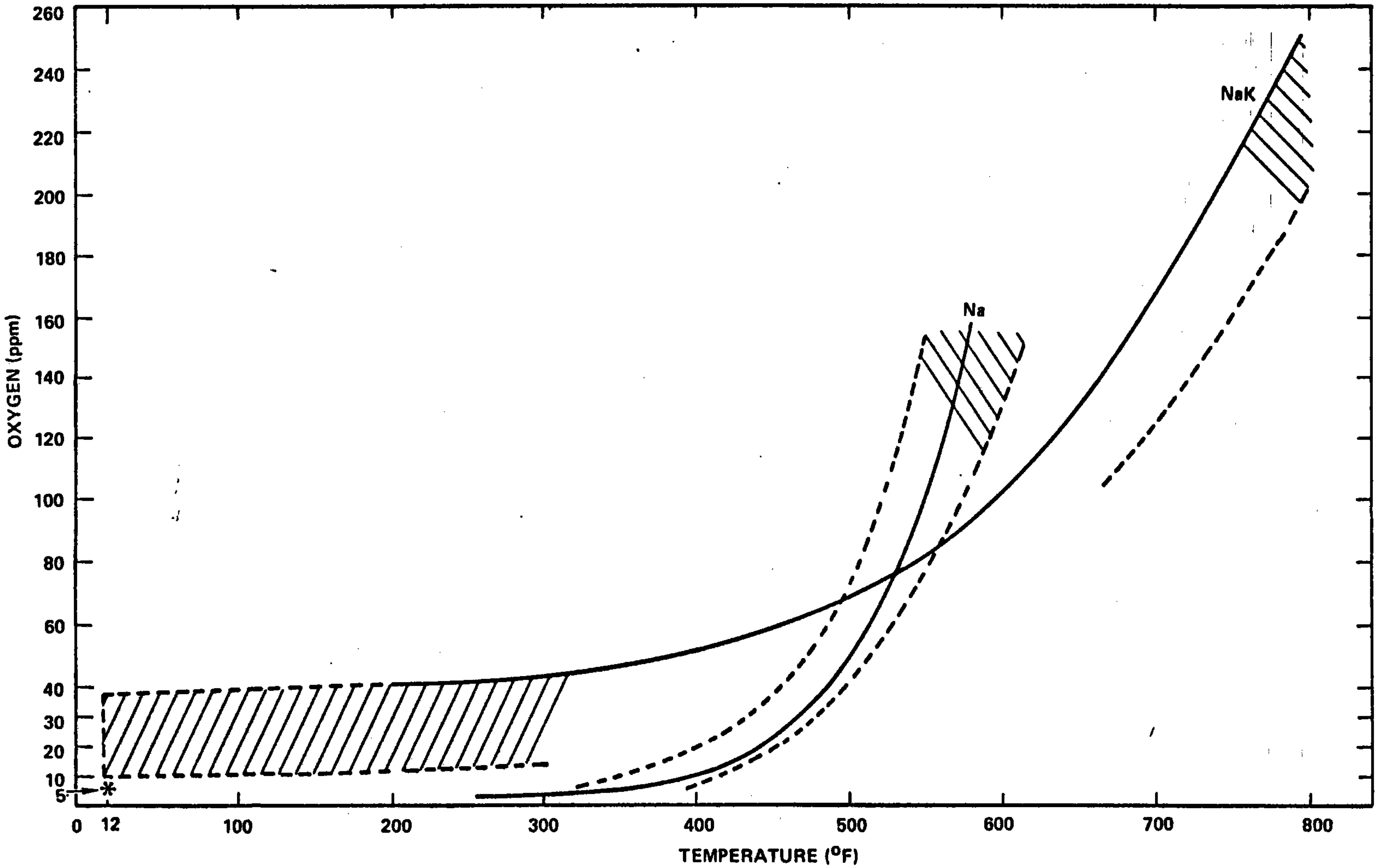

3-23-62
Rockwell International
Energy Systems Group
7593-5439-B

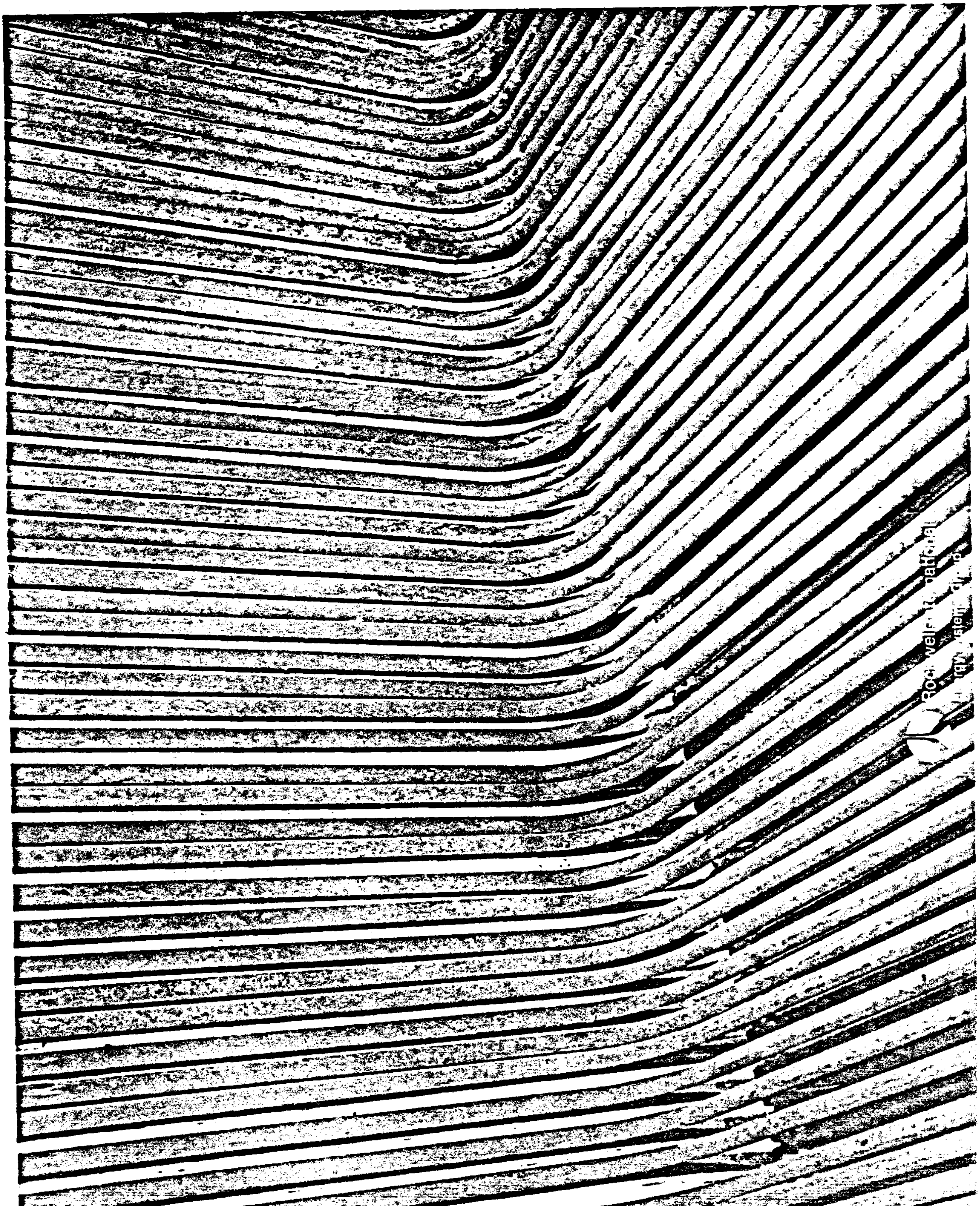

5424
nation

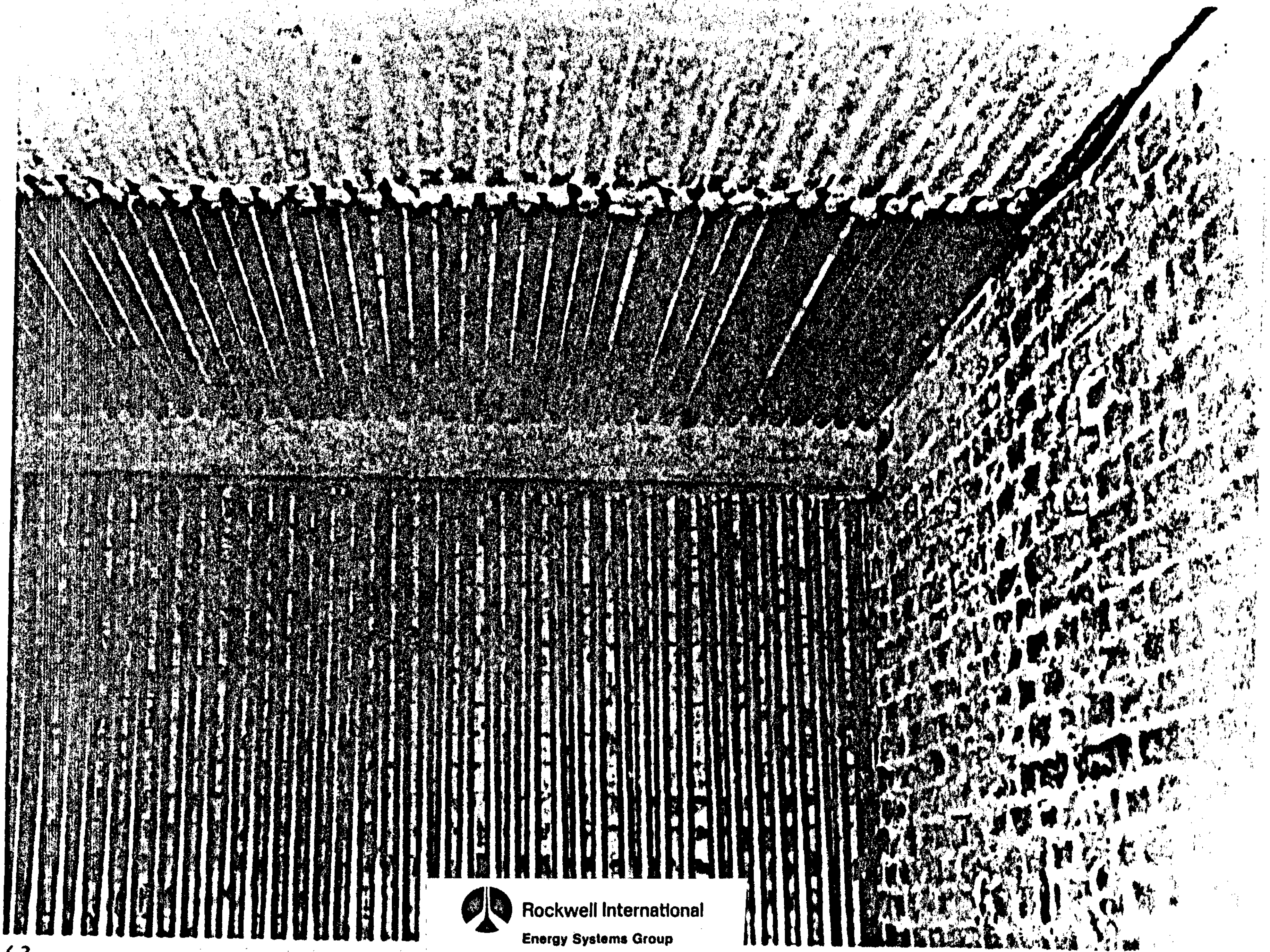

6-8-66
Rockwell International
Energy Systems Group
7593-5949

70-S2-048-384

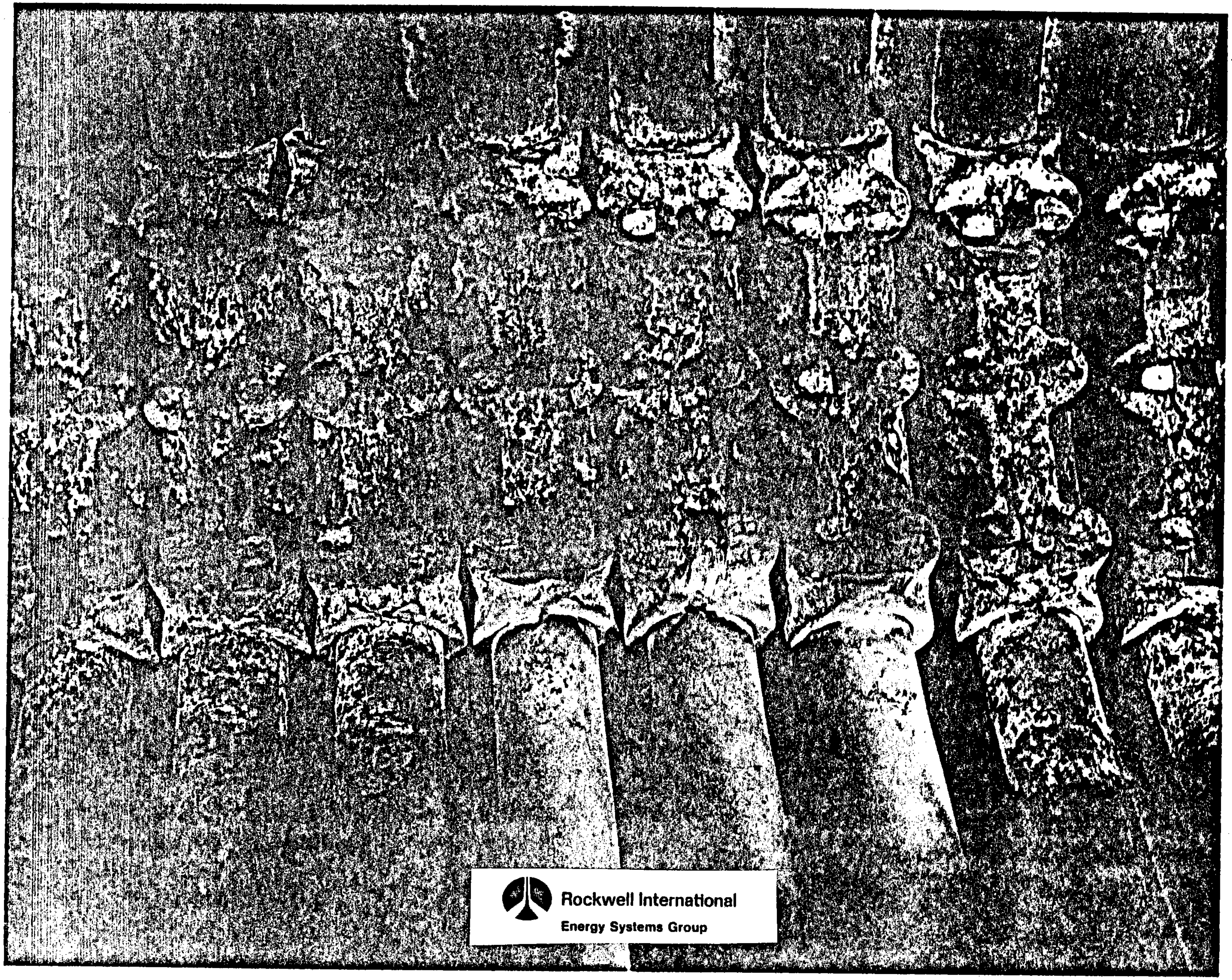
SATURATION CONCENTRATION FOR OXYGEN IN NaK AND SODIUM

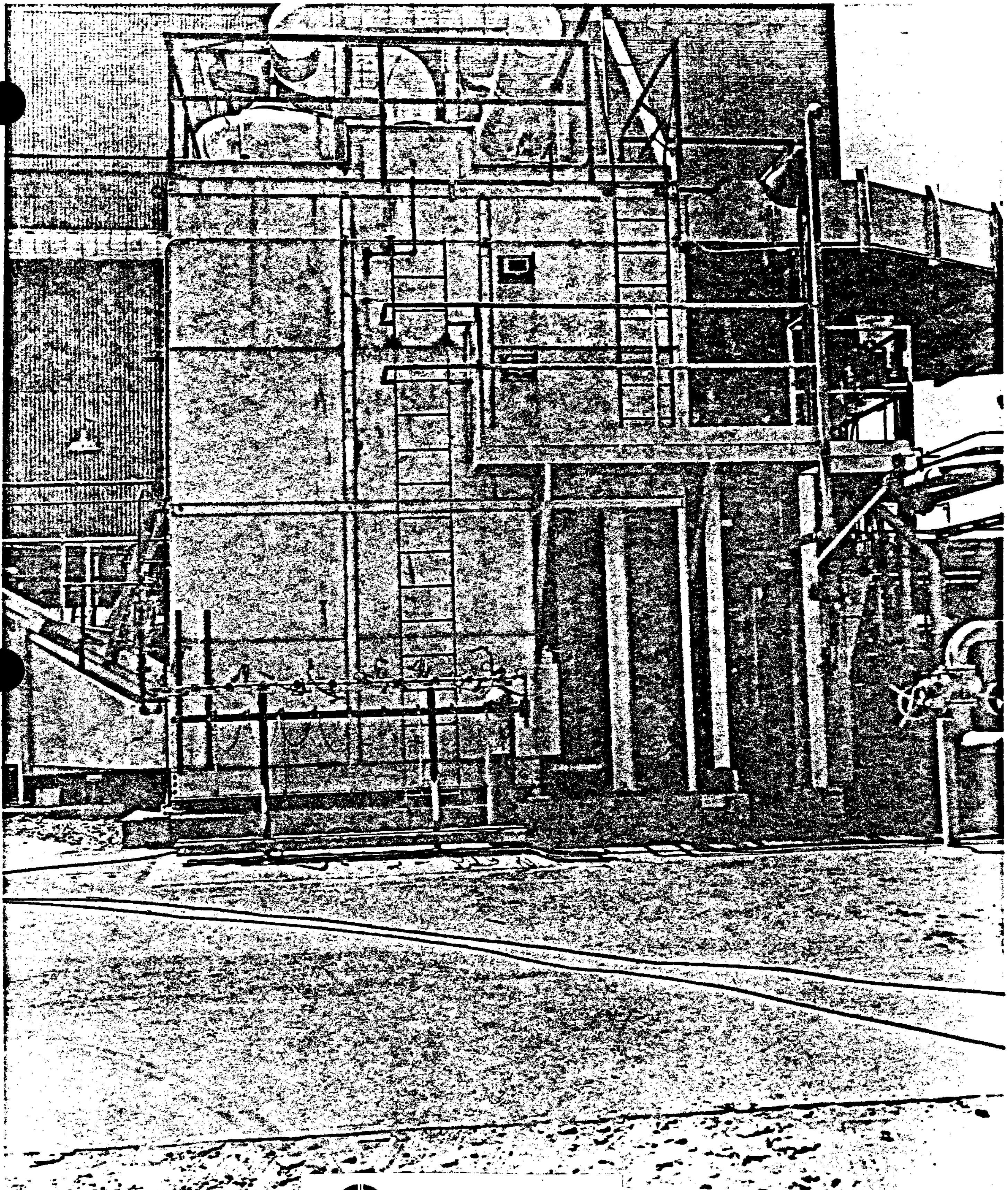




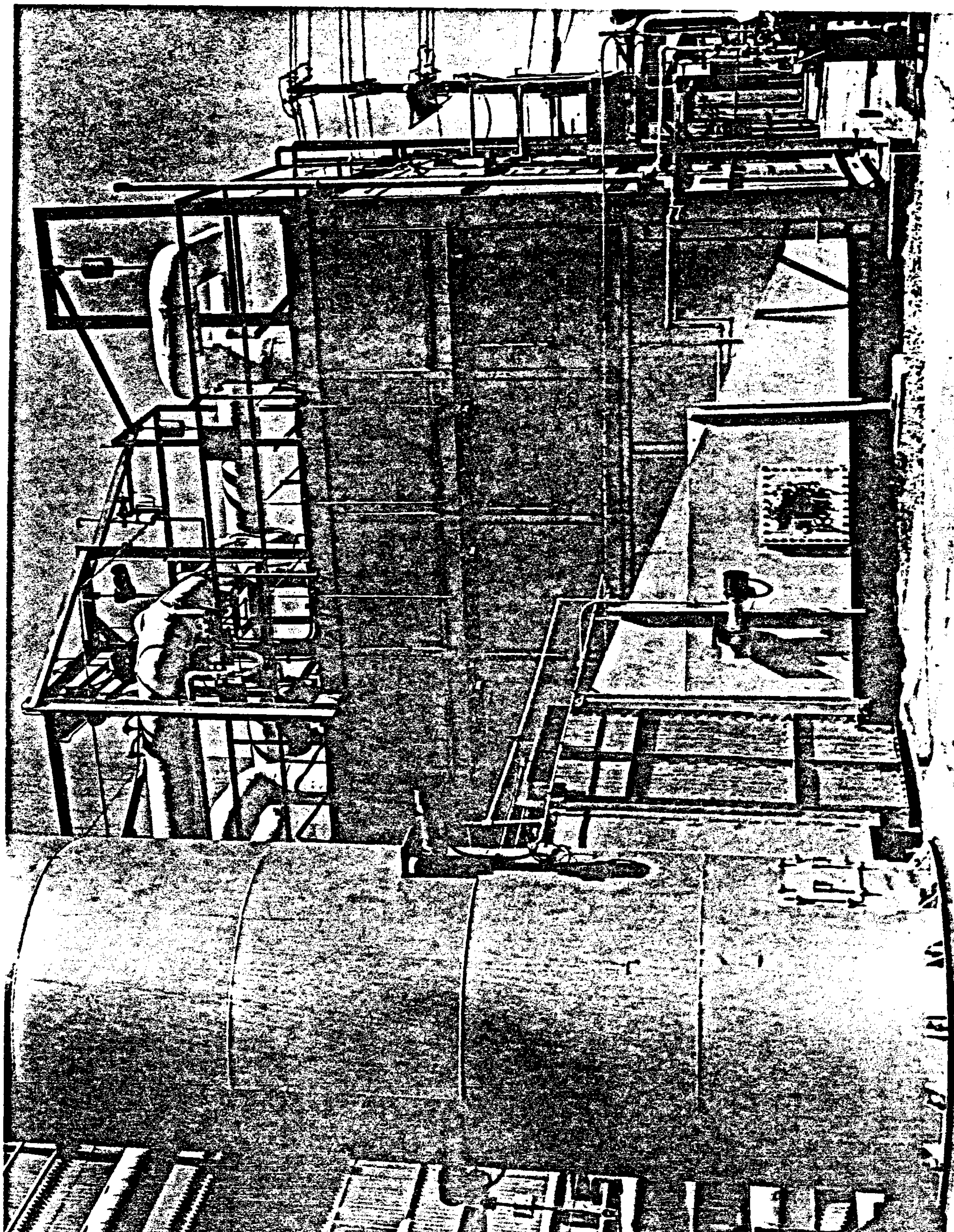


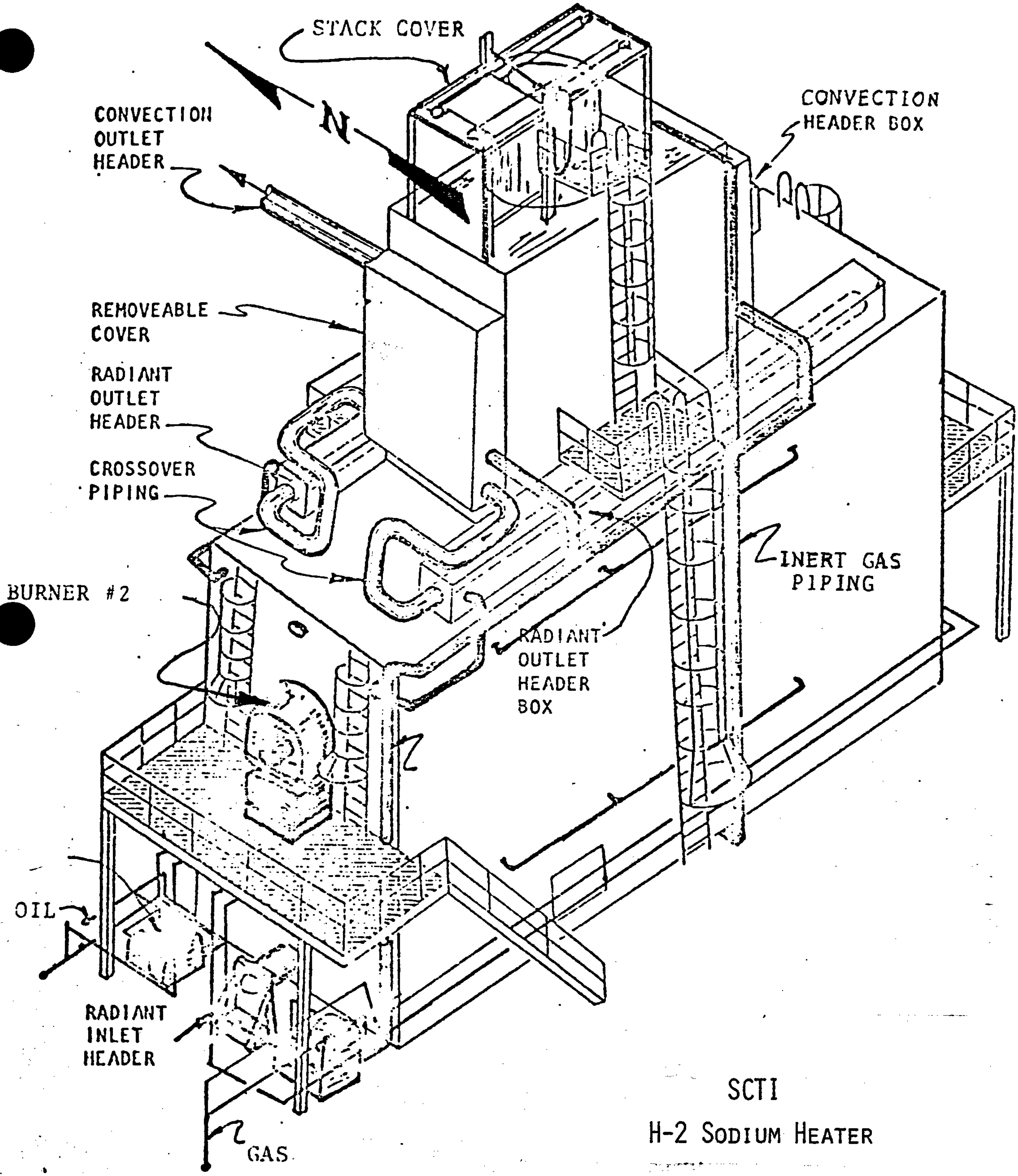
7593-5751


Rockwell International
Energy Systems Group



Rockwell International
Energy Systems Group

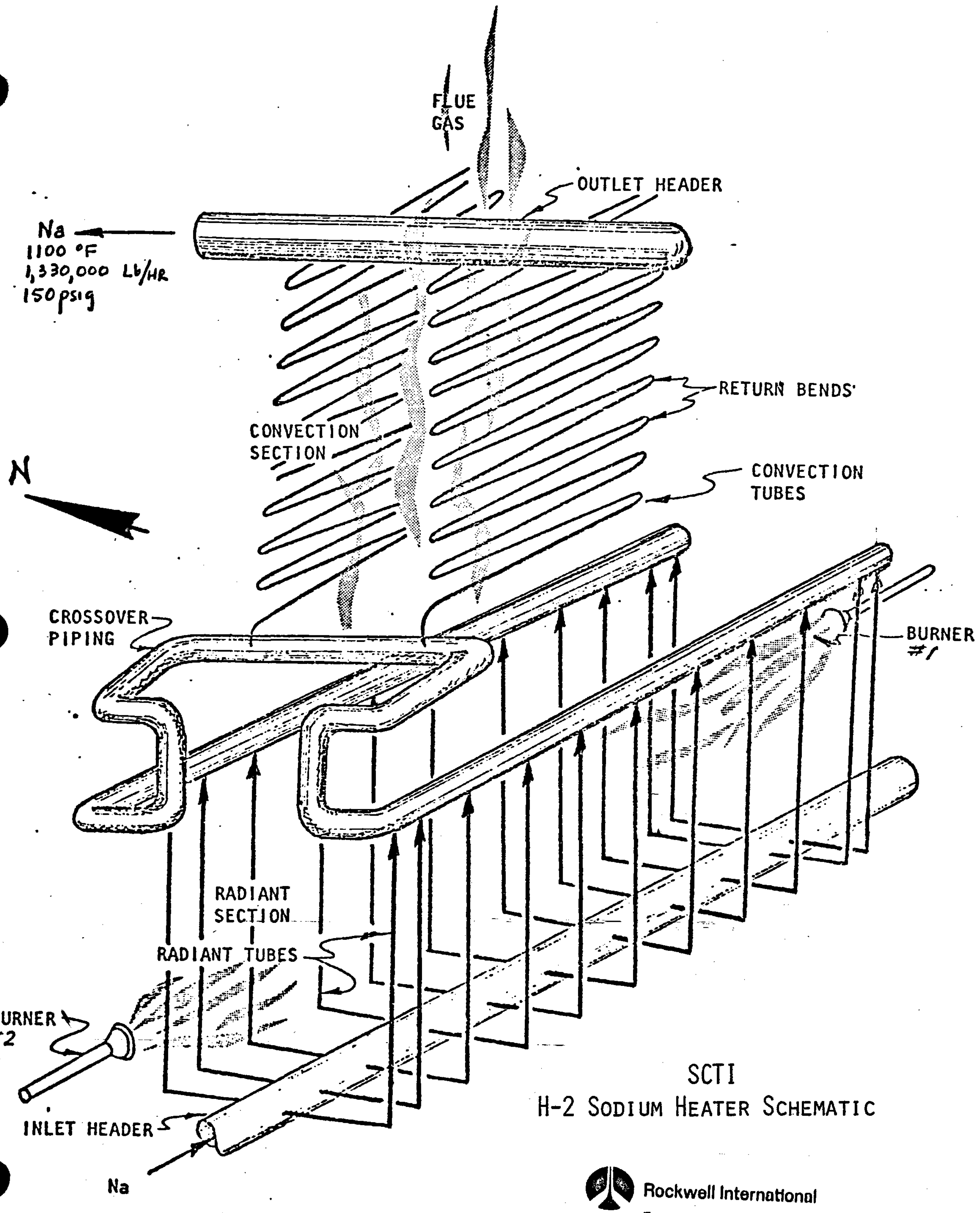




SCTI

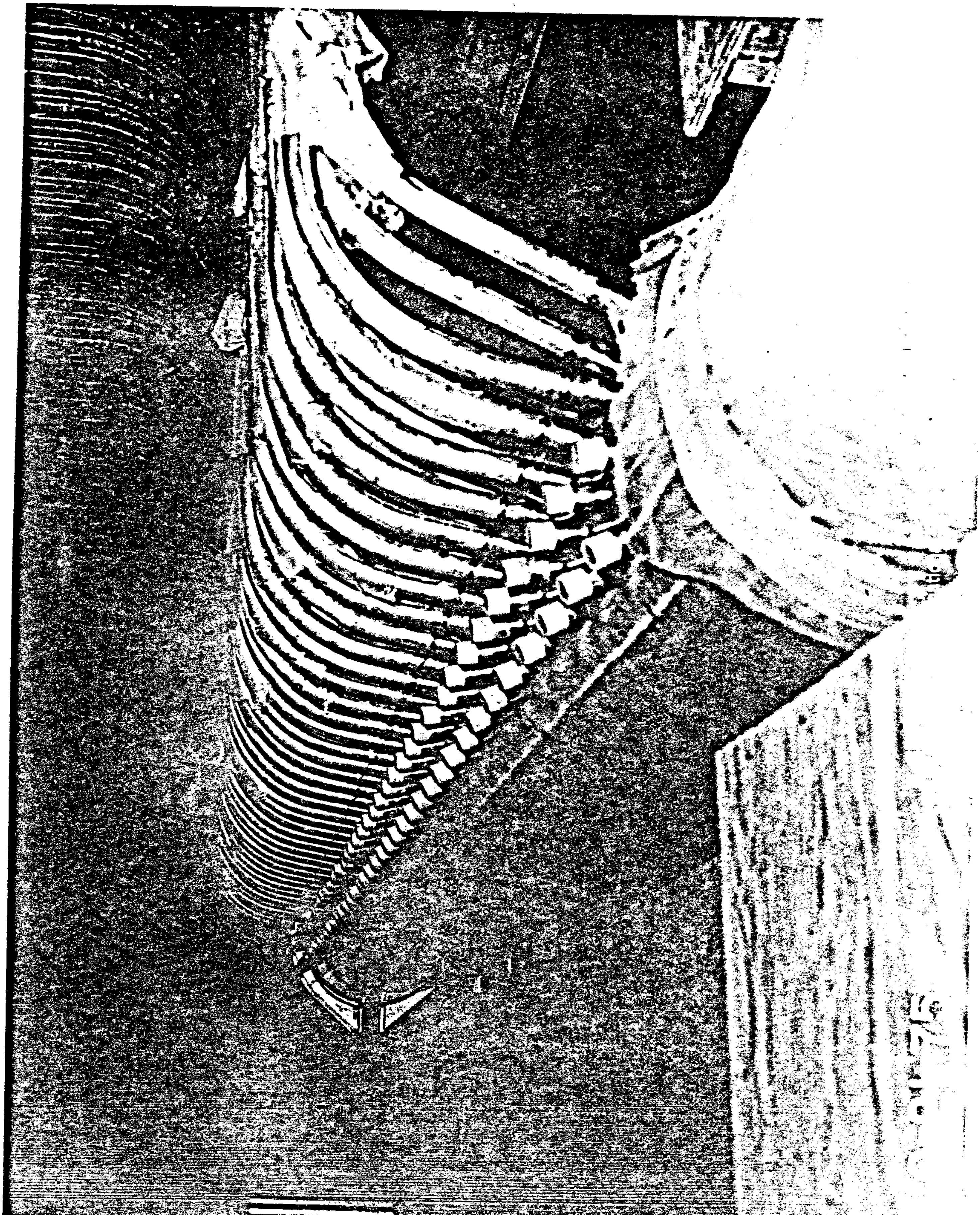
