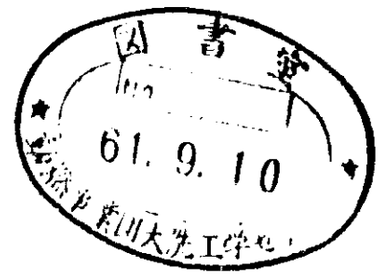
PNCT N9530 86-008

FBR MATERIAL DEVELOPMENT SECTION



POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORPORATION
OARAI ENGINEERING CENTER

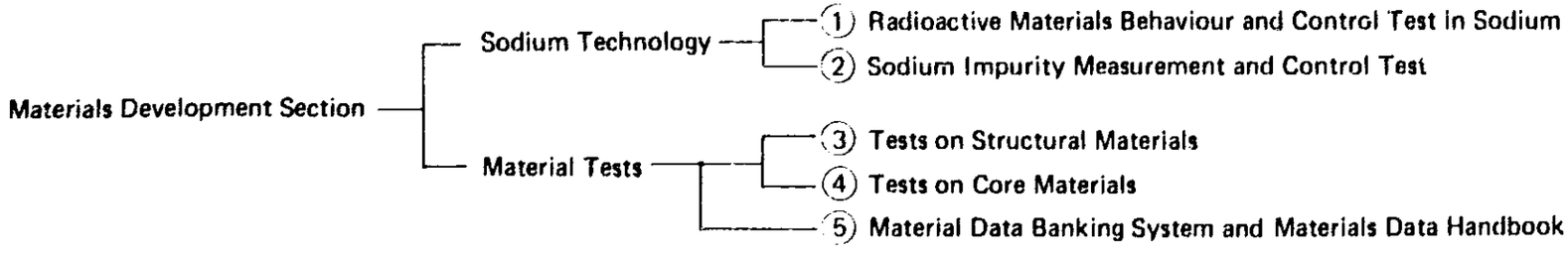
■ INTRODUCTION

Research and Development (R&D) in this section are consist of two activities on which are Liquid Sodium Technology and Materials Test for Fast Breeder Reactor (FBR).