H-2 SODIUM HEATER

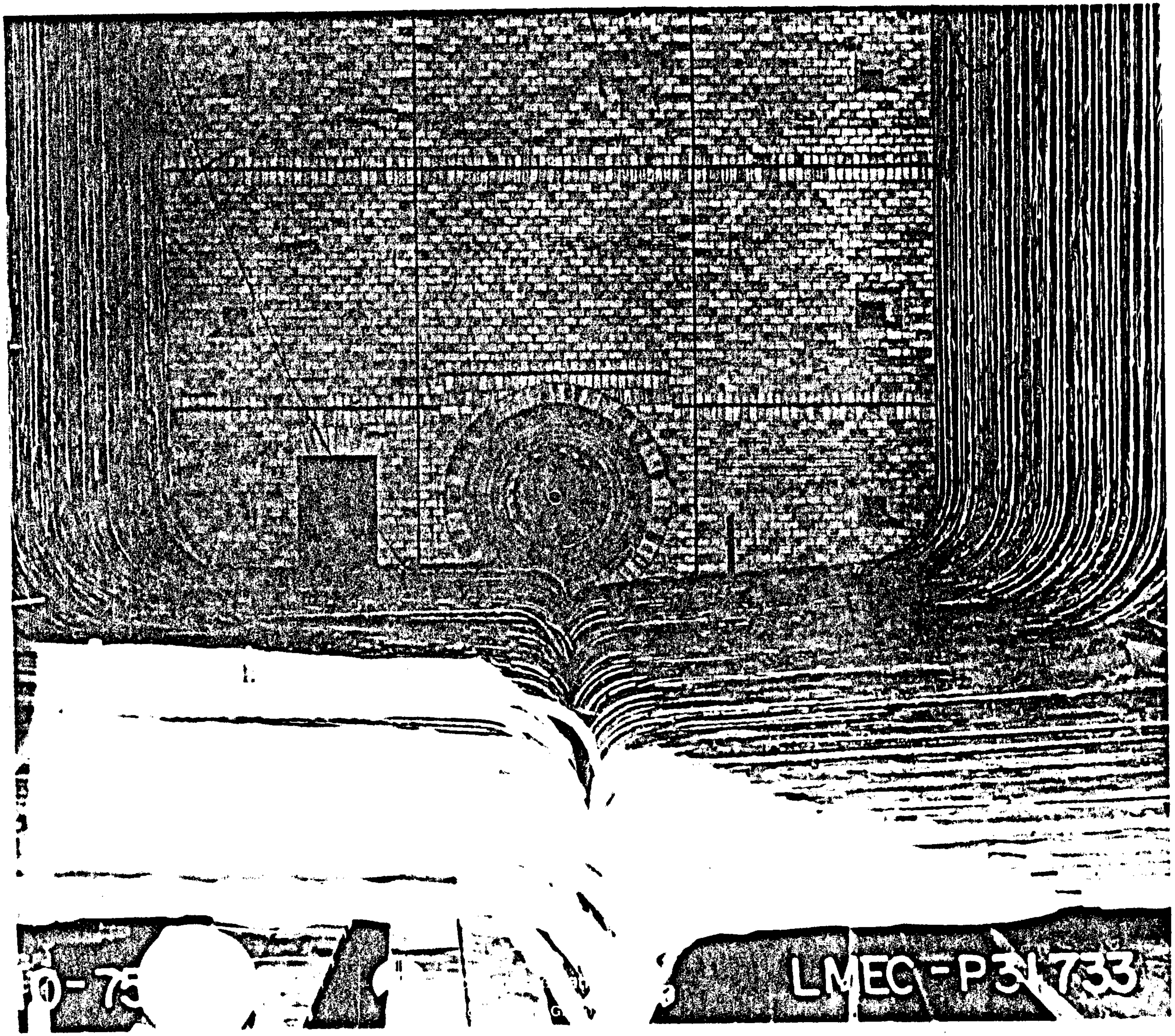
Rockwell International
Energy Systems Group



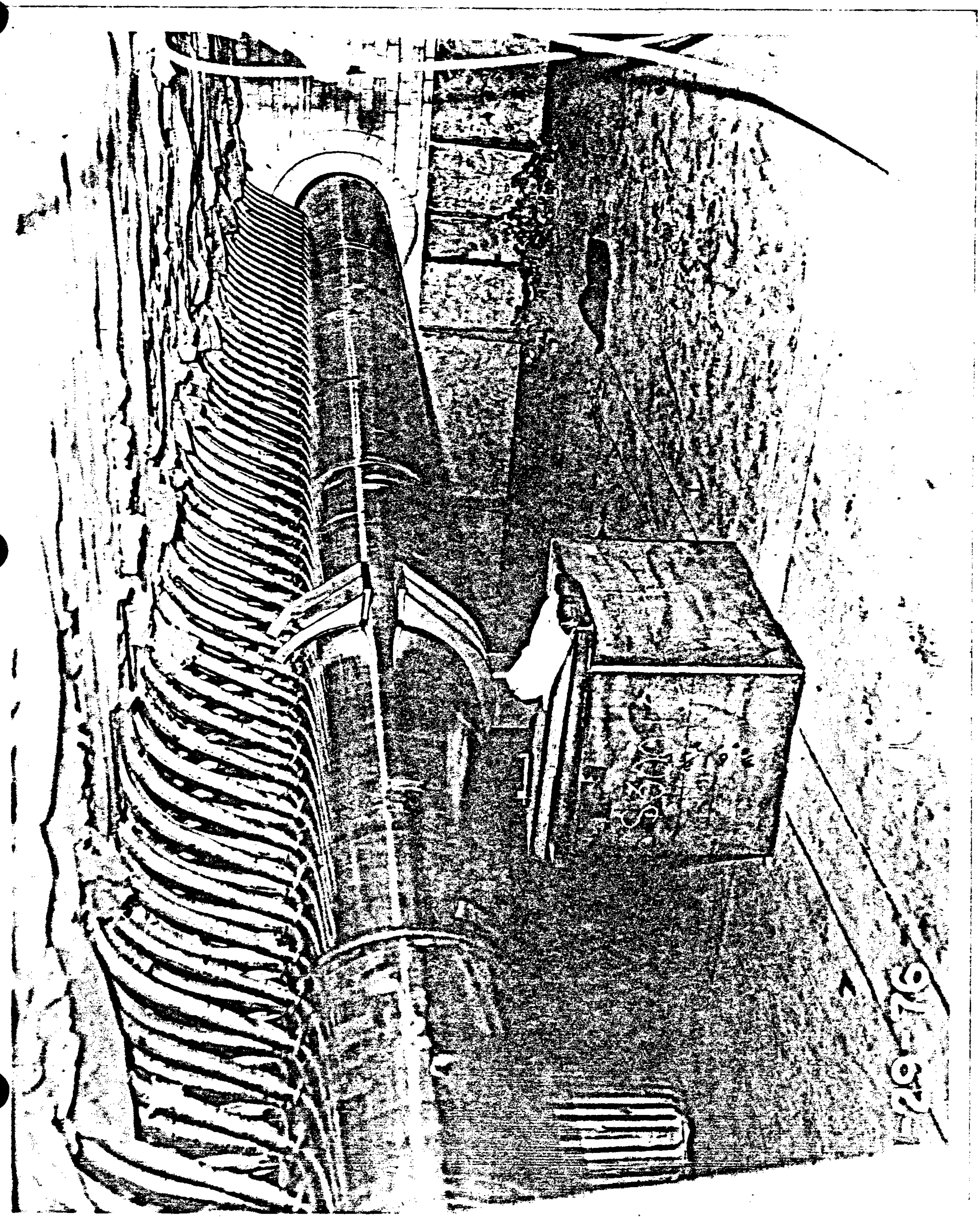
SCTI
H-2 SODIUM HEATER SCHEMATIC

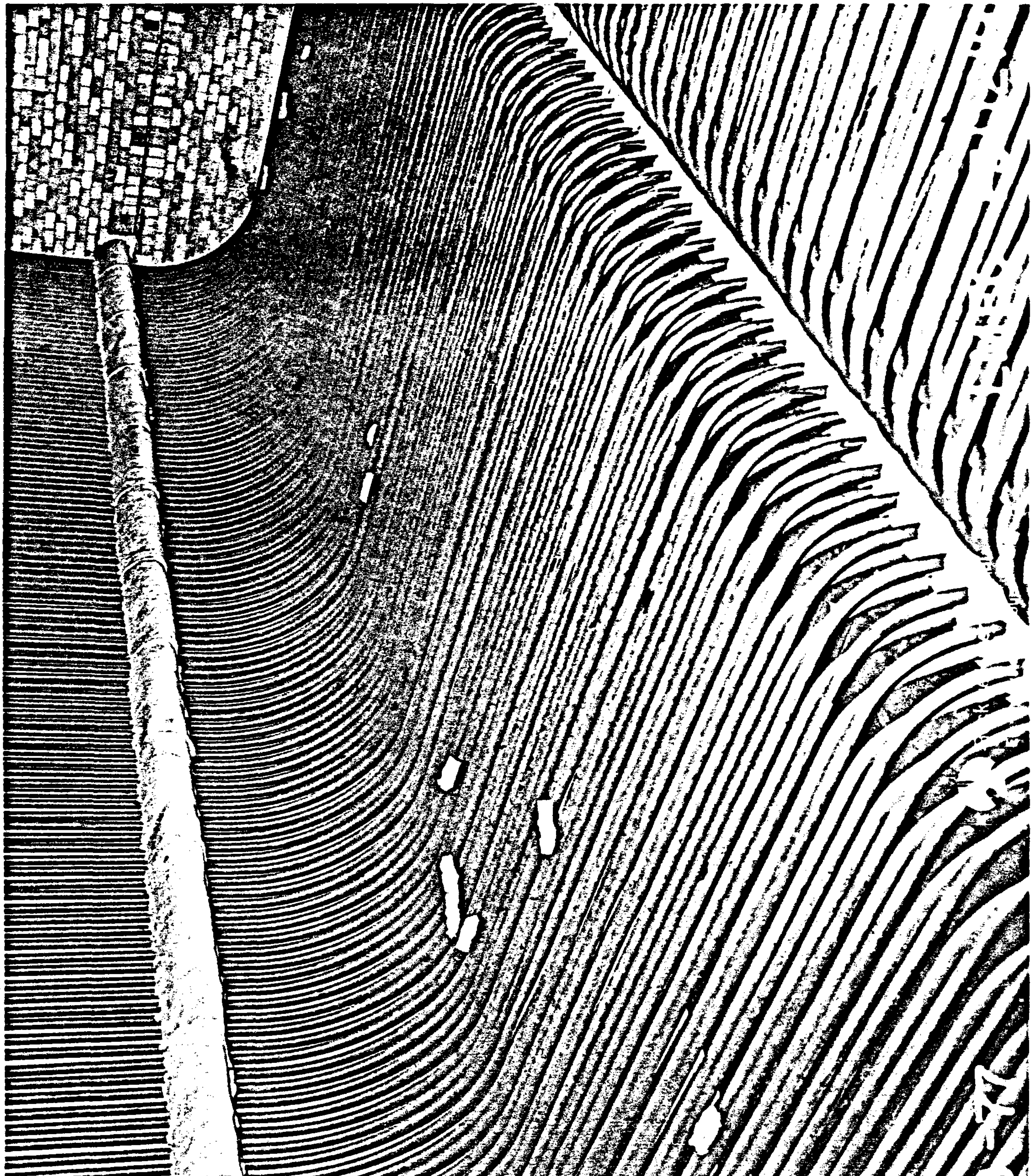
Rockwell International
Energy Systems Group





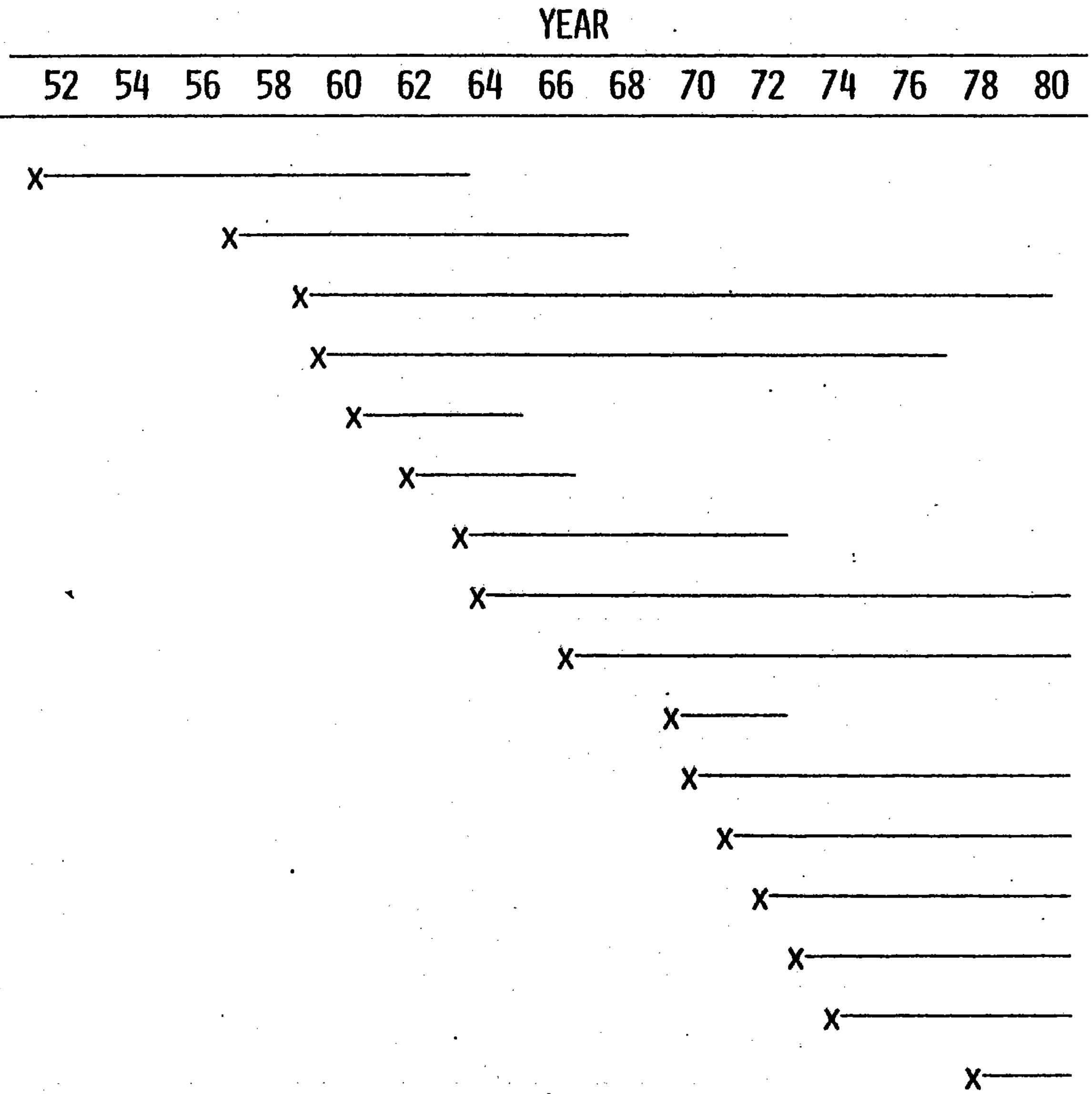
0-75
LMEC-P31733


79-76



WORLD LIQUID-METAL-COOLED REACTOR FACILITIES

	REACTOR	STARTUP DATE
~~AI~~ USA	EBR-I	8/24/51
A.I.	SRE	4/25/57
	BR-5,-10	1/ /59
	DFR	11/14/59
	LAMPRE	2/17/61
	HALLAM	8/25/62
	FERMI	8/23/63
	EBR-II	11/11/63
	RAPSODIE	1/28/67
	SEFOR	5/3/69
	BOR-60	12/14/69
	KNK	8/20/71
	BN-350	11/29/72
	PHENIX	8/31/73
	PFR	3/3/74
	JOYO	4/24/77

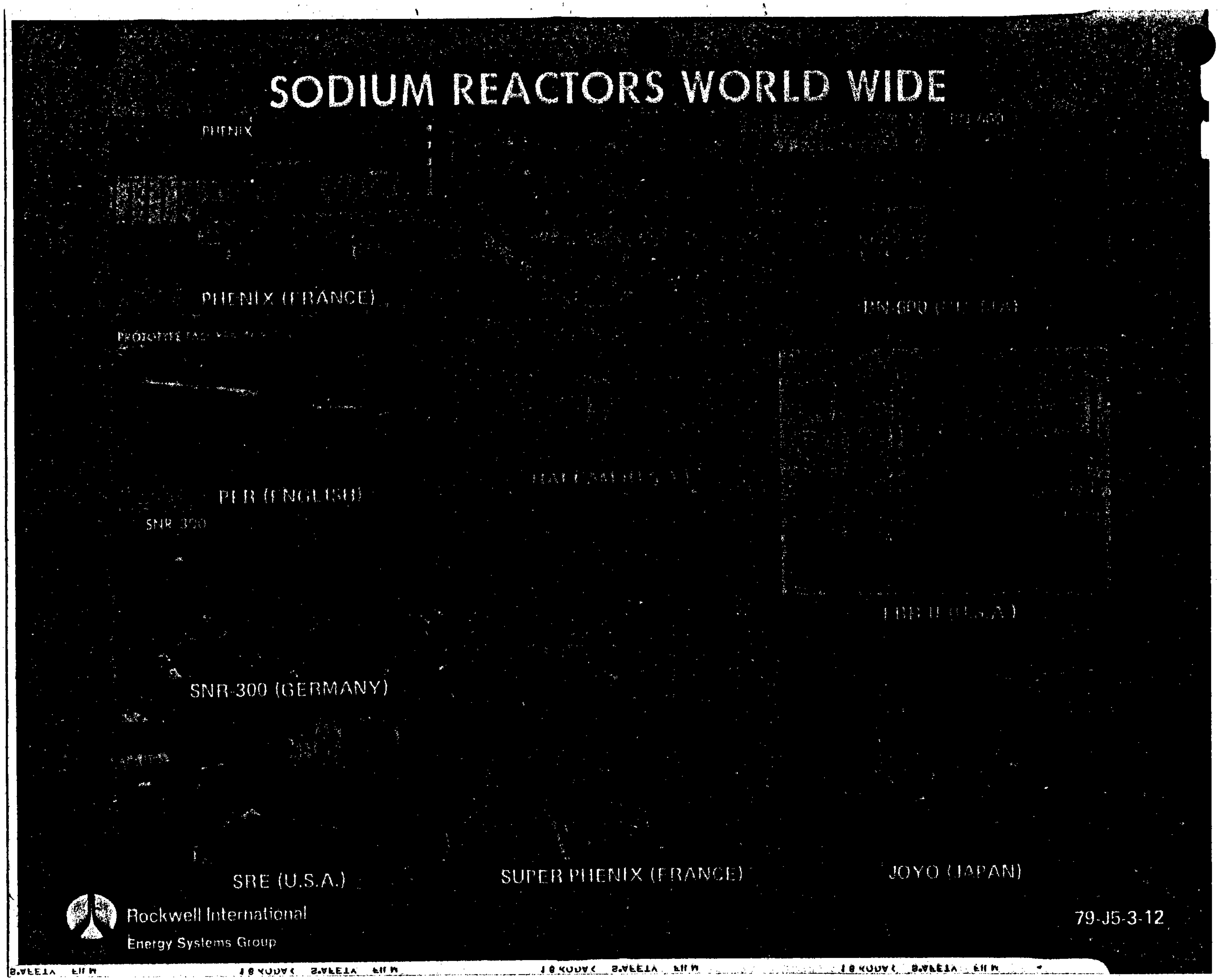


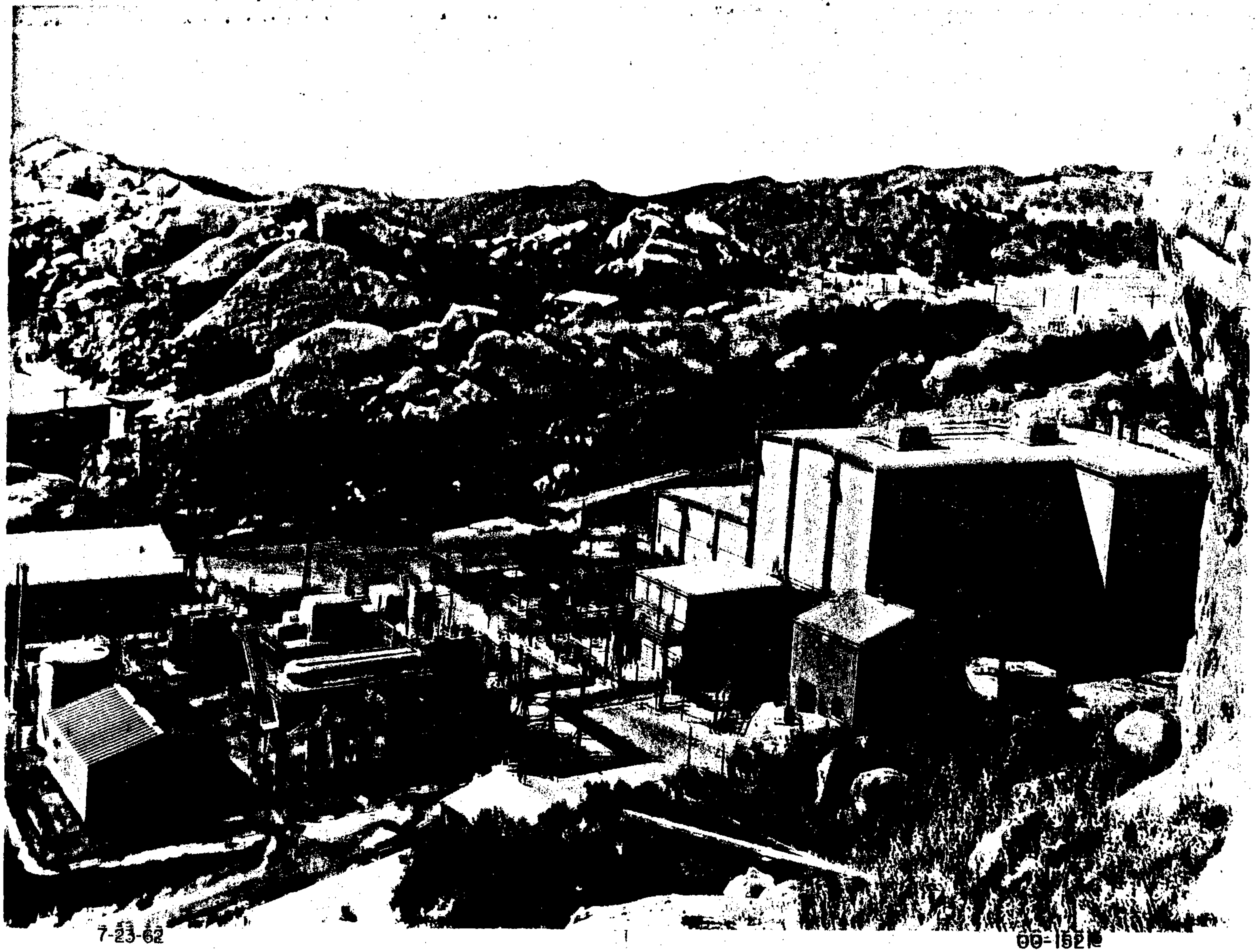
GLB:523

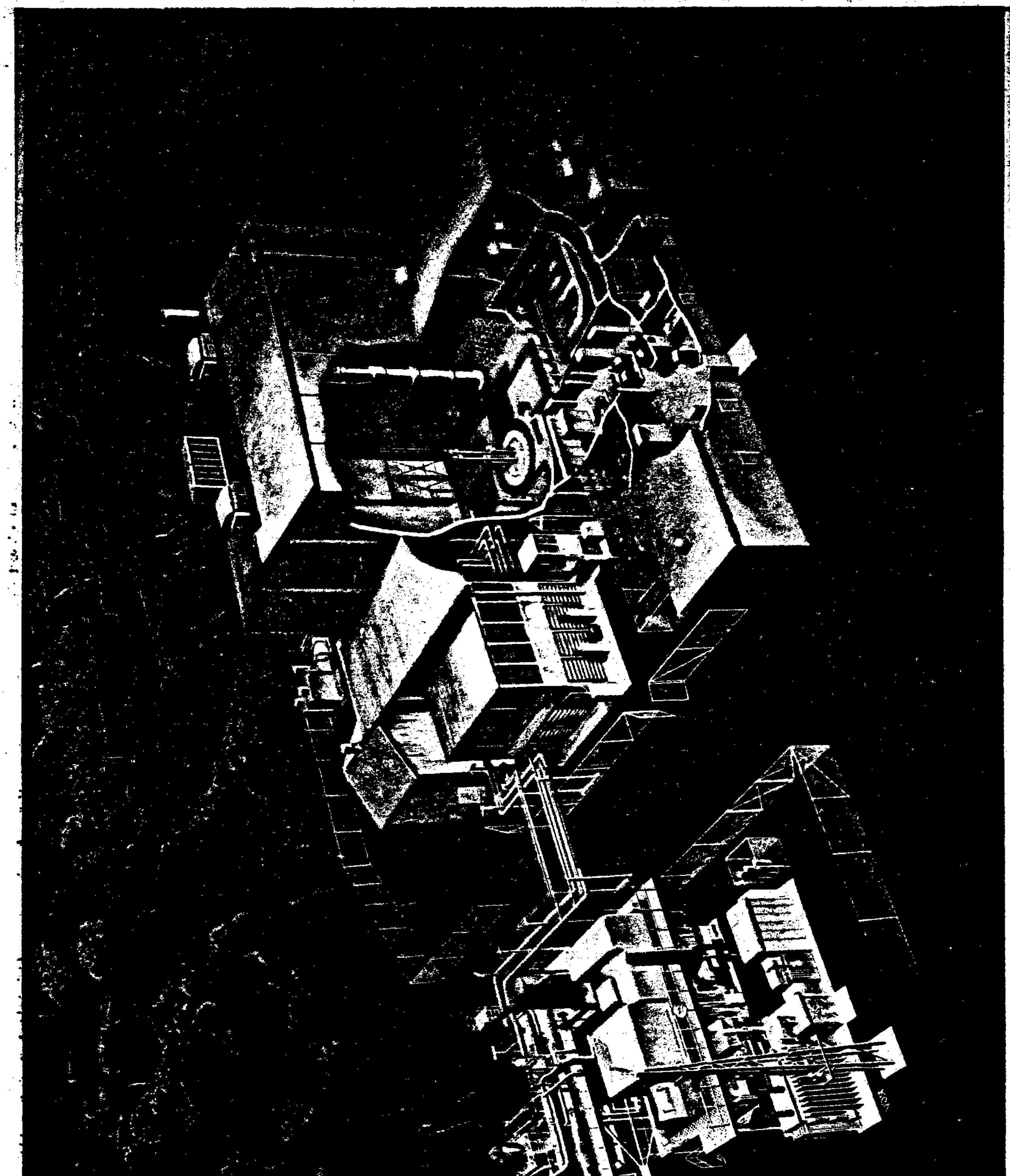
LIQUID METAL FAST BREEDER REACTOR PROJECTS THROUGHOUT THE WORLD

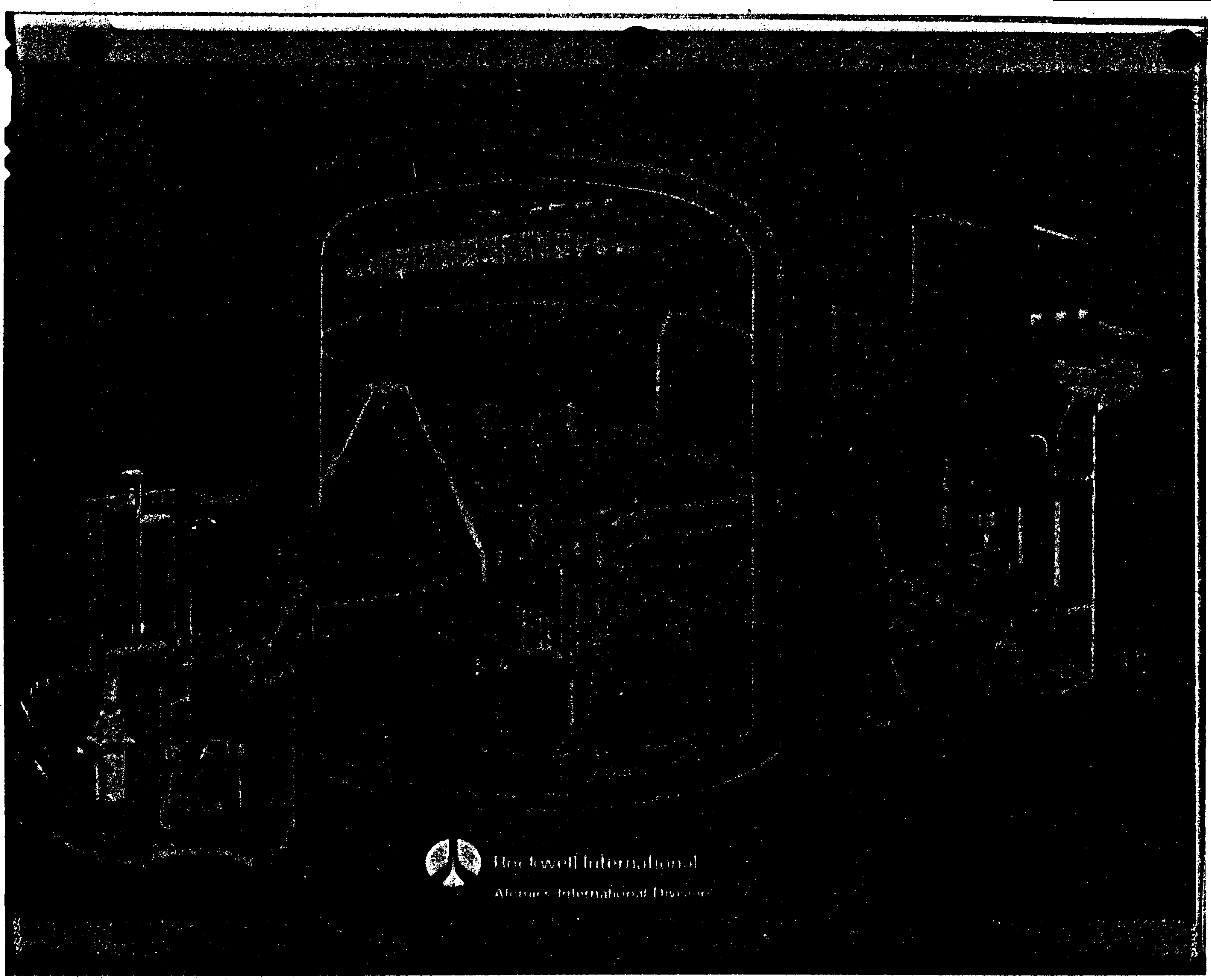
Name	Country	Type	Power (MWt)	Power (MWe)	Initial Operation
Operable					
BR-10*	USSR	Loop	10	--	1973
DFR+	United Kingdom	Loop	60	14	1959
EBR-II	United States	Pool	62	20	1963
Rapsodie	France	Loop	40	--	1967
BOR-60	USSR	Loop	60	12	1969
BN-350	USSR	Loop	1000	350 (equiv)	1972
Phenix	France	Pool	567	250	1973
PFR	United Kingdom	Pool	600	250	1975
Joyo	Japan	Loop	100	--	1977
KNK-2	Germany (FRG)	Loop	58	20	1977#
In Procurement/Construction					
BN-600	USSR	Pool	1470	600	1980
FFTF	United States	Loop	400	--	1979
PEC	Italy	Loop	135	--	1981
Madras FBTR	India	Loop	42	17	1981
SNR-300	Germany (FRG)	Loop	762	327	1983
Super Phenix - 1	France START CONST 74	Pool	3000	1200	1983
CRBRP	United States	Loop	975	350	1986
In Planning/Design					
Monju	Japan	Loop	714	300	1986
CDFR-1	United Kingdom	Pool	3250	1300	1990
SNR-2	Germany (FRG)	Loop	3250	1300	1990
BN-1600	USSR	Pool	4000	1600	1990
Super Phenix - 2 and 3	France	Pool	2 X 3500	2 X 1500	1989-90
DFBR	Japan	--	2800	1000	1993
CDS	United States		2600	1000	1991

*Following conversion from BR-5, which operated from 1959 to 1971.
+Decommissioned March 1977.
#Following conversion from the thermal neutron KNK-1, which operated from 1979 to 1974.


SODIUM REACTORS WORLD WIDE
PHENIX (FRANCE)
PFR (ENGLISH)
SNR-300 (GERMANY)
SRE (U.S.A.)
SUPER PHENIX (FRANCE)
JOYO (JAPAN)
Rockwell International
Energy Systems Group
79-J5-3-12


7-23-62
00-15212


7519-5010
6-27-60


Rockwell International
Atomics International Division

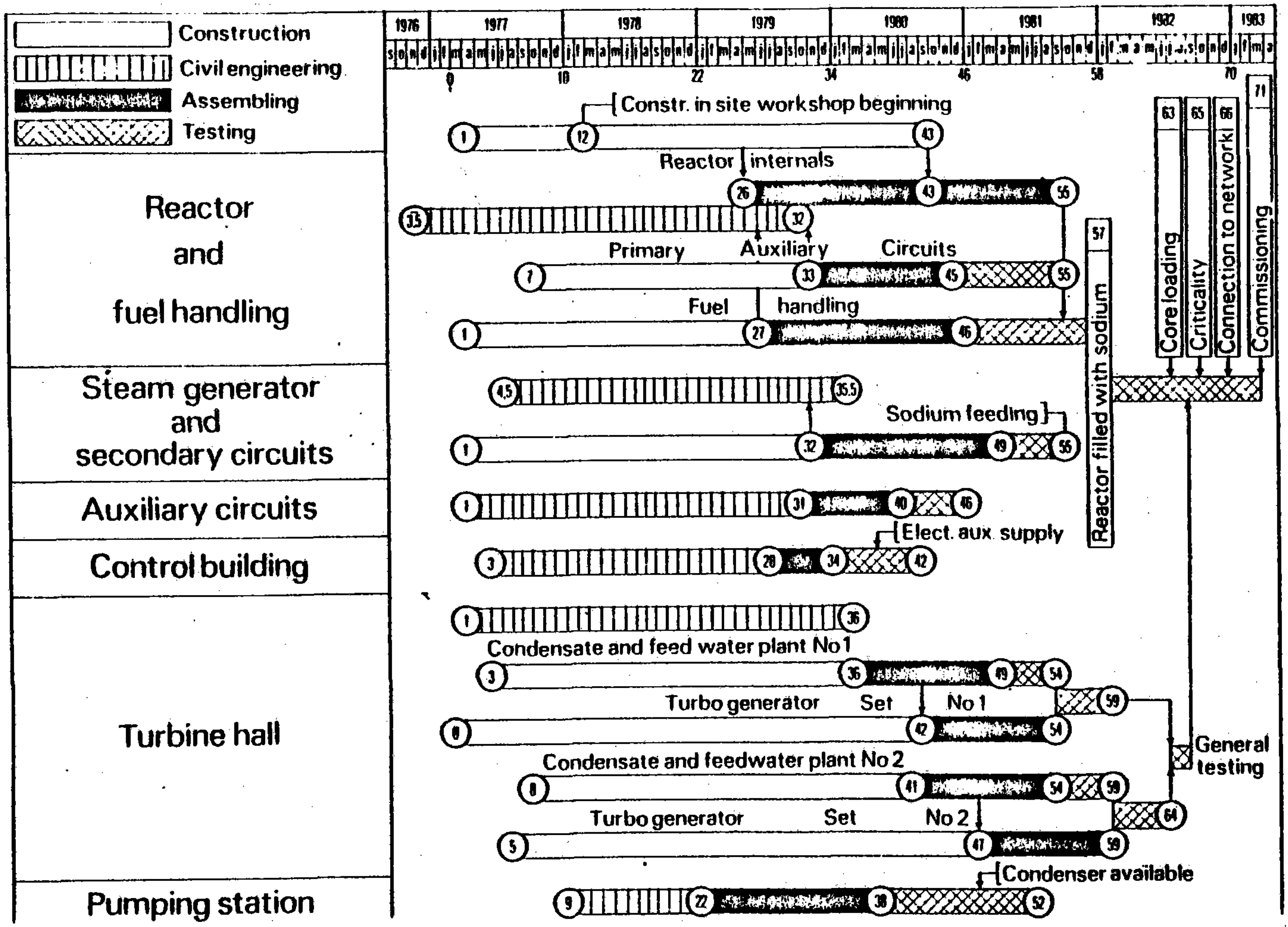
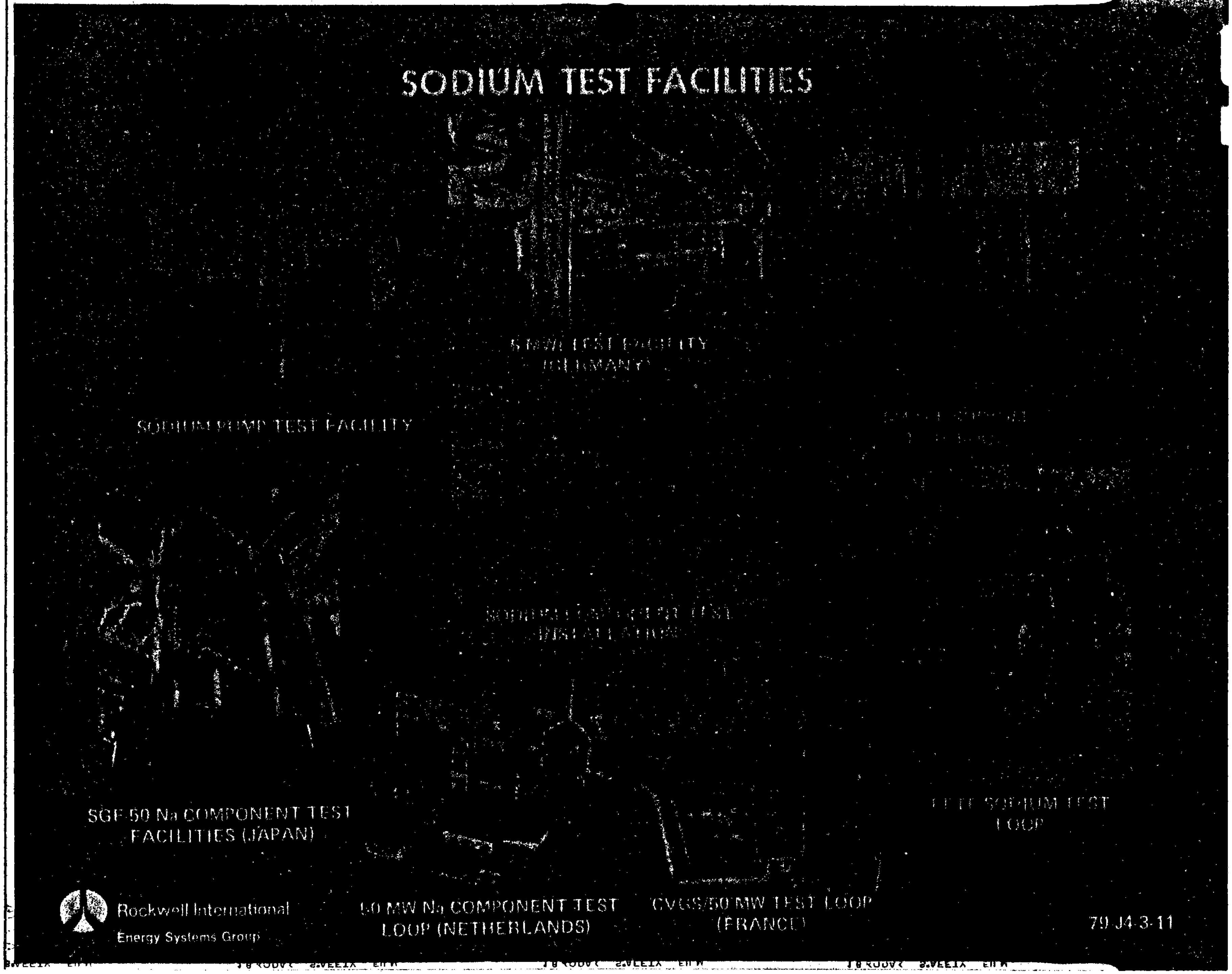
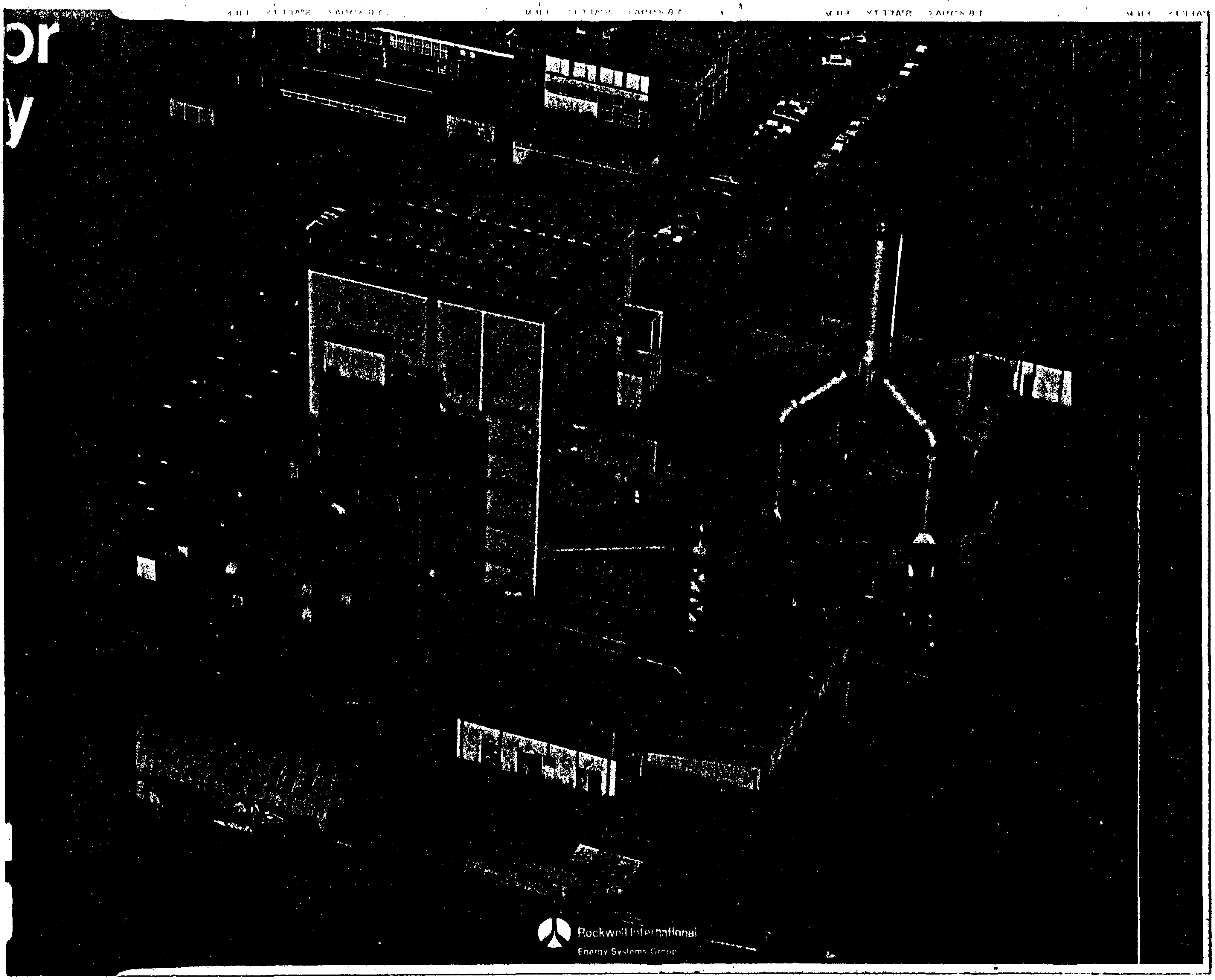


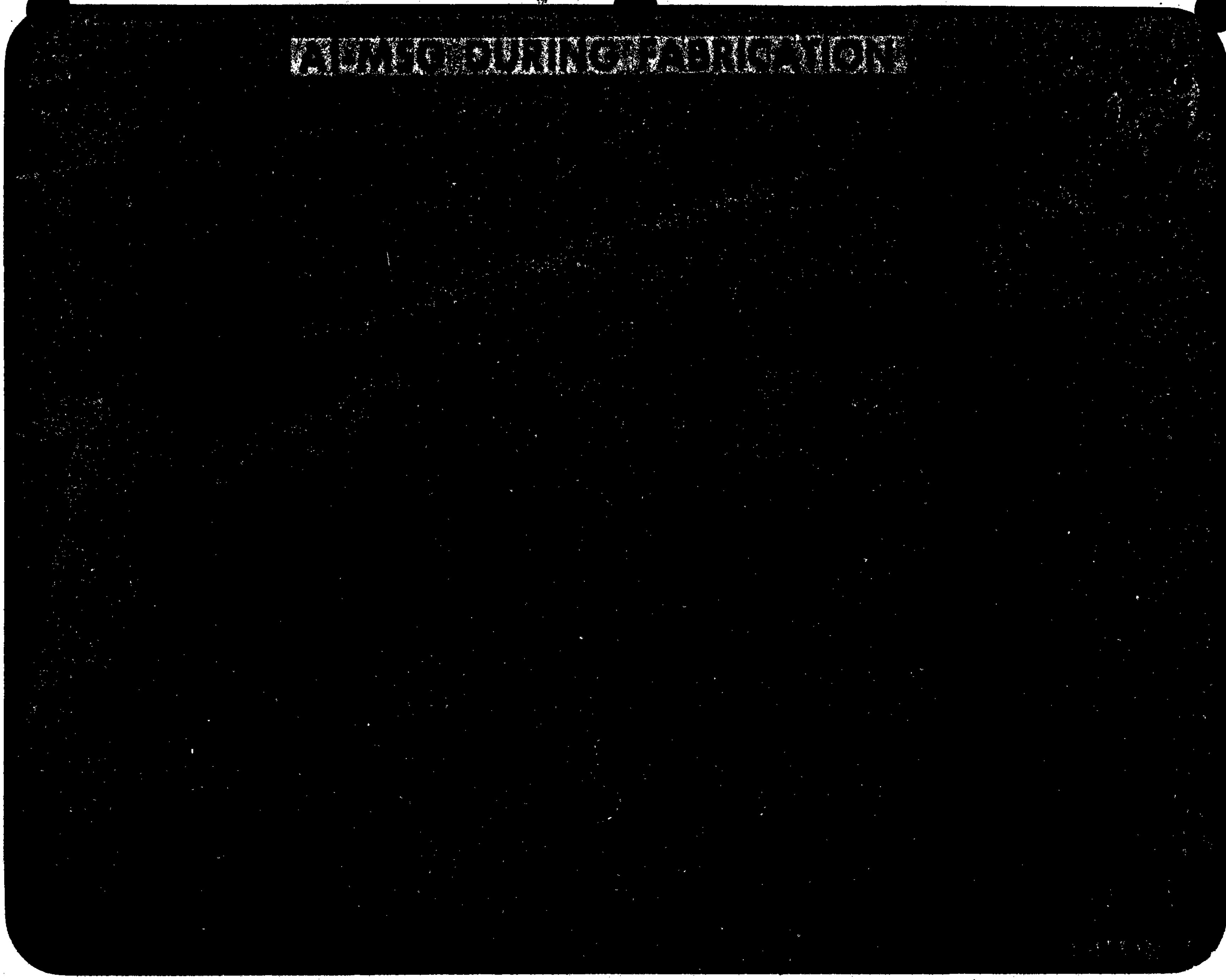
Fig. 14. Construction schedule for the Creys-Malville power station


SODIUM TEST FACILITIES
SODIUM PUMP TEST FACILITY
SGF-50 Na COMPONENT TEST FACILITIES (JAPAN)
50 MW Na COMPONENT TEST LOOP (NETHERLANDS)
CVGS/50 MW TEST LOOP (FRANCE)
Rockwell International
Energy Systems Group
79-J4-3-11

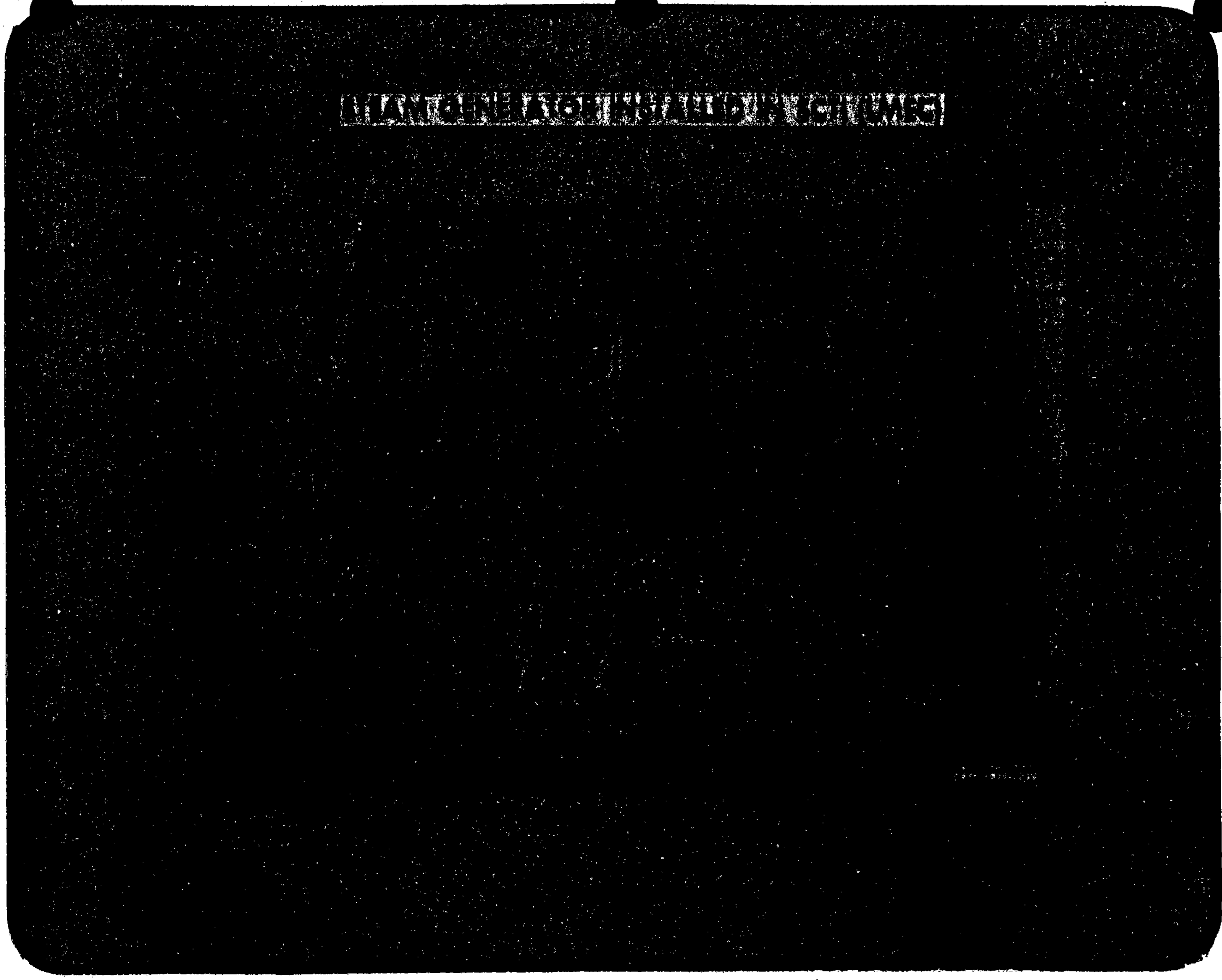
LIST OF NATIONS WITH SODIUM HEAT TRANSFER LOOPS

USA
FRANCE
FEDERAL REPUBLIC OF GERMANY
JAPAN
USSR
NETHERLANDS
UNITED KINGDOM
ITALY
BELGIUM
CZECHOSLOVAKIA
SPAIN
INDIA
AUSTRIA
LUXEMBOURG
SOUTH AFRICA
DEMOCRATIC REPUBLIC OF GERMANY
EGYPT
PEOPLES REPUBLIC OF CHINA

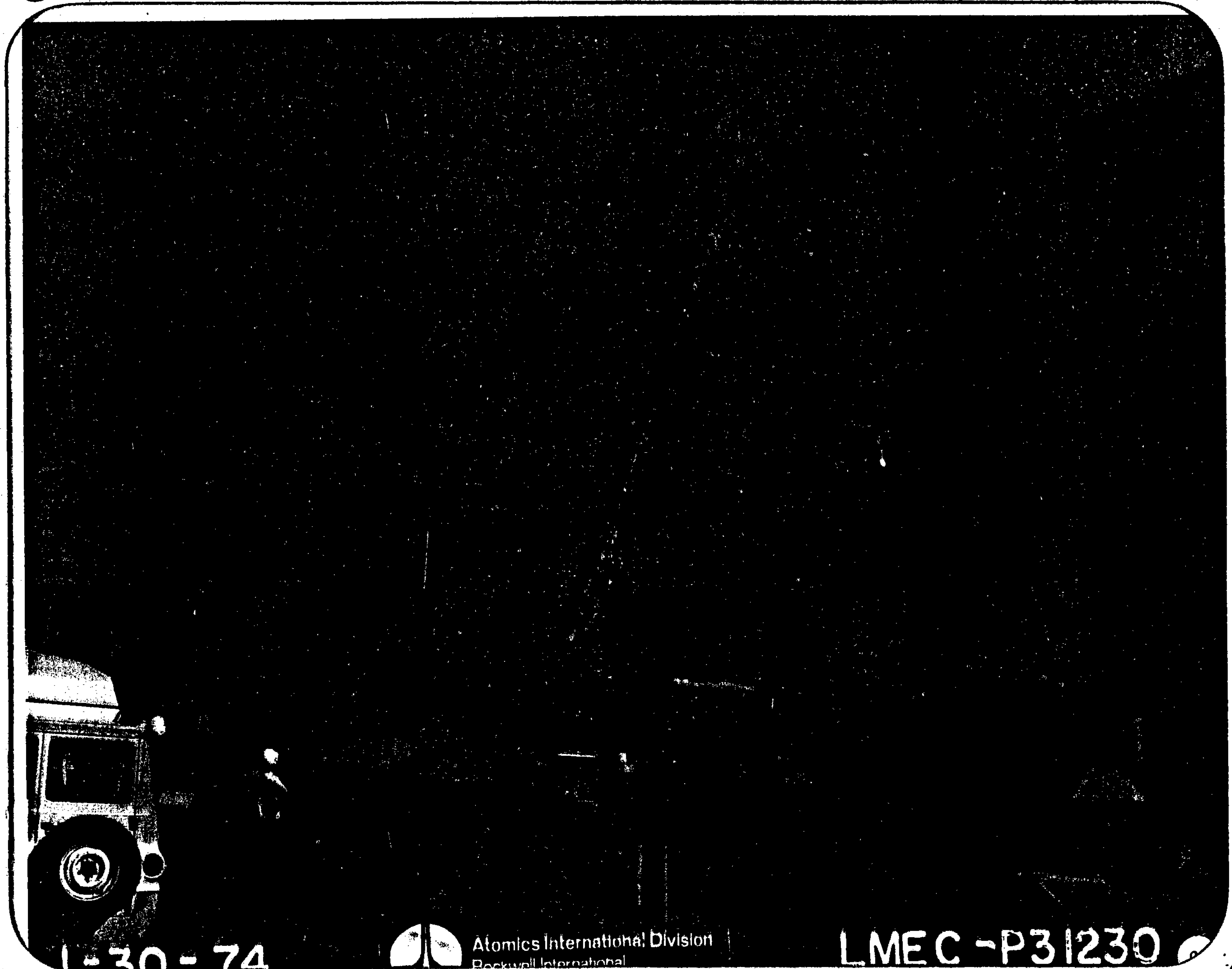

Rockwell International
Energy Systems Group



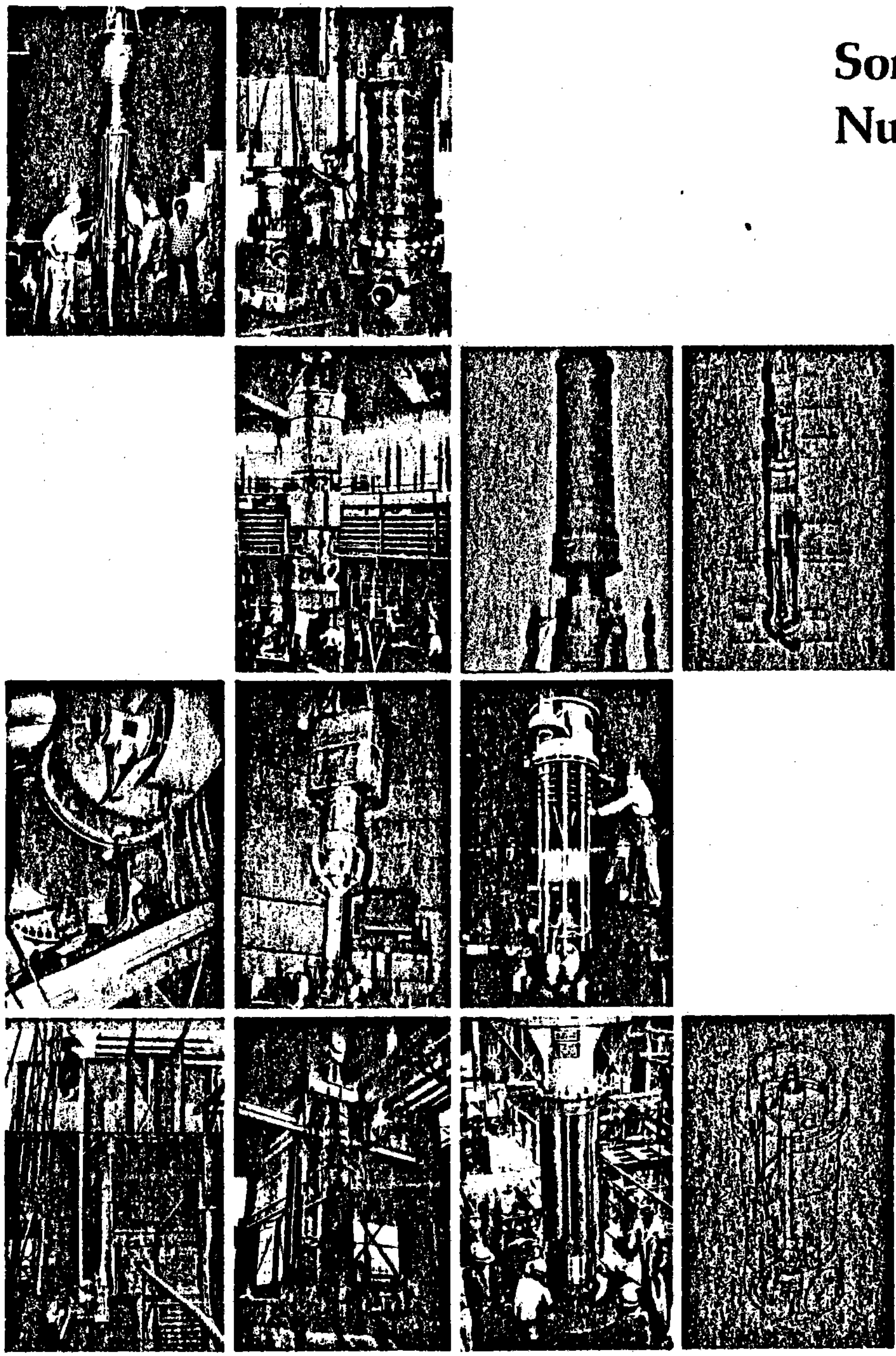
A EMSC DURING FABRICATION


GENERATOR INSTALLED IN

1.


1-30-74
Atomics International Division
Rockwell International
LMEC-P31230

5, 285, 000



Some Highlights from Liquid Metal Nuclear Pump Manufacturing History

- 1950 Submarine "Seawolf" Prototype Pump
- 1956 "SRE" Primary and Secondary Pumps
- 1957 Enrico Fermi Test Pump
- 1958 "CANEL" Project Test Loop Pumps
- 1960 Enrico Fermi Primary and Secondary Pumps
- 1961 "SCTI" Primary Loop Pump
- 1962 Hallam Prototype, Primary and Secondary Pumps
- 1963 "EBR II" Primary Pumps
- 1964 "SRE" Power Expansion Primary, Secondary and Auxiliary Pumps
- 1964 Argonne National Laboratory Liquid Sodium Pump
- 1967 "SNR" Prototype Pump
- 1971 "PNC" Primary and Secondary Pumps
- 1975 "CRBRP" Prototype, Primary and Intermediate Pumps
- 1977 "L-S LMFBR" Preliminary Designs, Prototype Primary and Intermediate Pumps

US "MILESTONE" LIQUID-SODIUM PRIMARY PUMPS

Designation	Manufacturer	Reactor Type	Capacity in GPM	Total Head in Feet	Temperature in F	RPM	HP	Operating * Hours	Pump type – number of stages and impeller type
SRE	BJ	LOOP	1200	80	1200	1160	30	21,400	Single stage, single suction
Fermi	BJ	LOOP	11,000	310	1000	900	1000	45,000	Single stage, single suction
Hallam	BJ	LOOP	7200	160	1000	870	350	20,000	Single stage, single suction
EBR II	BJ	POOL	5500	200	800	1075	300	72,000	Single stage, single suction
SCTI	BJ	LOOP	4000	160	1200	1750	200	45,000	Single stage, single suction
SNR 2 (W.Germany)	BJ	LOOP	7900	410	1022	1500	880	29,850	Single stage, single suction
PNC (Japan)	BJ	LOOP	4870	257	986	1425	500	12,000	Single stage, single suction
FFTF	West	LOOP	14,500	500	1050	1030	2200	3,000	Single stage, single suction
CRBR (proto)	BJ	LOOP	33,700	450	995	1116	5000	----	Single stage, double suction

*Per Pump

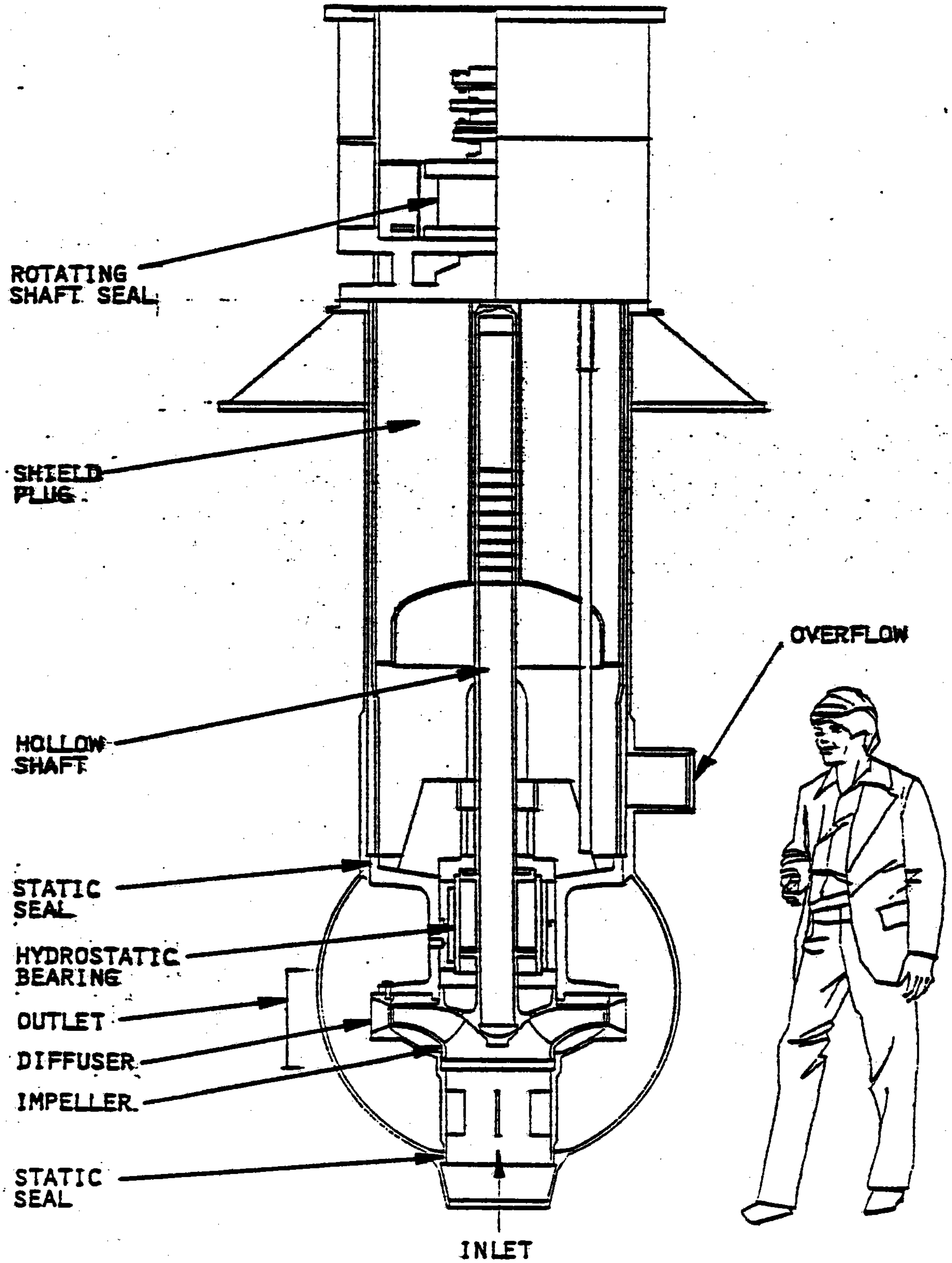
FIG 8a

REPRESENTATIVE FOREIGN LIQUID-SODIUM PRIMARY PUMPS

Designation	Country	Reactor Type	Capacity in GPM	Total Head in Feet	Temperature in F	RPM	HP	Pump type - number of stages and impeller type
Rapsodie	France	LOOP	1670	105	1000	1100	72	Single stage, single suction
Phenix	France	POOL	18,700	250	1000	1000	1600	Single stage, single suction
Super Phenix	France	POOL	76,000	230	752	500	6000	Single stage, single suction
BN-350	USSR	LOOP	14,080	360	900	970	1400	Single stage, double suction
BN-600	USSR	POOL	42,800	312	770	970	4000	Single stage, double suction
SNR-300	W Ger	LOOP	22,000	279	1075	960	1600	Single stage, single suction
Joyo	Japan	LOOP	5,560	230	842	930	440	Single stage, single suction
Monju 300	Japan	LOOP	23,300	295	770	850	2400	Single stage, single suction
PFR	UK	POOL	20,900	317	932	960	1550	Single stage, double suction
CFR	UK	POOL	46,300	365	662	480	5500	Two stage, sungle suction

FIG 8b

HALLAM



ROTATING SHAFT SEAL
SHIELD PLUG
HOLLOW SHAFT
STATIC SEAL
HYDROSTATIC BEARING
OUTLET
DIFFUSER
IMPELLER
STATIC SEAL
INLET
OVERFLOW

FIG 3

EBR II

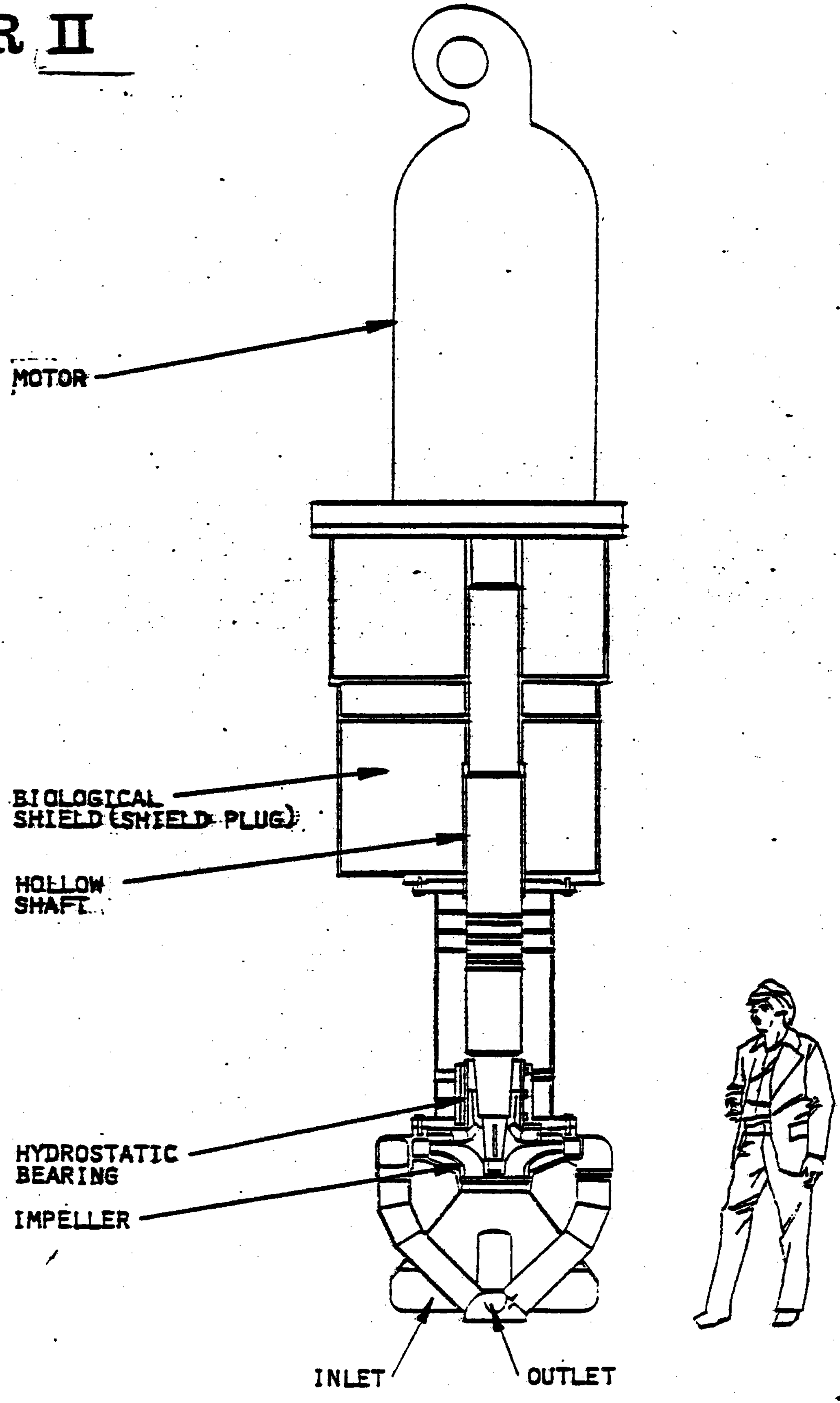

MOTOR
BIOLOGICAL SHIELD (SHIELD PLUG)
HOLLOW SHAFT
HYDROSTATIC BEARING
IMPELLER
INLET
OUTLET

FIG 5

FERMI

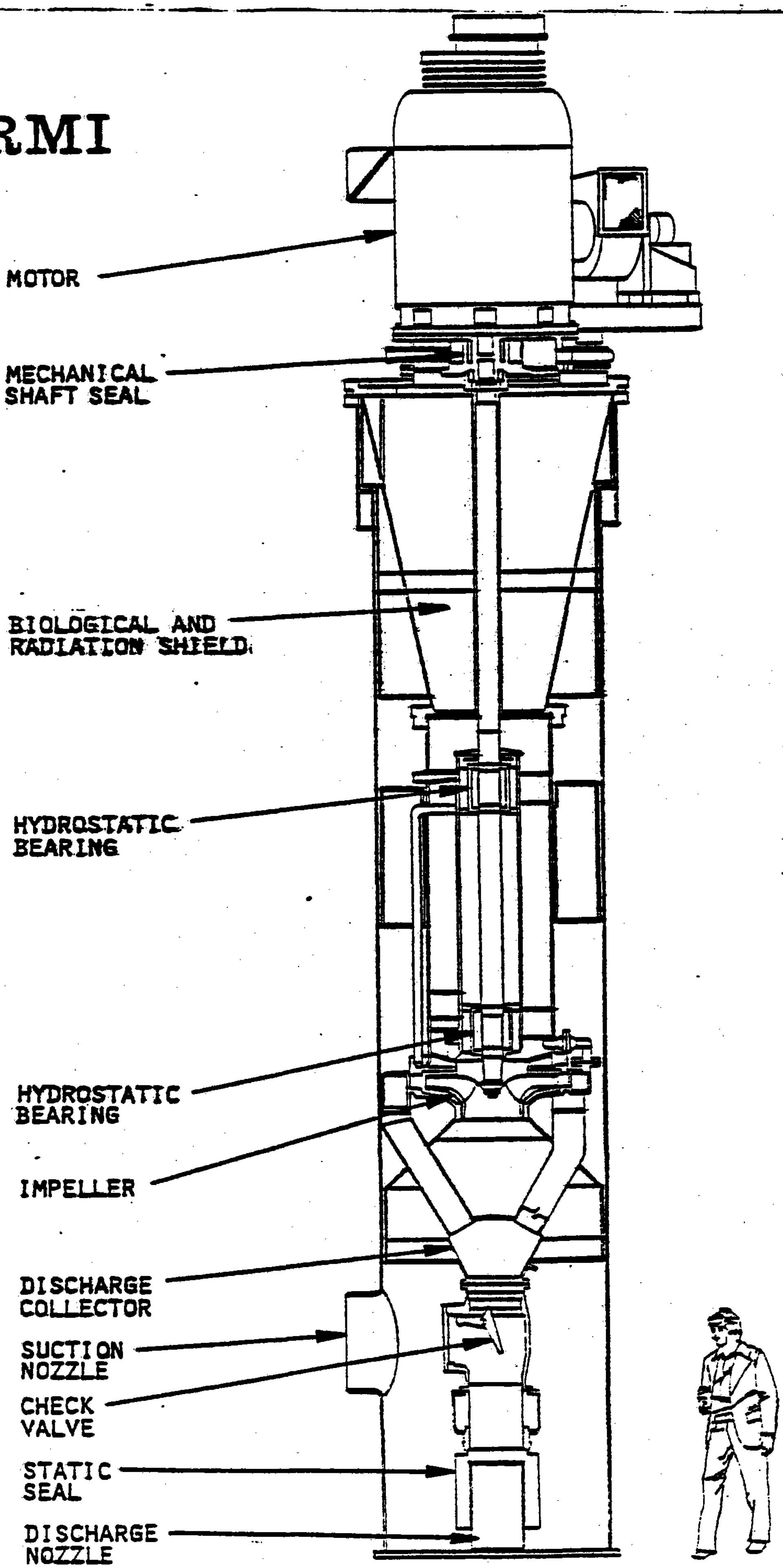

MOTOR
MECHANICAL SHAFT SEAL
BIOLOGICAL AND RADIATION SHIELD
HYDROSTATIC BEARING
HYDROSTATIC BEARING
IMPELLER
DISCHARGE COLLECTOR
SUCTION NOZZLE
CHECK VALVE
STATIC SEAL
DISCHARGE NOZZLE

FIG 4

FFTF

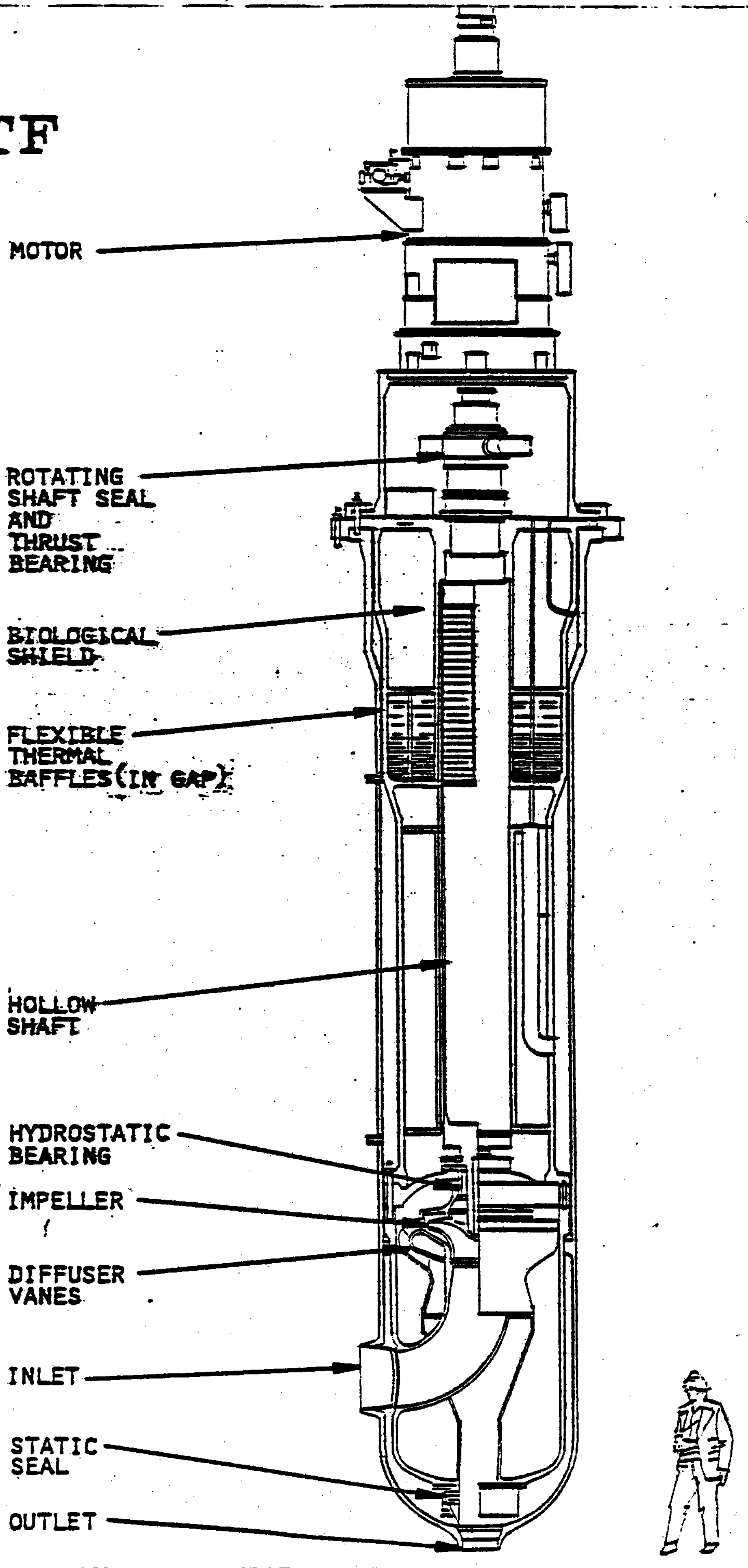
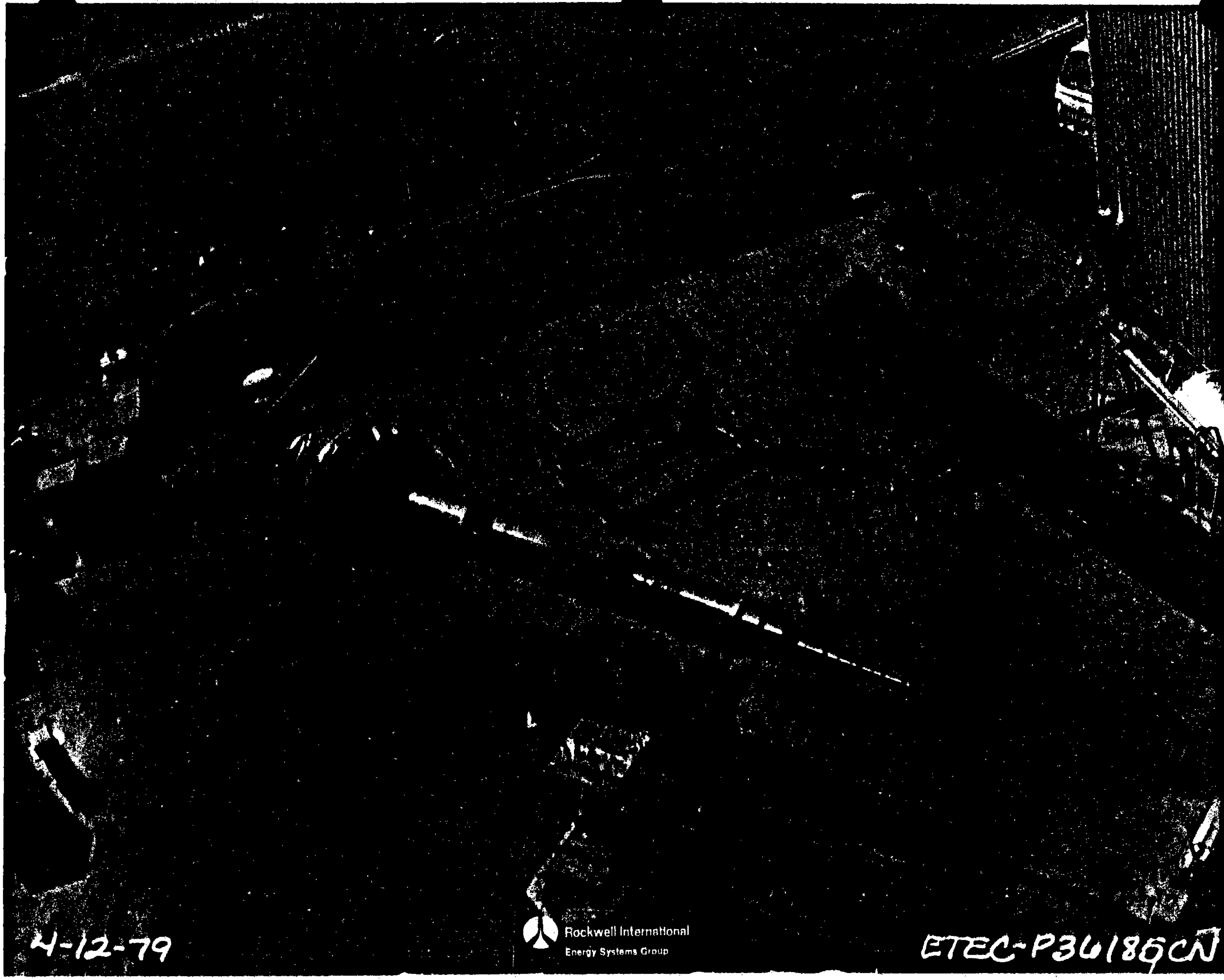

MOTOR
ROTATING SHAFT SEAL AND THRUST BEARING
BIOLOGICAL SHIELD
FLEXIBLE THERMAL BAFFLES (IN GAP)
HOLLOW SHAFT
HYDROSTATIC BEARING
IMPELLER
DIFFUSER VANES
INLET
STATIC SEAL
OUTLET

FIG 11


4-12-79
Rockwell International
Energy Systems Group
ETEC-P36186CN

SODIUM POWER STATISTICAL RECAP

141 REACTOR-YEARS OF SODIUM-COOLED REACTORS

1.8 MILLION MEGAWATT-DAYS OF NUCLEAR HEAT TRANSFERRED BY SODIUM

27-1/2 YEARS SINCE EBR-I FIRST PRODUCED ELECTRICITY (DECEMBER 1951)

21 YEARS OF EXPERIENCE ON SOVIET BR-5/10

16 CONTINUOUS YEARS OF SODIUM MECHANICAL PUMP SERVICE (EBR-II)

1200 MWE FRENCH SUPERPHENIX 1 NOW UNDER CONSTRUCTION

1600 MWE SOVIET BN-1600 NOW IN ADVANCED DESIGN

WBW JUNE 1979

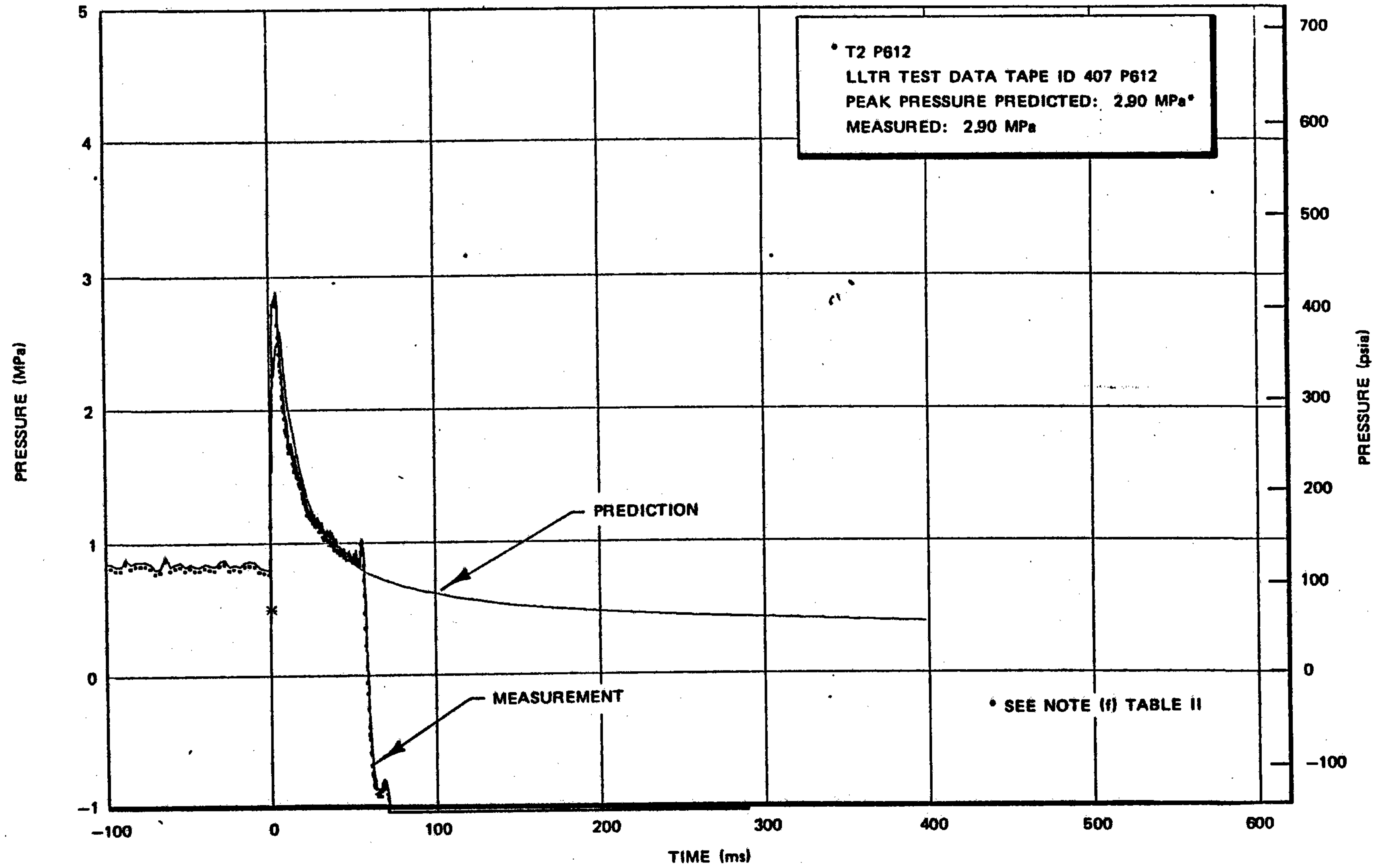


Figure 4. Comparison of TRANSWRAP II Predicted Reaction Zone Bubble Pressure with Measurements from Transducer P612 in SWR-1

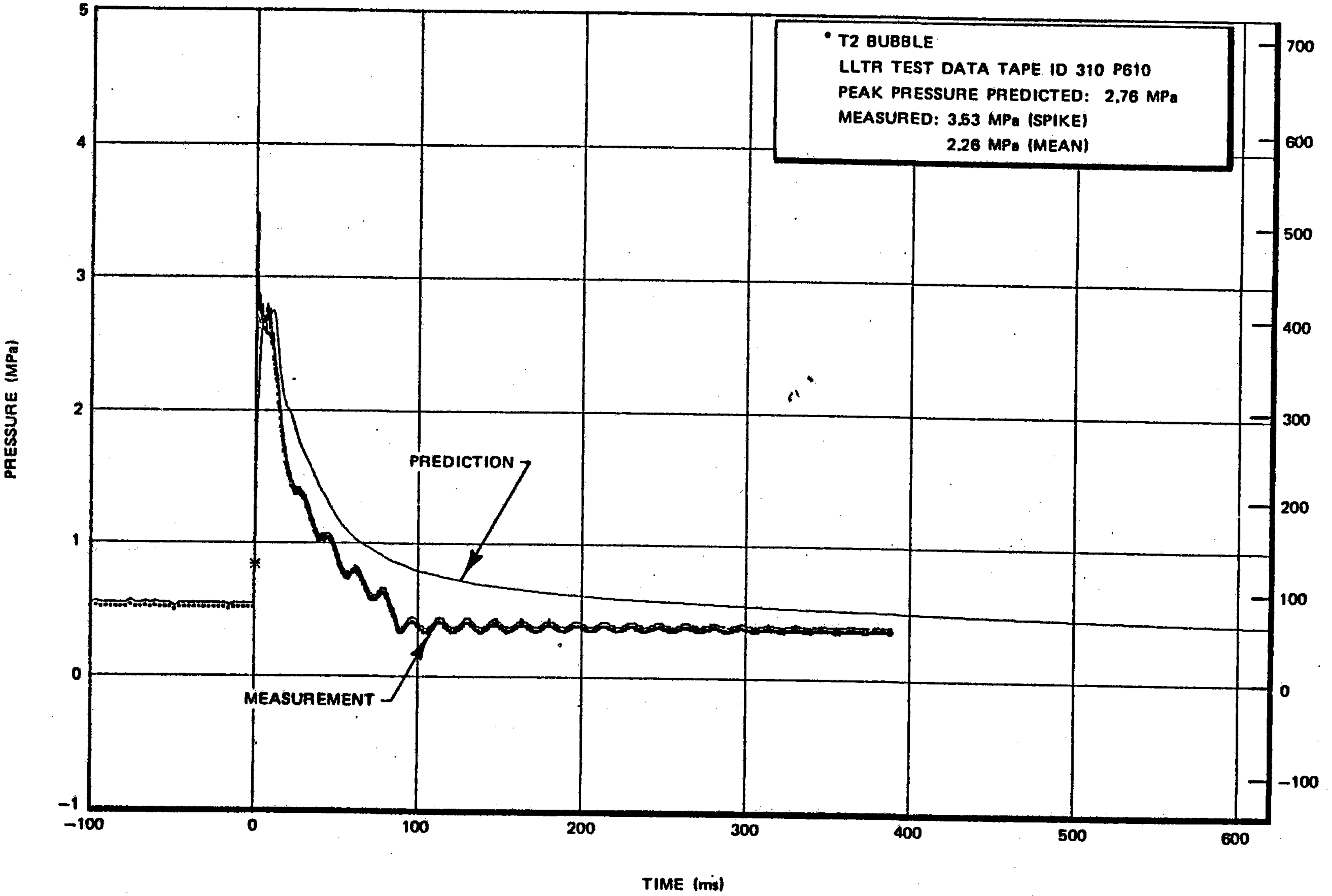


Figure 5. Comparison of TRANSWRAP II Predicted Reaction Zone Bubble Pressure with Measurements from Transducer P610 in SWR-2

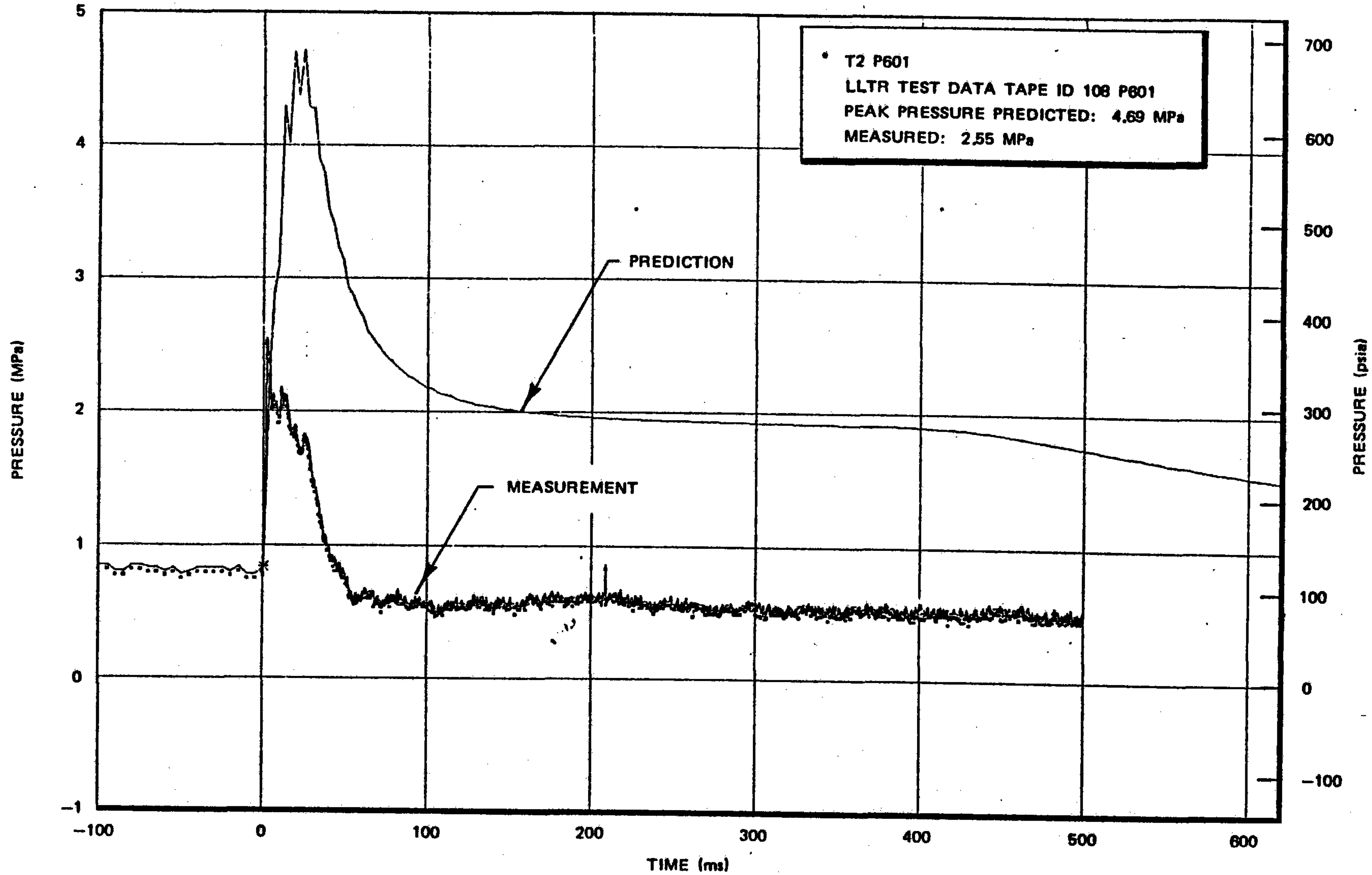


Figure 6. Comparison of TRANSWRAP II Predicted Reaction Zone Bubble Pressure with Measurements from Transducer P601 in SWR-3

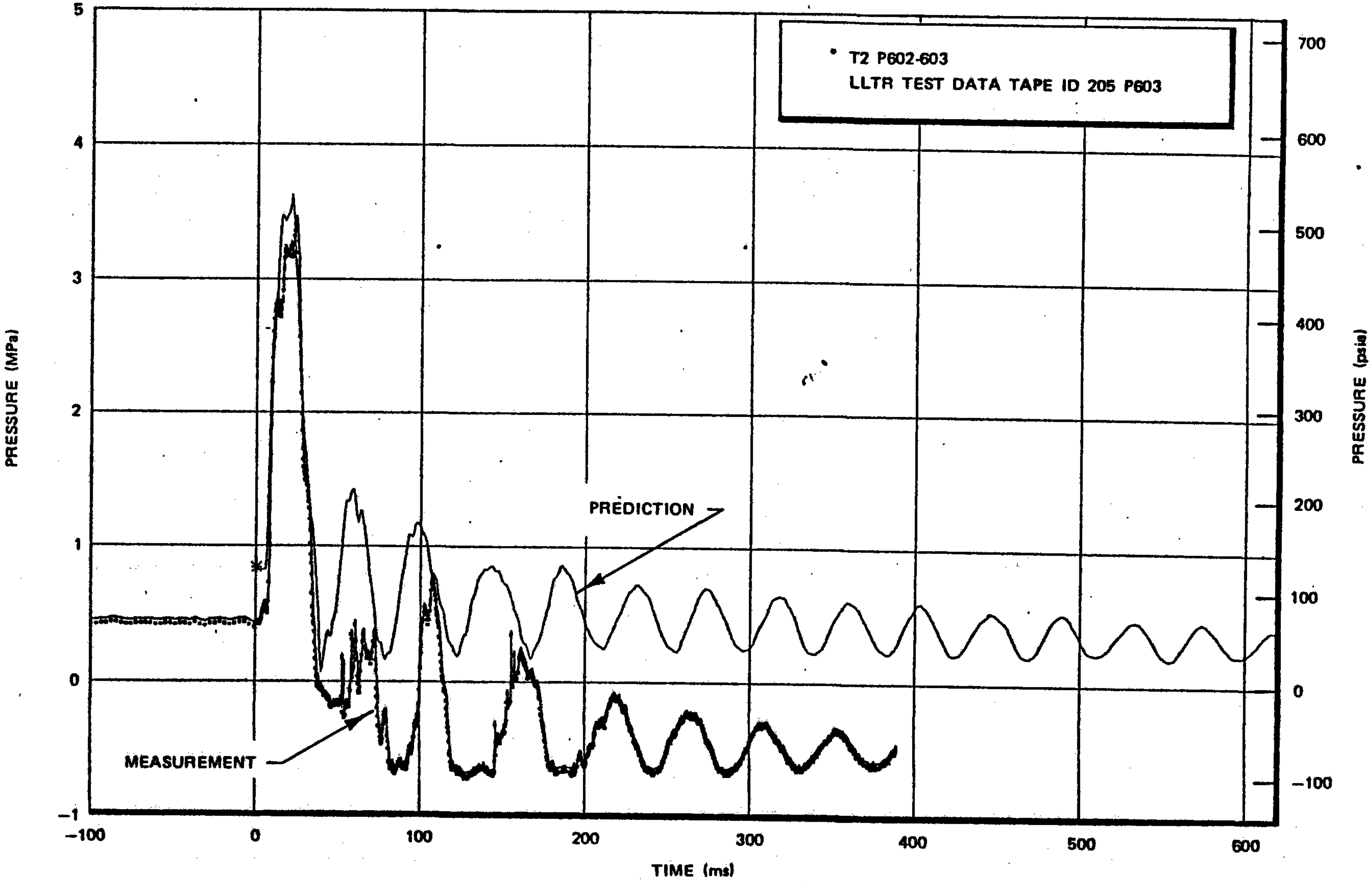


Figure 7. Comparison of TRANSWRAP II Predicted Pressure at the Hockey Stick Elbow with Measurements from Transducer P603 in SWR-2

TABLE 1

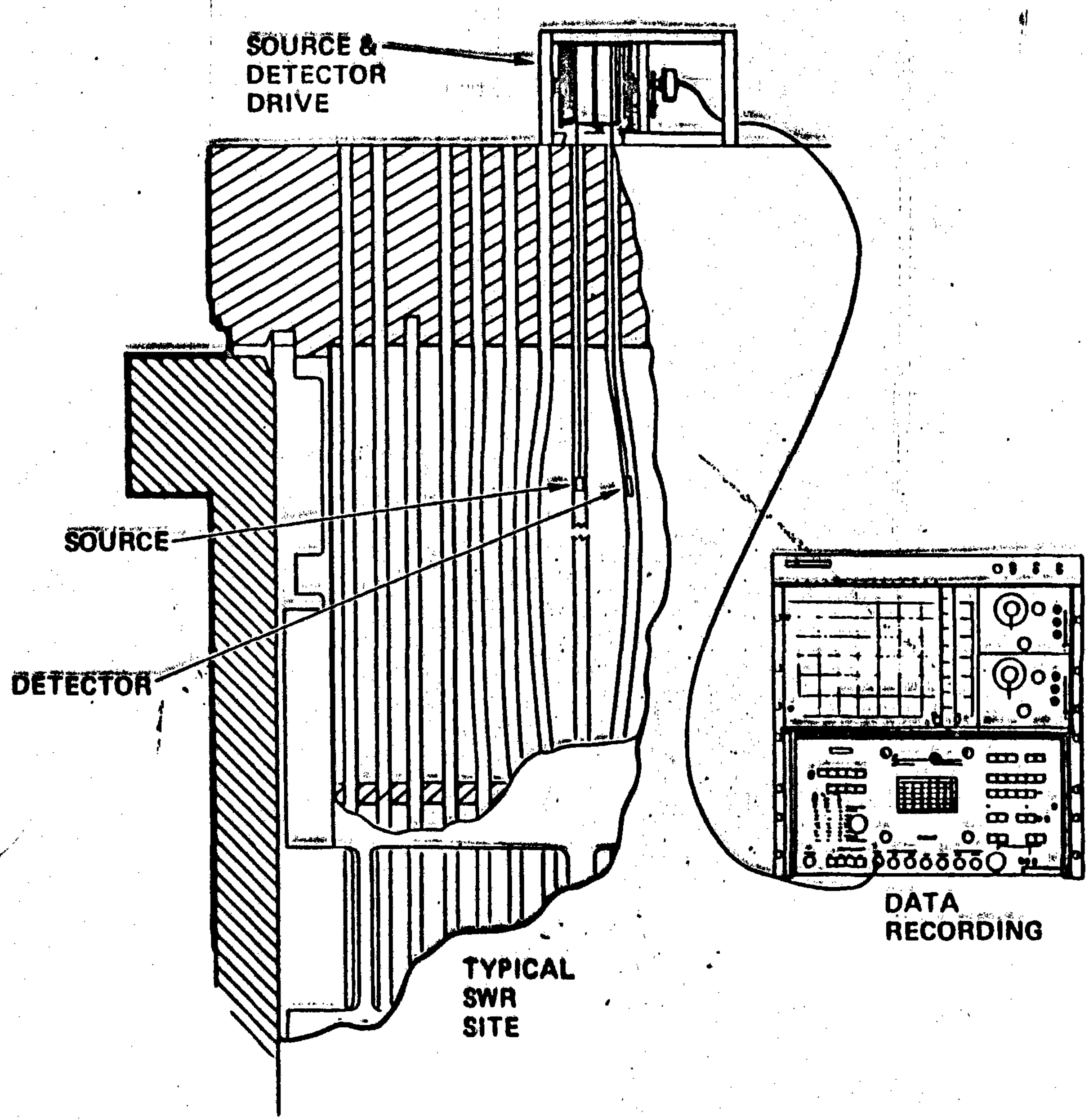
LARGE LEAK SERIES I TEST RESULT SUMMARY

	TEST #1	TEST #2	TEST #3	TEST #4	TEST #5	TEST #6**
Injection Rate (Steady State)	2.4 lbs/sec (1.1 kg/sec)	2.5 lbs/sec (1.1 kg/sec)	8 lbs/sec (3.6 kg/sec)	4.2 lbs/sec (1.9 kg/sec)	4 lbs/sec* (1.8 kg/sec)	10 lbs/sec (4.5 kg/sec)
Peak Pressures Measured in Test Article at Different Locations	350-500 psia (2.4-3.5 MPa)	400-500 psia (2.8-3.5 MPa)	300-350 psia (2.1-2.4 MPa)	330-450 psia (2.3-3.1 MPa)	240-400 psia (1.6-2.8 MPa)	530-675 psia (3.7-4.7 MPa)
Maximum Temperatures Measured in Test Article	~1500°F (815°C)	~1700°F (927°C)	~1700°F (927°C)	~1500°F (815°C)	800°F(Na Temp) (427°C)	~1700°F (927°C)
Measured Wastage of Surrounding Tubes (By UT)	4-16 mils (.1-.4 mm)	4 mils max. (.1 mm)	4 mils max. (.1 mm)	no change	no change	no change
He Leak Indication After Test	7 Tubes @ 10^{-4} to 10^{-7} cc/sec	None	None	None	None	None
Deformation of Tubes by X-Ray	None	Bowing of Secondary Tubes Near Leak Site	None	None	None	None
Extent of Reaction Product Residual	Slight	Heavier Below Lower Window	Additional Buildup Below Lower Window + Above Lower Window	Slight Deposit on Tubes at Upper Window. No Significant Additional Buildup Below Lower Window.	no change	Slight Additional Deposit on Tubes at Upper Window. No Significant Additional Buildup Below Lower Window.
Agreement with TRANSWRAP Predictions	Good	Good	Code Over-Predicted	Code Over-Predicted	Code Over-Predicted	Code Over-Predicted

*Nitrogen used in place of H_2O for Test #5.

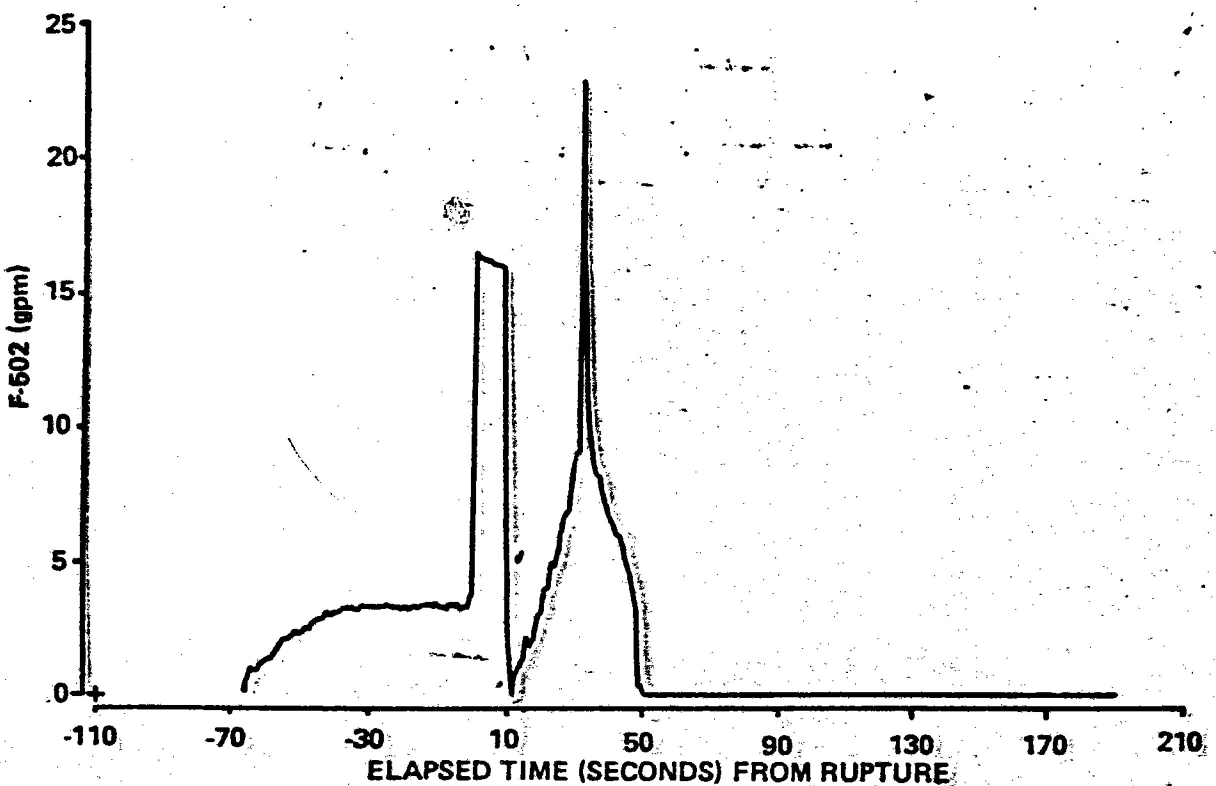
**3-DEG Rupture Tube

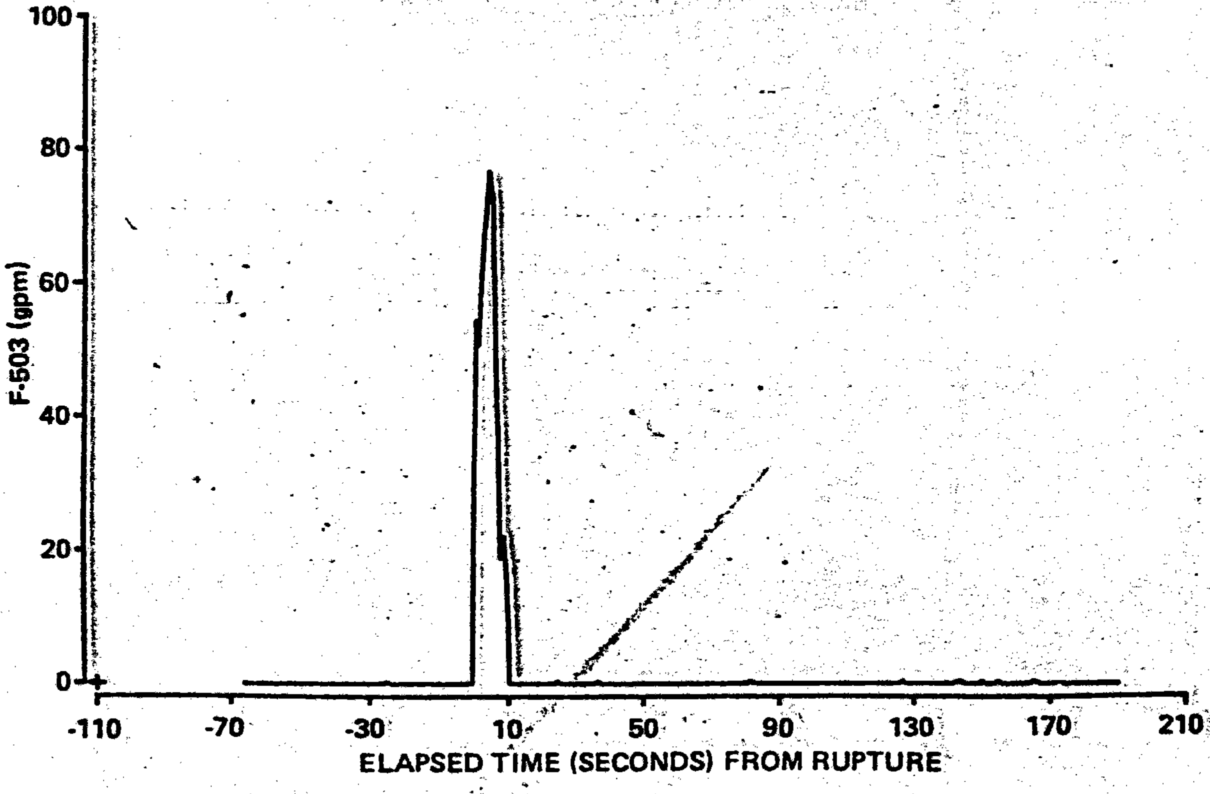
ISOTOPE SCANNING TEST (IST)



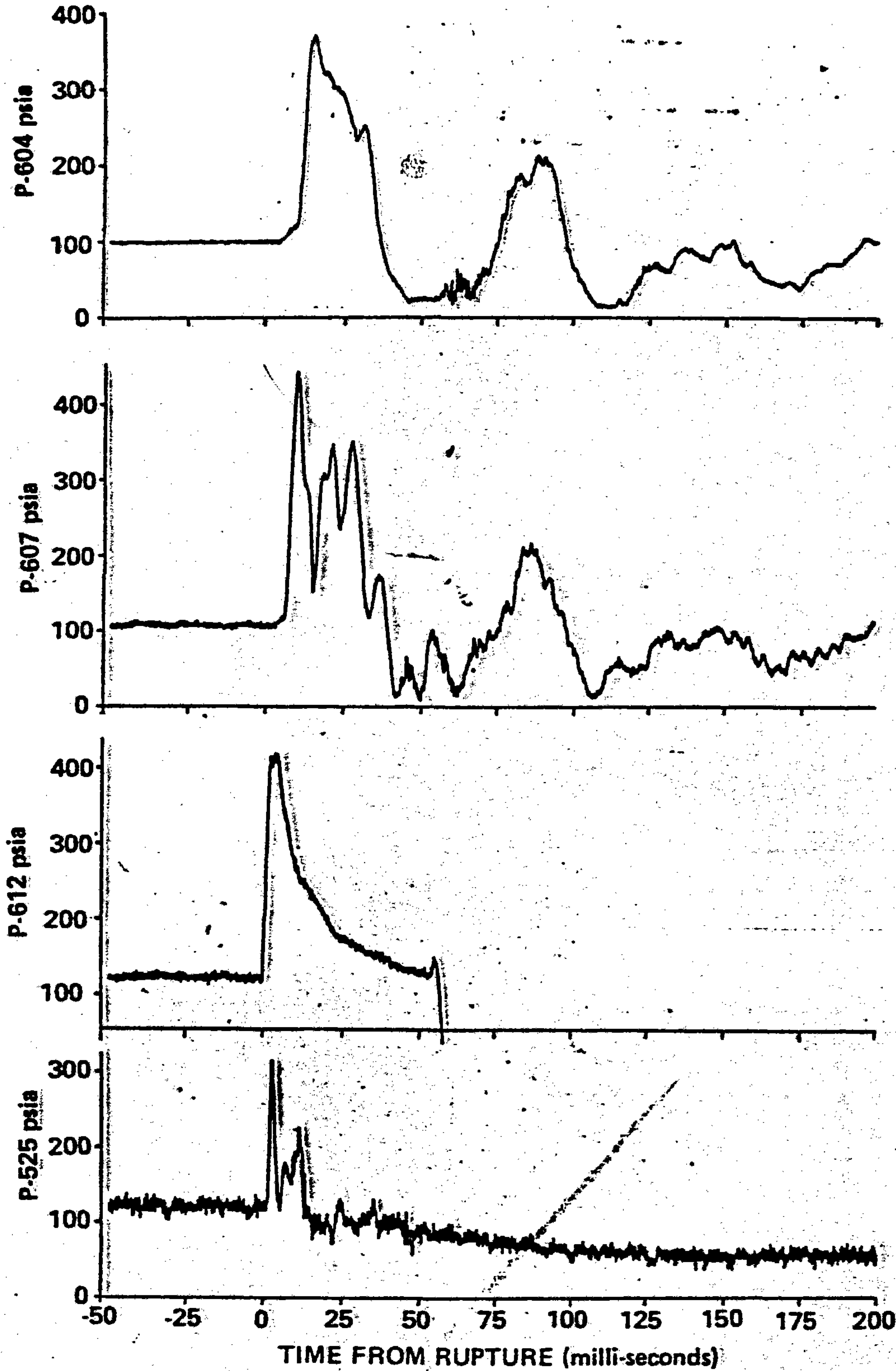
Rockwell International
Energy Systems Group

SWR-1F DDAS PLOT 7-24-76

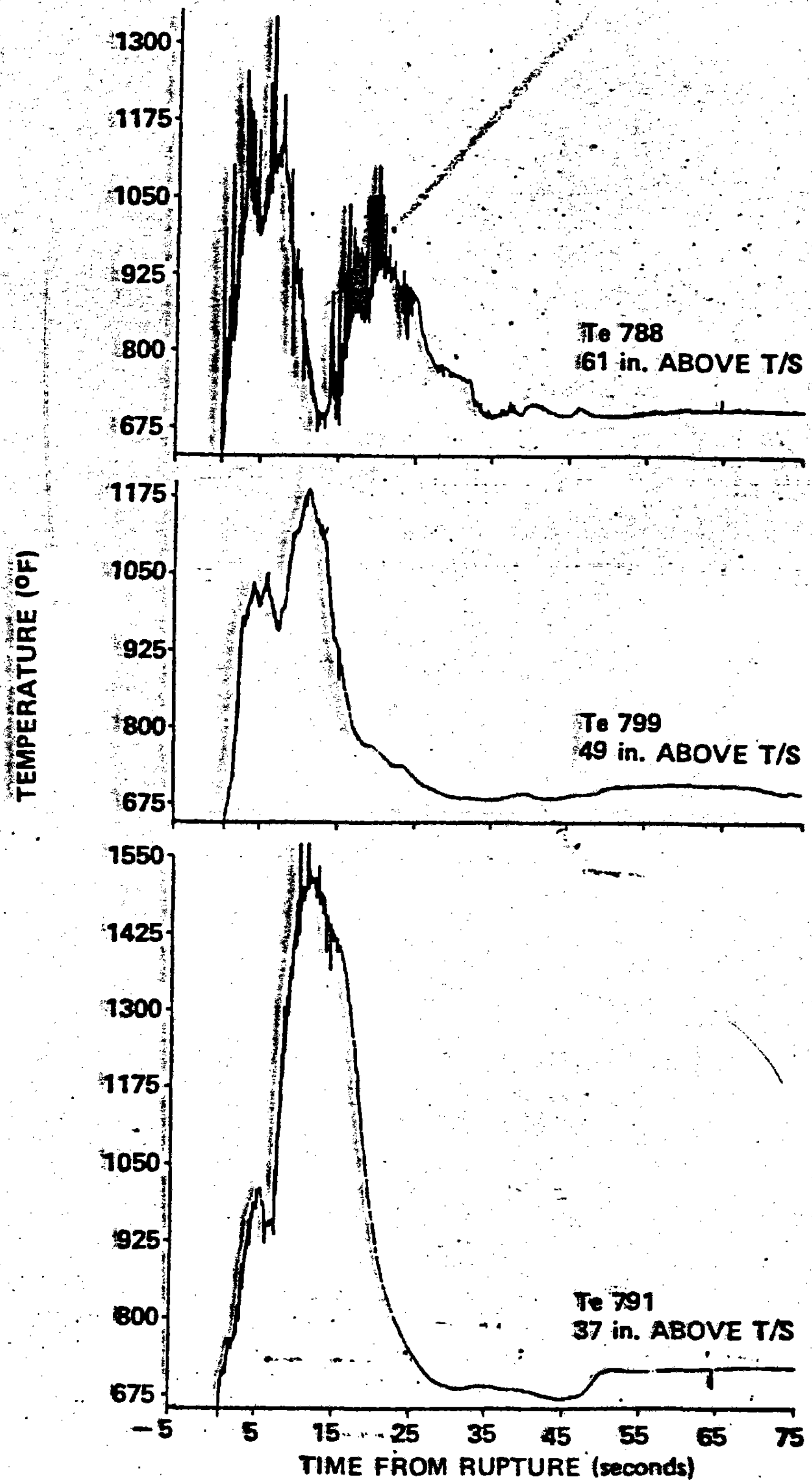


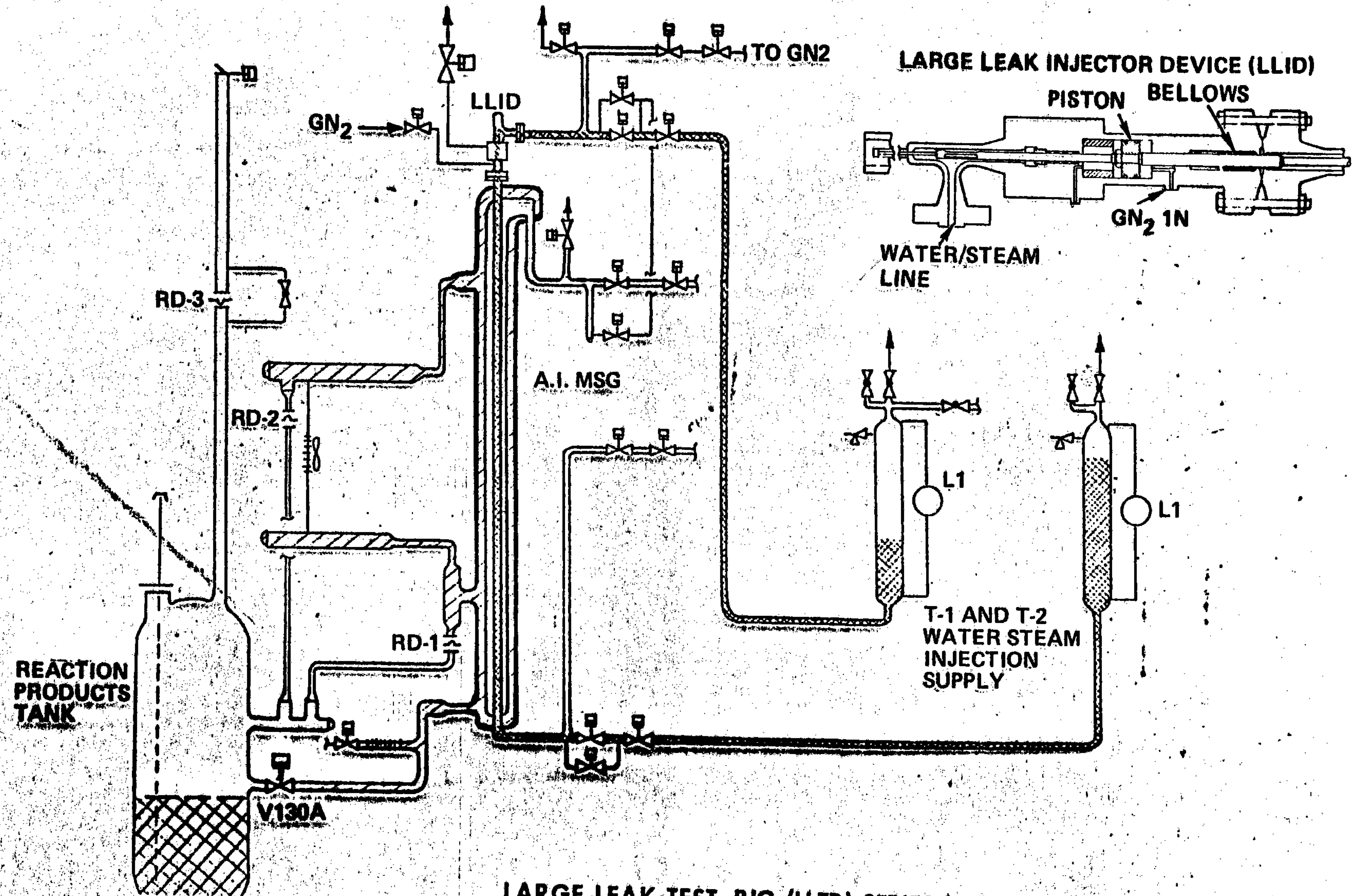


SODIUM PRESSURE DUE TO SWR-1F



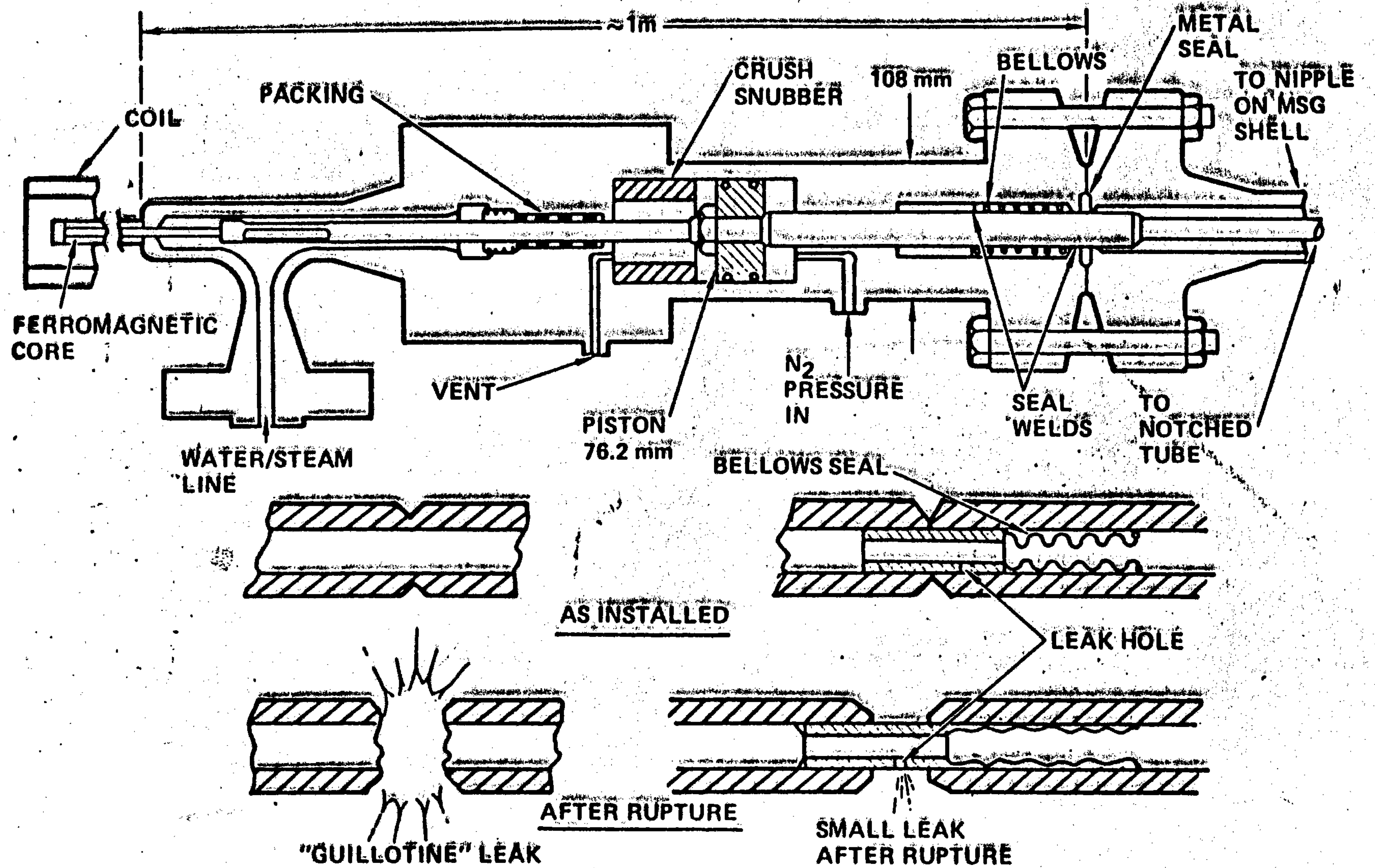
LLTR SWR-1F 7-24-76





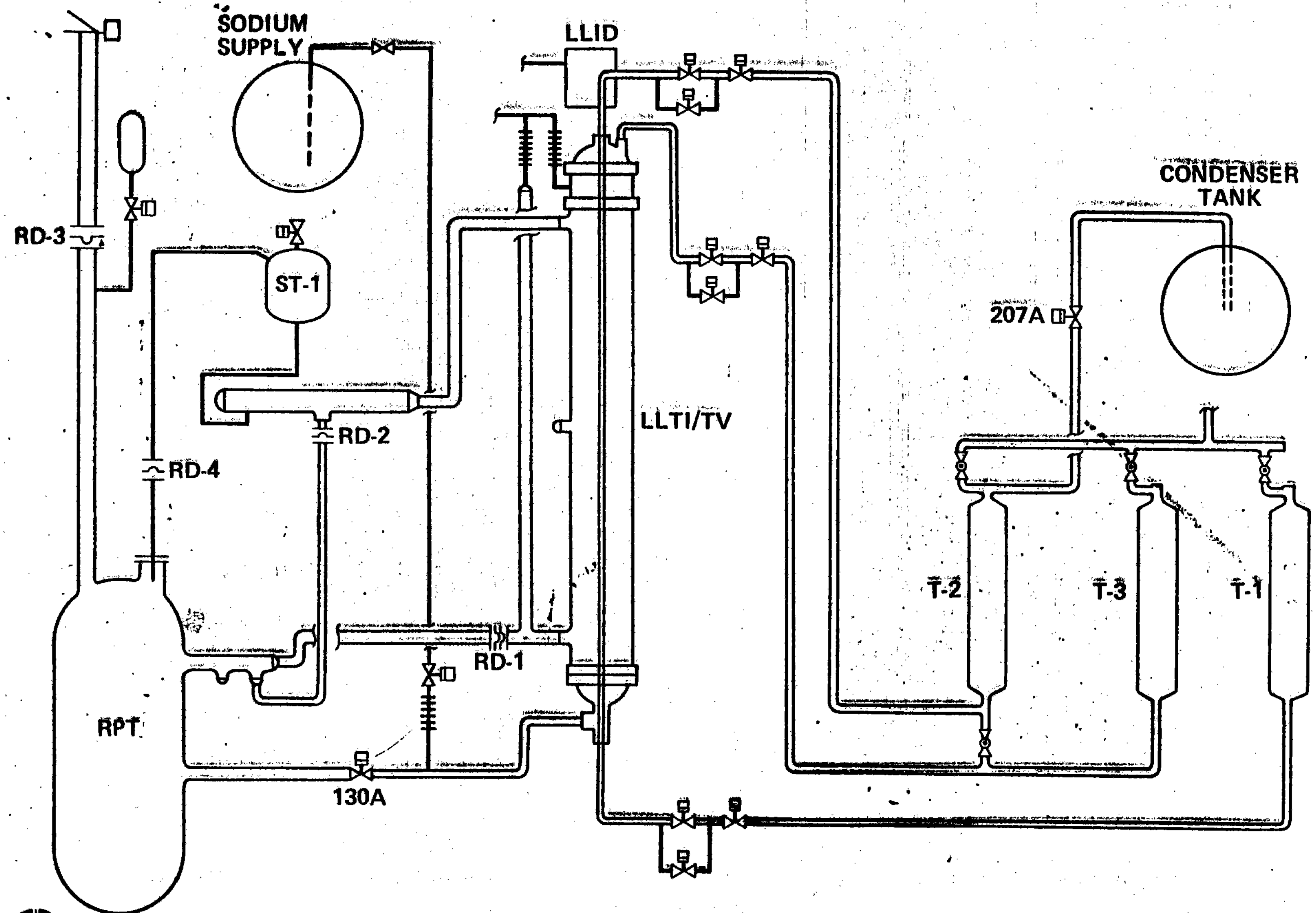
LARGE LEAK TEST RIG (LLTR) SERIES 1 TEST

LARGE LEAK INJECTION DEVICE (LLID)



79-A3-33-19

LARGE LEAK TEST RIG (LLTR) SERIES II



Rockwell International
Energy Systems Group

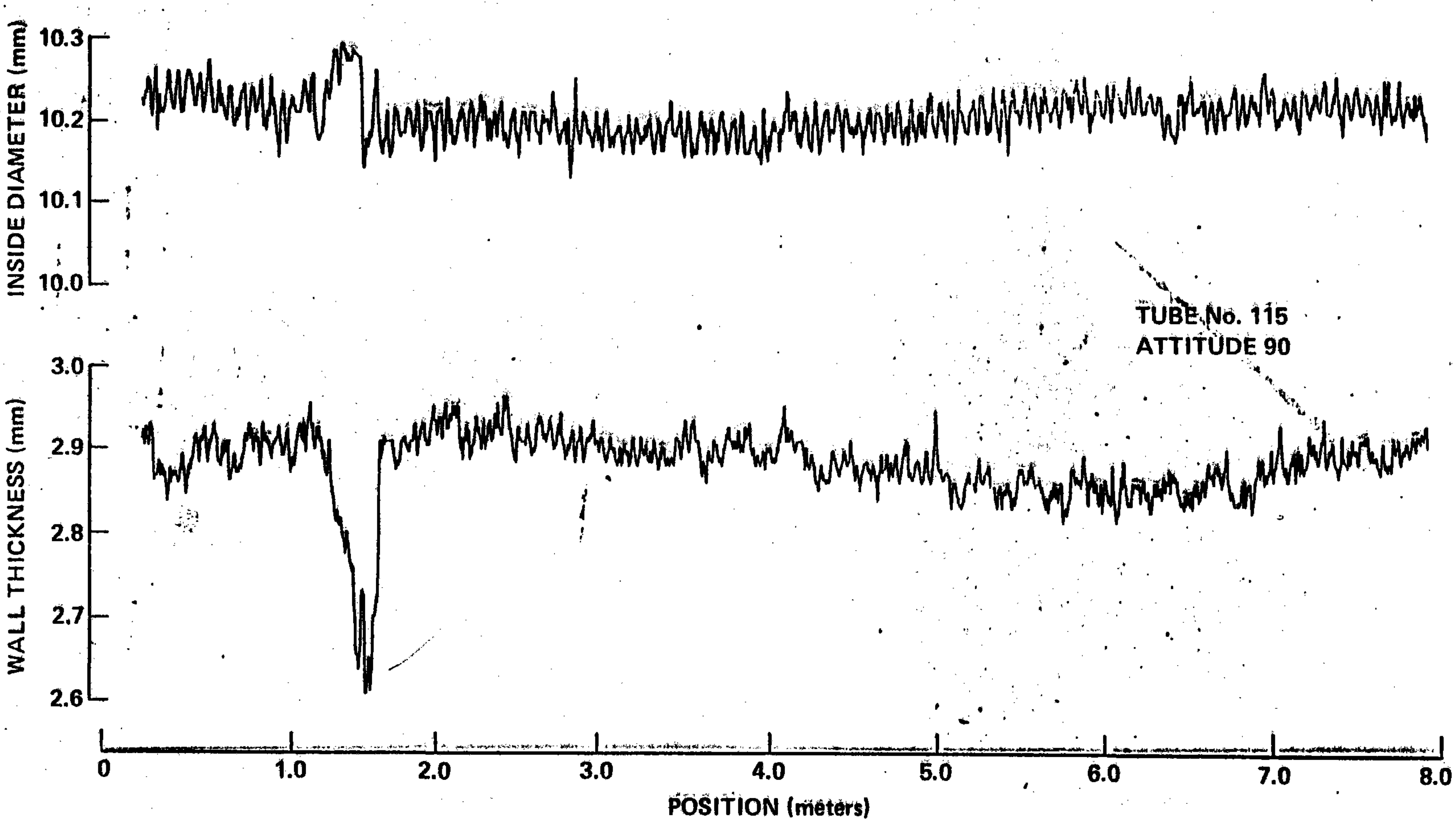
lower shroud.
3) H_2O inlet temp.

LLTR SERIES II TEST CONDITIONS

GROUP A TESTS

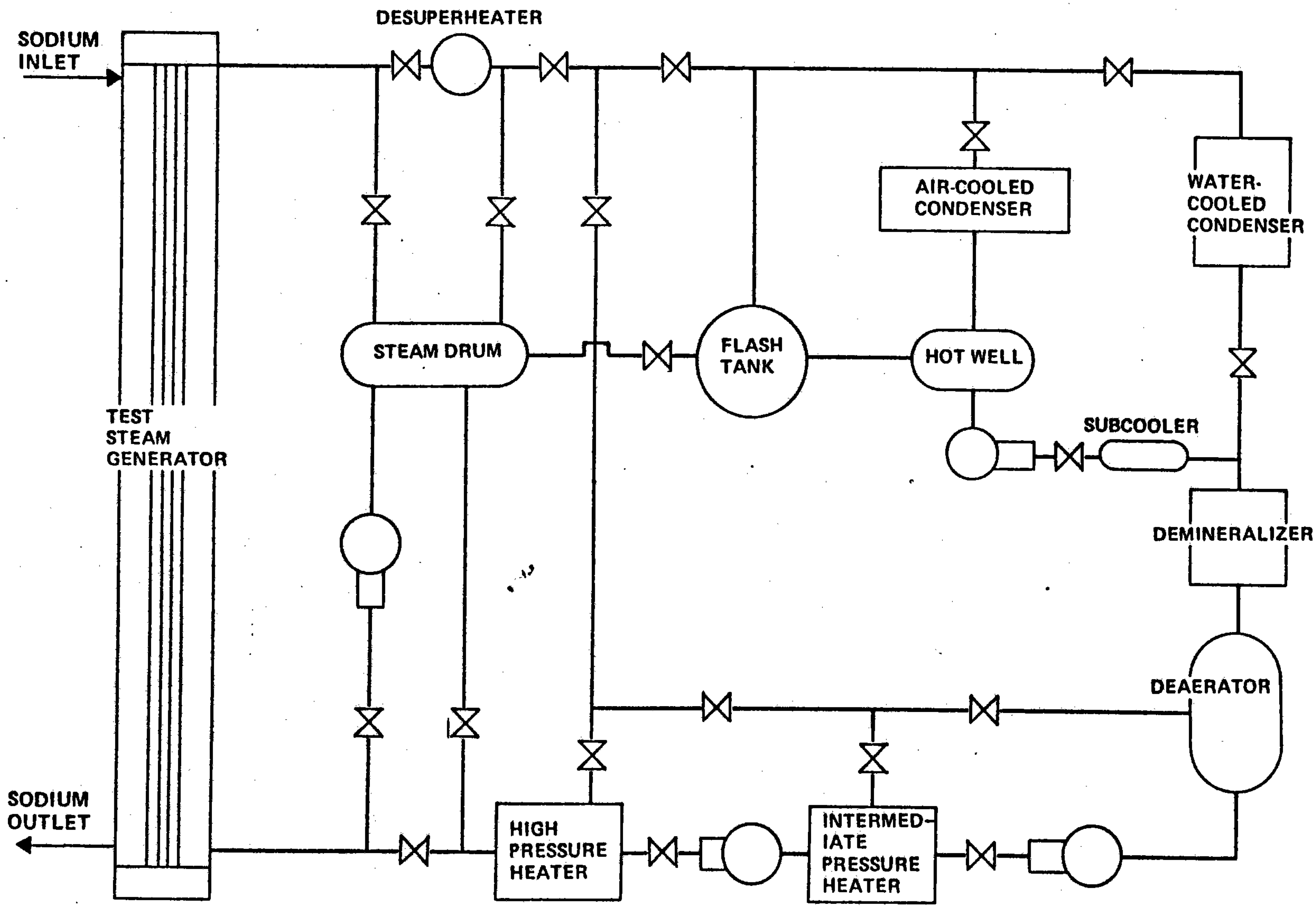
TEST NO.	LEAK SIZE	RADIAL POSITION	H_2O PRESS. PSIA	LEAK ORIENTATION	REMARKS
A-1A	1-DEG	CENTER	NITROGEN 2000	DNA	NON-REACTIVE TEST – DOUBLE MEMBRANE.
A-1B	1-DEG	CENTER	NITROGEN 2000	DNA	NON-REACTIVE TEST – SINGLE MEMBRANE.
A-2	1-DEG	CENTER	1700	DNA	LARGEST PRIMARY LEAK
A-3	TUBE WASTAGE LK. (0.1#/SEC)	CENTER	1700	BETWEEN ADJACENT TUBES	LEAK PROGRESSION FROM UNCONTROLLED NATURAL LEAK
A-4	TRANSITION SIZE LK. (0.8#/SEC)	CENTER	1700	BETWEEN ADJACENT TUBES	MAX. TUBE EXPOSURE TO REACTION PRODUCTS
A-5	MAX. W/O BURST DISC (2.0#/SEC)	CENTER	1700	BETWEEN ADJACENT TUBES	MAX. REACTION W/O RELIEF
A-6	1-DEG	BUNDLE EDGE	1700	TBD	CENTER VS. EDGE STRUCTURAL INTEGRITY CHECK.

SWR-6 UT DATA — AVERAGED



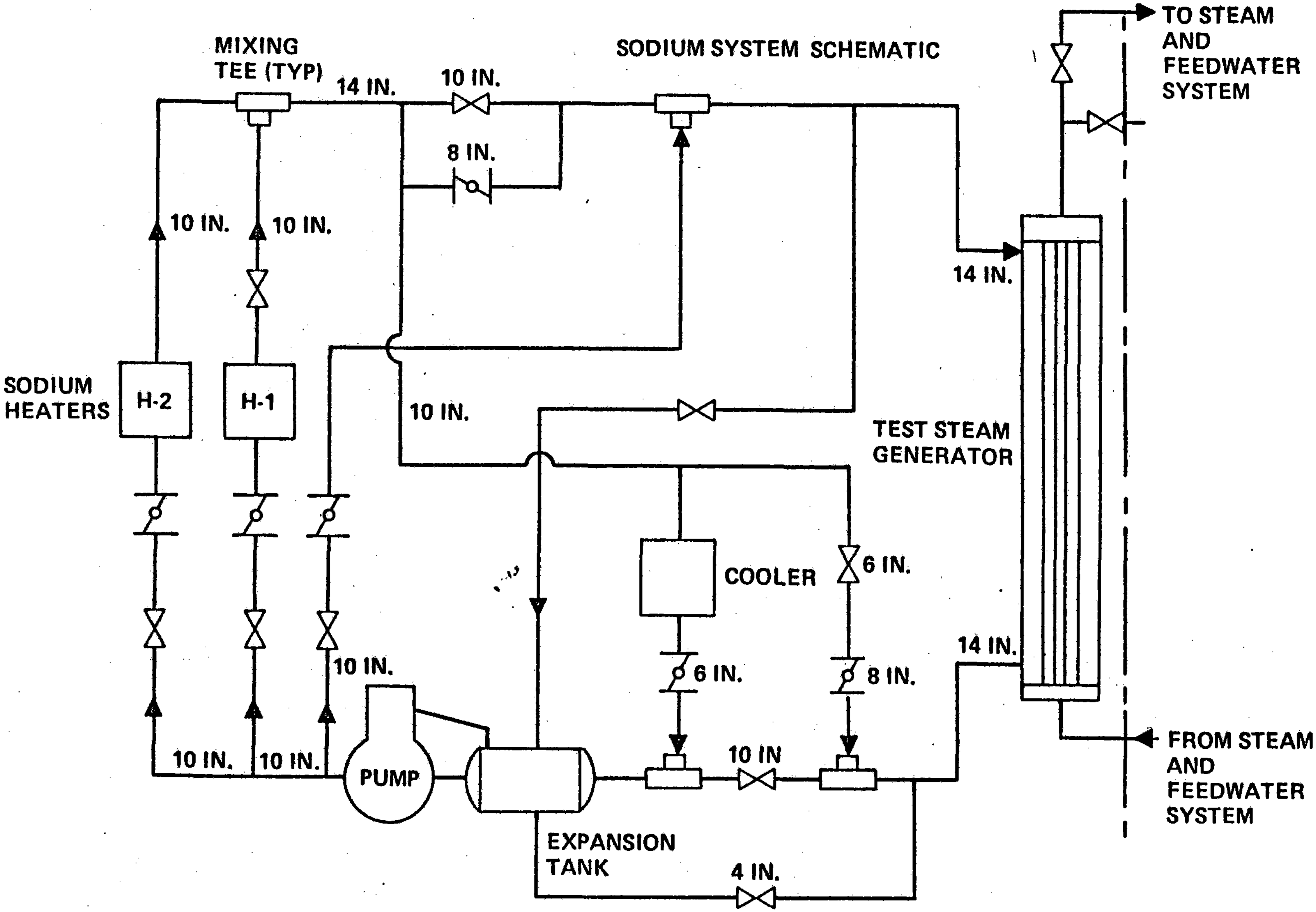
SODIUM COMPONENTS TEST INSTALLATION (SCTI)

STEAM & FEEDWATER SYSTEM SCHEMATIC



79-A3-33-7

SODIUM COMPONENTS TEST INSTALLATION



79-A3-33-6

IMPACT OF SERI CONFERENCE

SECTION IX

IMPACT OF SERI CONFERENCE

SERI MATERIALS WORKSHOP - DECEMBER 1978

Pohlman
Roger Staely. OSU
Corrosion xpert.

CHRONOLOGY:

1ST AM	INTRODUCTION, OBJECTIVE:
	"TO PROVIDE BALANCE TO DESIGN MOMENTUM"
1ST PM, 2ND DAY	TASK GROUPS MEET
	HEAR SCOPING PAPERS
	LIST ISSUES
	VOTE, PRIORITIZE
	WRITE-UP WINNERS
3RD AM	RECONVENE MAIN GROUP
	REVIEW TASK GROUP REPORTS
	VOTE ON URGENCY OF WORK
LATER	SERI SENDS OUT DRAFT REPORT FOR REVIEW AND COMMENT

SERI MATERIALS WORKSHOP - DECEMBER 1978

COMMENTS:

- PARTICIPANTS WERE RESEARCH-ORIENTED, REPRESENTING GRANT - OR CONTRACT-FUNDED INSTITUTIONS

- SOME ISSUES WERE PRESENTED MORE EFFECTIVELY THAN OTHERS

- SOME PARTICIPANT'S OBJECTIVITY MAY HAVE BEEN CLOUDED BY:

  - LMFBR TECHNICAL BACKGROUND
  - LMFBR BUDGETARY PROGNOSIS
  - SALT VS. SODIUM

- AFTER ALL, IT WAS DONE BY A COMMITTEE, IN A HURRY

SERI MATERIALS WORKSHOP - DECEMBER 1978

PRINCIPAL ISSUES IN ORDER OF PRIORITY	ESG COMMENT
1. CREEP/FATIGUE BEHAVIOR IN SODIUM AND SALT UNDER RECEIVER PROTOTYPICAL CONDITIONS	1. WE AGREE THAT MORE WORK IS NEEDED TO REDUCE THE CONSERVATISM IN HI-TEMP CODE CASE. MOST EXPERIMENTAL WORK TO SUPPORT SODIUM CAN BE DONE IN INERT ATMOSHPERE. 95% OF WORK APPLICABLE TO Na can be done in air, performance better in Na NO COMMENT ON WORK TO SUPPORT SALT TECHNOLOGY. CREEP/FATIGUE PROBLEMS ARE COMMON TO ALL HIGH TEMPERATURE SOLAR SYSTEMS.
2. PHYSICOCHEMICAL DATA (427 - 593°C) ON ALKALI NITRATE SALT MIXTURES	2. WE AGREE THAT CURRENT DATA BASE IS INADEQUATE FOR CONFIDENT LONG-TERM SYSTEM DESIGN

SERI MATERIALS WORKSHOP - DECEMBER 1978 CONTD

ISSUES	ESG COMMENT
3. SODIUM CORROSION STUDIES AT OXYGEN CONCENTRATIONS GREATER THAN 1 PPM COUPLED WITH MASS TRANSPORT STUDIES *ESG says low priority*	3. WE DO NOT AGREE: MAINTENANCE OF A CLEAN SYSTEM IS INEXPENSIVE *ESG could test*
4. DEVELOP HIGH STRENGTH FERRITIC ALLOY	4. WE AGREE THAT SUCH AN (9 CR - 1 Mo) WOULD BE USEFUL, ESPECIALLY IN STEAM GENERATOR. *ORNL CE.*
5. THERMAL STRIPING AND THERMAL FATIGUE DAMAGE *TEMP CYCLING CAN BE AVOIDED THRU DESIGN*	5. WE DO NOT AGREE THAT THIS IS AS MUCH OF A CONCERN IN SOLAR AS IN LMFBR (UPPER INTERNALS) APPLICATIONS. WE DO AGREE THAT T MIXING DESERVES COMPETANT DESIGN/ ANALYSIS.
6. FORCED CONVECTION LOOP STUDIES OF MOLTEN NITRATE (DRAIN) SALT	6. WE AGREE

SERI MATERIALS WORKSHIP - DECEMBER 1978 CONTD

ISSUES	ESG COMMENT
7. DEVELOP AND/OR QUALIFY COOLANT CONTAINMENT ALLOYS FOR RECEIVER OPERATION TO 704°C (1300°F) FOR SECOND GENERATION PLANT DESIGNS	7. WE DO NOT AGREE THAT THERE IS ANY INCENTIVE IN EXCEEDING STEAM SYSTEM CONDITIONS DESIRED BY UTILITIES.
8. CAUSTIC CRACKING OF STEAM GENERATOR TUBES	8. WE DO NOT AGREE THAT CAUSTIC INTRUSION TO THE WATER/STEAM SYSTEM IS PROBABLE; WE DO AGREE THAT THE UNITS OF CAUSTIC SCC COULD BE MORE PRECISELY DEFINED
9. STRESS CORRISION CRACKING BY MOLTEN SALT	9. WE AGREE

CRITIQUE OF SODIUM
SECTION OF ASSESSMENT
REPORT

OVERALL

DOES NOT PROVIDE A BALANCED REPORT OF STATE-OF-THE-ART OF SODIUM TECHNOLOGY;

TOO MUCH ATTENTION TO RESEARCH (TREES) VIS A VIS COMPONENTS AND SYSTEMS (FOREST)

SELECTED CRITICISMS

NO COMMENT ON YEARS AND DOLLARS INVESTED IN SODIUM TECHNOLOGY.

"CORROSION" EFFECTS OVEREMPHASIZED. 2/3 of report, too negative

VALVE SECTION MUCH TOO NEGATIVE. – uninformed – no hard facing etc.

COAL PLANT STACK GAS CLEANUP

Bill Wall

FLUE GAS CLEANING SYSTEM

- TWO-STAGE DRY SCRUBBING SYSTEM
- SO_2 AND FLY ASH CONTROL
  - SPRAY DRYER SCRUBBER
  - FABRIC FILTER

THIS NEW CONCEPT IS OFFERED BY

Wheelabrator-Frye Inc.   Rockwell International

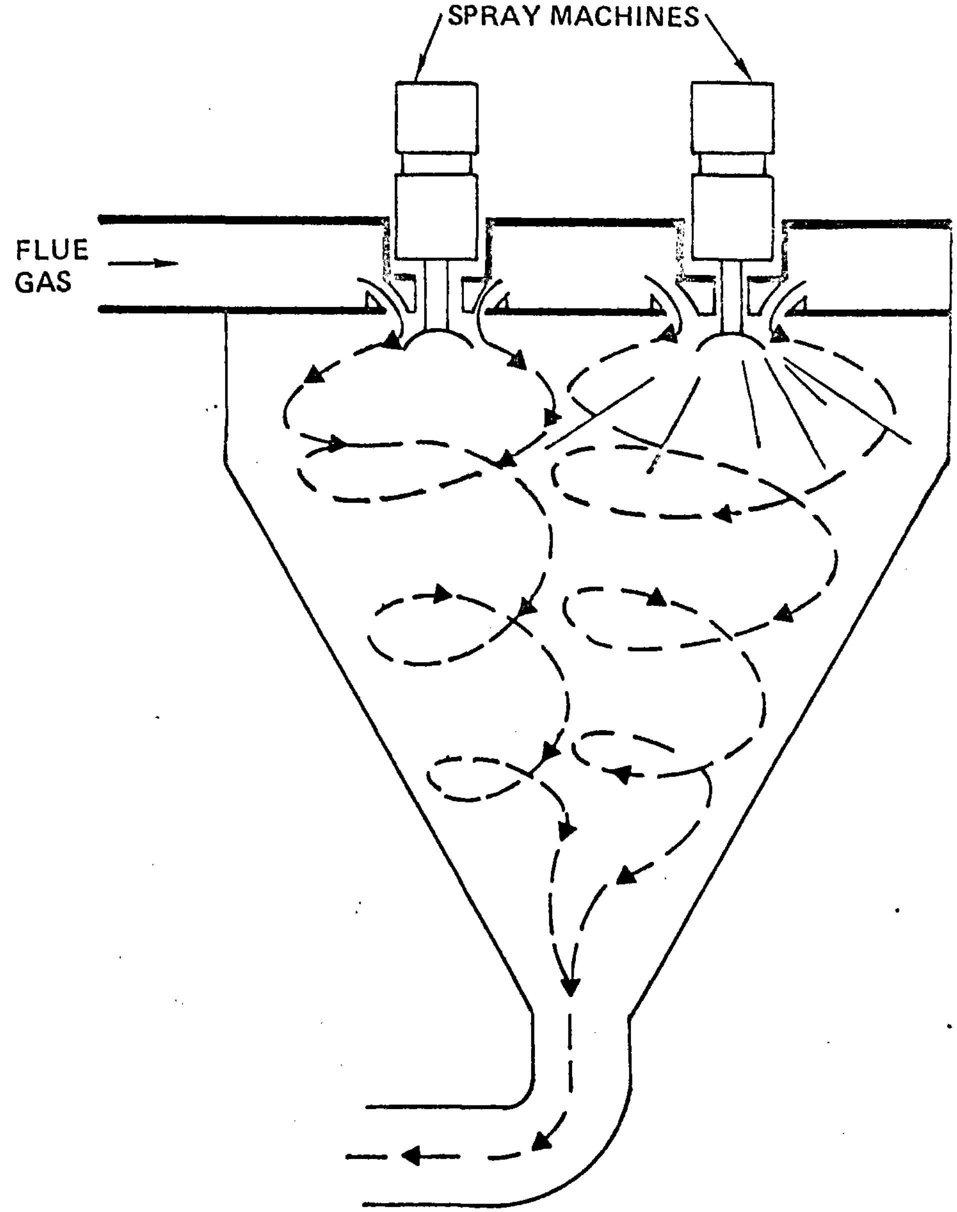
A JOINT VENTURE

WHICH PROVIDES THE FOLLOWING ADVANTAGES –

- FULL CAPABILITIES AND SUPPORT OF TWO LARGE CORPORATIONS
- INTEGRATED SYSTEM APPROACH FOR ENTIRE AIR POLLUTION CONTROL SYSTEM
- SINGLE CONTRACTING ENTITY AND POINT OF CONTACT
- PERFORMANCE WARRANTEE PACKAGE FOR ENTIRE SYSTEM

SPRAY DRYER

- FINE ATOMIZATION PROVIDES GOOD GAS-LIQUID CONTACT
- EFFICIENT SO_2 REMOVAL WITH LOW LIQUID FLOW RATES
- HEAT FROM FLUE GAS DRIES LIQUID BEFORE CONTACTING CHAMBER WALLS
- OUTLET GAS TEMPERATURE ABOVE DEW POINT; NO REHEAT REQUIRED



78-M30-54-9A

SCRUBBER CHEMISTRY AND TECHNOLOGY

- $Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$
- $CaSO_3 + 1/2\ O_2 \rightarrow CaSO_4$
- SPRAY DRYER ATOMIZER PRODUCES FINE DROPS OF LIME SLURRY
- DROPS ARE DRIVEN THROUGH FLUE GAS STREAM
- SO_2 IS ABSORBED AND REACTS WITH LIME IN DROPS
- WATER EVAPORATES LEAVING DRY PARTICLES
- EXCELLENT GAS – LIQUID CONTACT GIVES HIGH SO_2 REMOVAL
- FLUE GAS NOT SATURATED WITH WATER VAPOR

SPRAY DRYER EXPERIENCE

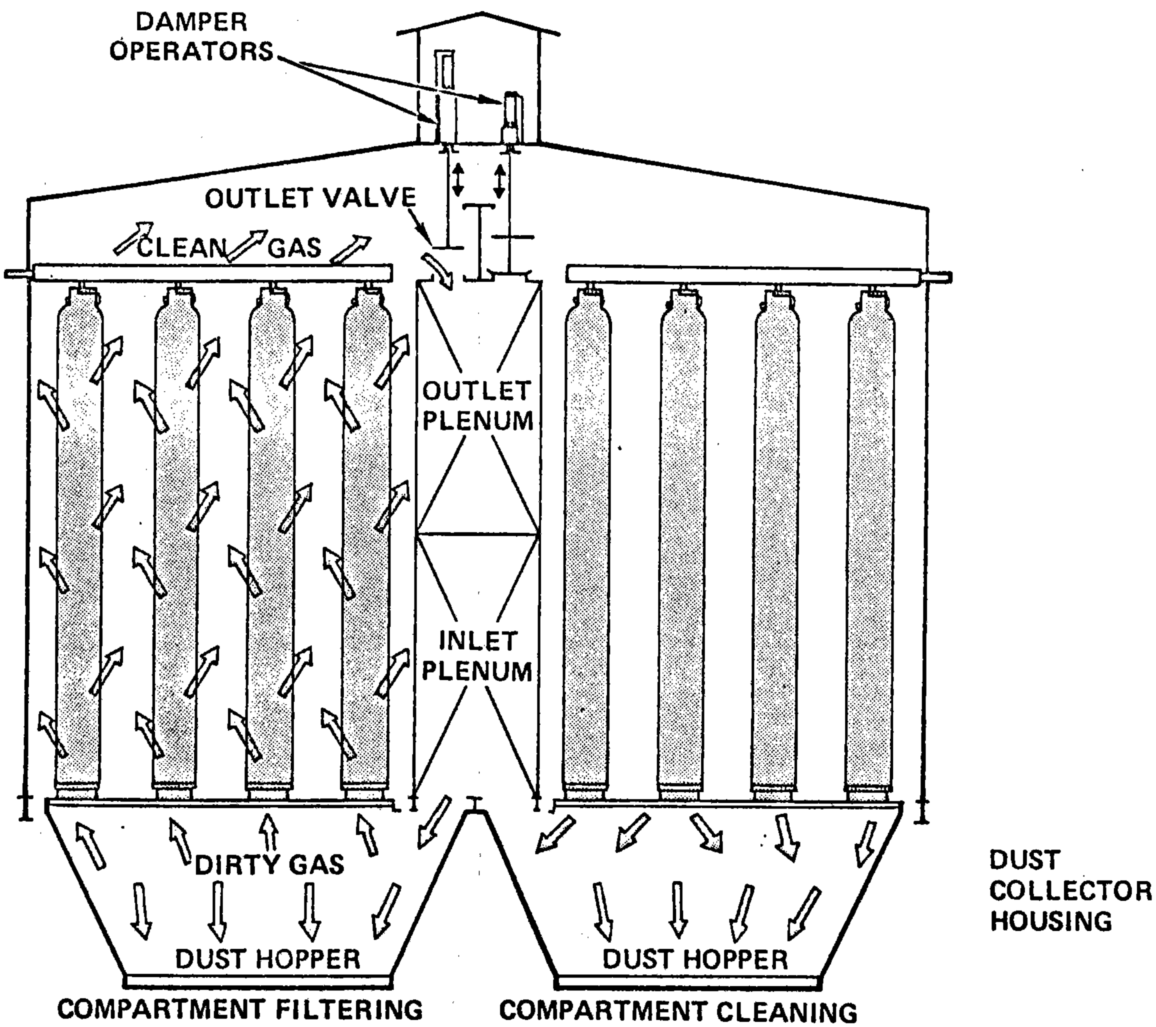
- GENERAL
  - MORE THAN 1200 UNITS CURRENTLY IN SERVICE WORLDWIDE
  - MATURE TECHNOLOGY (~50 YEARS)
- SO_2 REMOVAL
  - MORE THAN 600 TESTS OF SO_2 REMOVAL IN PILOT SPRAY DRYERS OVER 7-YEAR PERIOD
    - ▲ POWER PLANT BOILER FIRED WITH BLACK MESA COAL (MOHAVE)
    - ▲ IN-LINE GAS/OIL BURNER FOR HOT GAS GENERATION (BOWEN)
    - ▲ CYCLONE, BOILER FIRED WITH LIGNITE (LELAND OLDS)
    - ▲ CYCLONE ELECTROSTATIC PRECIPITATOR, AND FABRIC FILTERS USED FOR PRODUCT COLLECTION
    - ▲ SO_2 CONCENTRATIONS FROM 200 TO 8000 ppm
    - ▲ INLET GAS TEMPERATURES FROM 250^{o} TO 500^{o}F
    - ▲ DRYER GAS FLOWS FROM 800 TO 4000 acfm
    - ▲ SODA ASH, TRONA, SODIUM BICARBONATE, HYDRATED LIME, QUICKLINE, LIMESTONE, POTASH, FLY ASH, AND VARIOUS COMBINATIONS OF THESE USED AS SO_2 ABSORBENTS

78-JU7-54-12A

FABRIC FILTER

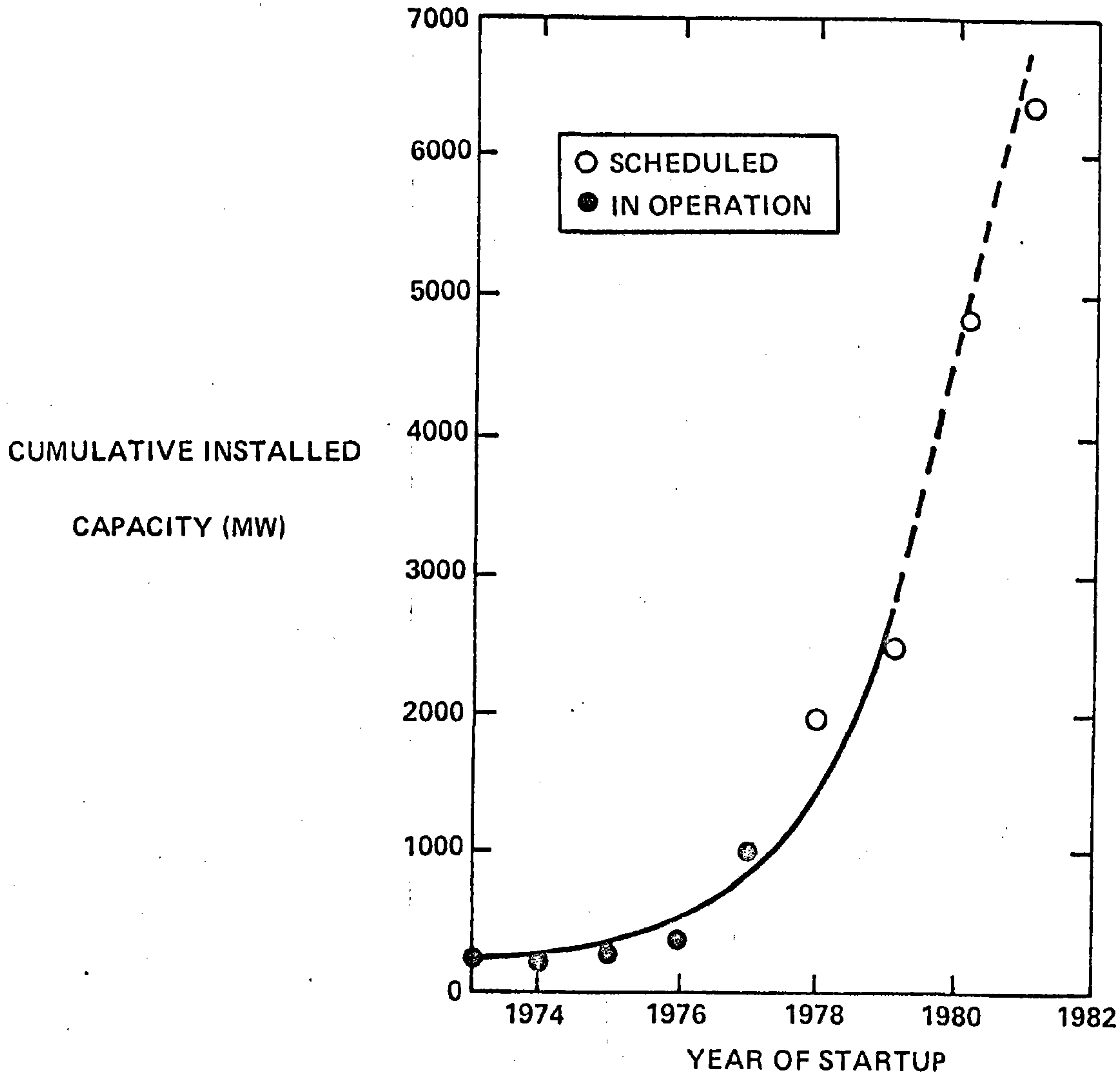
- HIGH COLLECTION EFFICIENCY
- PROVEN APPLICATION IN MANY PROCESS INDUSTRIES
- GAINING WIDE ACCEPTANCE ON COAL FIRED BOILERS
- USED WITH SPRAY DRYER ON MOST SPRAY DRYER APPLICATIONS
- CAN EASILY BE MAINTAINED WHILE SYSTEM IS OPERATIONAL
- FLUCTUATIONS IN TEMPERATURE OR DUST LOAD HAVE LITTLE EFFECT ON PERFORMANCE OF COLLECTOR

FABRIC FILTER



77-M10-20-26

BAGHOUSES ON COAL FIRED UTILITY POWER PLANTS



REF. J. S. TROUPE, BECHTEL, PAPER PRESENTED AT 1978 APPA WORKSHOP,
SAN FRANCISCO, CAL., FEB. 28, 1978

78-A4-54-15

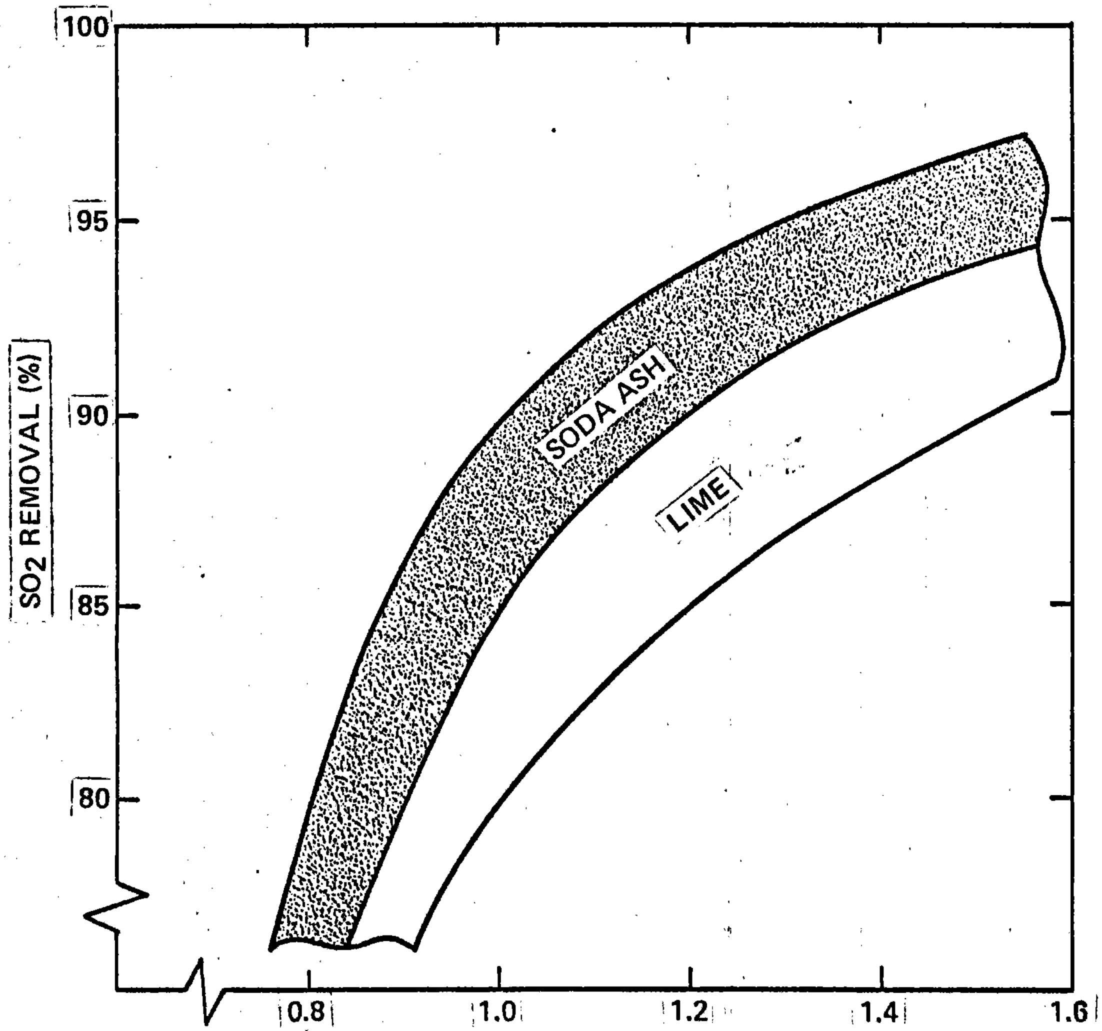
WFI'S FABRIC FILTER EXPERIENCE IN POWER INDUSTRY

• *COYOTE STATION UNIT No. 1	440 MW
• SOUTHWESTERN PUBLIC SERIVCE HARRINGTON No. 2 & No. 3	700 MW
• TEXAS UTILITIES MONTICELLO No. 1 & No. 2	880 MW
• *PENNSYLVANIA POWER & LIGHT HOLTWOOD, PENNSYLVANIA	40 MW
• COLORADO-UTE NUCLA, COLORADO No. 1, No. 2, & No. 3	39 MW

*TURNKEY INSTALLATIONS

78-JU7-81-8

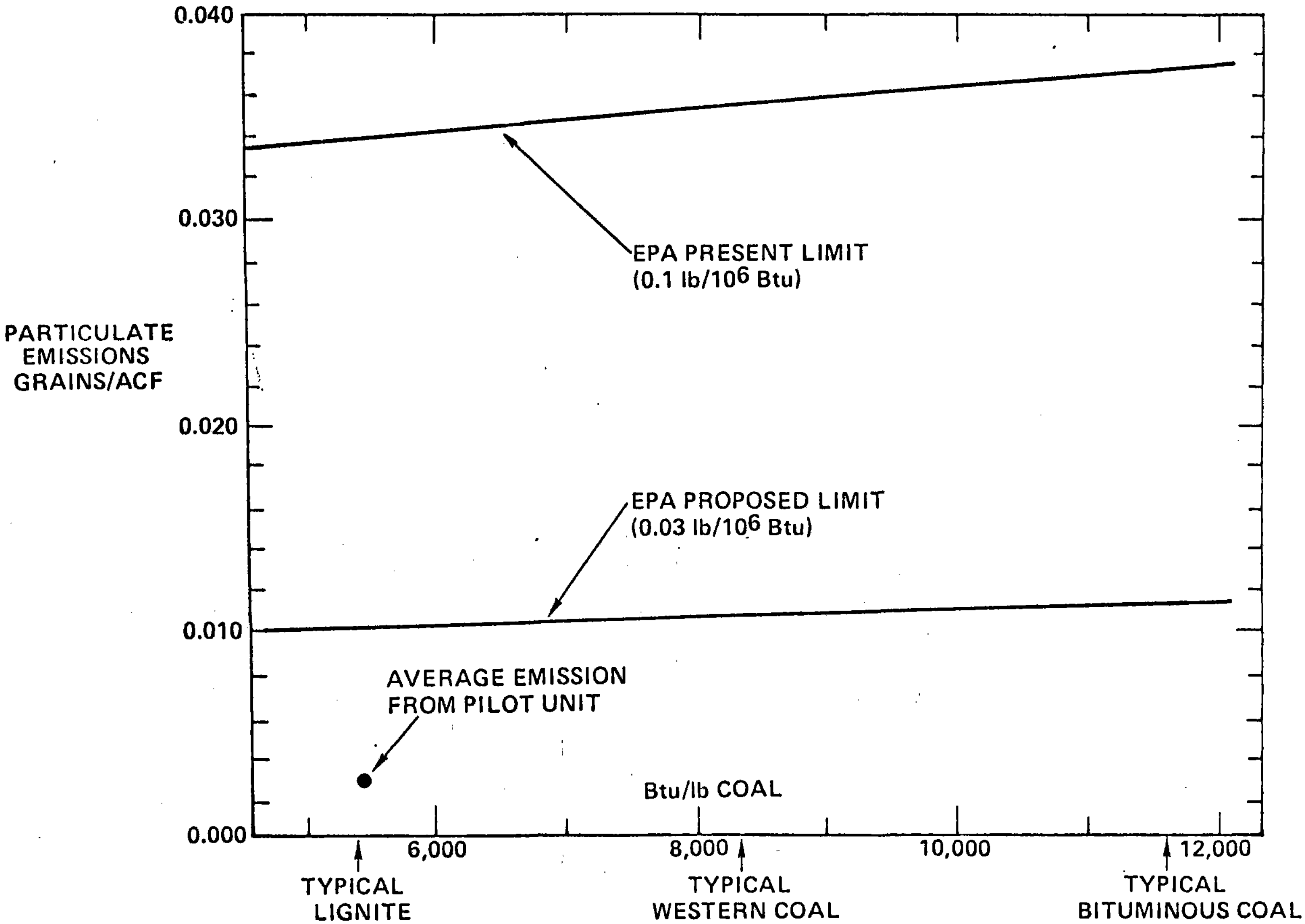
TYPICAL PERFORMANCE OF DRY FGD SYSTEM USING SODA ASH SOLUTION OR LIME SLURRY FOR ABSORBENT



STOICHIOMETRIC RATIO

(REACTANT ADDED/REACTANT THEORETICALLY REQUIRED TO REMOVE 100% OF THE SO_2)

PARTICULATE EMISSION CONTROL REQUIREMENTS



78-JU7-81-5A

SUMMARY OF KEY FEATURES

	FEATURES	TECHNICAL ADVANTAGES	PAYOFF TO USER
SPRAY DRYER	• WET CONTACT • DRY PRODUCT • LOW l/g	• HIGH SO_2 REMOVAL EFFICIENCY • NO PLUGGING OR SCALING • NO CORROSION OR EROSION • SMALL PIPES AND PUMPS • LOW POWER REQUIREMENTS • CAN USE BLOW DOWN WATER	• MEETS FGD REQUIREMENTS • HIGH AVAILABILITY • LOW MAINTENANCE COSTS • LOW CAPITAL AND OPERATING COSTS • REDUCED WATER USAGE
BAGHOUSE	• FABRIC FILTERS • MECHANICAL AND PNEUMATIC CLEANING	• HIGH PARTICULATE REMOVAL EFFICIENCY • PROVIDES ADDITIONAL SO_2 REMOVAL • HIGH PERFORMANCE WITH REDUCED FILTER AREA • LESS FREQUENT BAG CLEANING	• MEETS STRINGENT PARTICULATE AND SO_2 REQUIREMENTS • LOWER CAPITAL AND OPERATING COSTS
THE SYSTEM	• SIMPLICITY WITH PROVEN TECHNOLOGY	• HIGH RELIABILITY WITH LOW OPERATING AND MAINTENANCE REQUIREMENTS	• LOW CAPITAL AND OPERATING COSTS

Friday

Meets new source performance standards

90% SO_2 removed
or

2.6 # SO_2 / 10^6 Btu burned — 1.2 after abatement
if below must demo. removed 70% of SO_2

1.2 # SO_2 / 10^6 Btu burned.

75-80
KW installed
ductwork. from to
less fan

78-JY3-54-14B

90-100 KW
for wet.

– Stearns-Rogers
– B&W Bech. B&V

DRY SO_2 AND PARTICULATE REMOVAL SYSTEM

Through a joint venture, the Air Pollution Control Division of Wheelabrator-Frye Inc. and the Atomics International Division of Rockwell International have merged their respective resources and process knowledge to solve the problem of fossil-fuel boiler emissions.

The Wheelabrator/Rockwell dry-products SO_2 and particulate removal system relies on components which have proved their reliability in over 50 years of operation.

The Atomics International Division of Rockwell has developed the use of spray dryers for SO_2 removal.

Wheelabrator-Frye is a leader in air pollution control technology, specializing in applications of fabric filters and electrostatic precipitators for coal-fired boiler installations.

For additional information on this dry system, write: Marvin Long, Wheelabrator-Frye Inc./Rockwell International Joint Venture, P.O. Box 717, Pittsburgh, PA 15230. Or, call him at (412) 288-7290.

Wheelabrator-Frye Inc. Rockwell International

A Joint Venture

JV-1 10-8-3

A dry-product system which removes both SO_2 and particulates

Wheelabrator-Frye Inc. and Rockwell International have developed a simple, economical, dry-product system* for cleaning boiler flue gas. This system has application on utility and industrial boilers of virtually any size, fired with coal or oil. The system is an open-loop process which uses a spray dryer and a fabric filter collector for SO_2 and particulate removal. Alternately, an electrostatic precipitator can serve as the particulate collector.

*Patent pending

Key features and benefits

- Simple, reliable system with proven components
- High availability
- Meets emission standards
- Low capital costs

These features result in overall low annualized costs. In addition, here's what you avoid:

- Sludge ponds
- Water chemistry and pH control problems
- Flue gas reheat
- Scaling, erosion or corrosion problems

Here's how the system works

1. Boiler flue gas is passed through a spray dryer where it reacts with a mist of a dilute sodium carbonate solution or calcium hydroxide slurry. Immediate chemical reaction removes the SO_2 from the flue gas and the sensible heat of the flue gas evaporates the water and dries the solution to form a dry powder. Since the flue gas does not become saturated, many of the operational problems associated with wet scrubbers cannot occur.

2. The flue gas leaving the spray dryer, containing dry powder and boiler fly ash, enters the collector. As the fly ash and powder are removed from the flue gas in the collector, additional reaction of the SO_2 takes place, increasing the efficiency of the system.

3. The clean gas is then exhausted through a stack to the atmosphere without reheat.

4. All particulates (fly ash and powder) are removed from the hoppers of the collector in a dry form for disposal.


A spray dryer installation


A power boiler fabric filter installation

A tested system

Years of operating experience have proved fully the components of the system. The most recent demonstration testing was performed at the Leland Olds Station of Basin Electric Power Cooperative. Tests of operational characteristics were conducted with a number of sorbents and filter fabrics. The comprehensive test program demonstrated the ability of the system to achieve high SO_2 and particulate removal efficiences under varied flue gas conditions.

Through a joint venture of Wheelabrator-Frye Inc. and Rockwell International, a 410 MW (1,890,000 ACFM) turnkey SO_2 and particulate removal system has been contracted for the North Dakota Coyote Station, owned by Otter Tail Power Company, Minnkota Power Cooperative, Inc., Montana-Dakota Utilities Company, Northwestern Public Service Company and Minnesota Power and Light Company.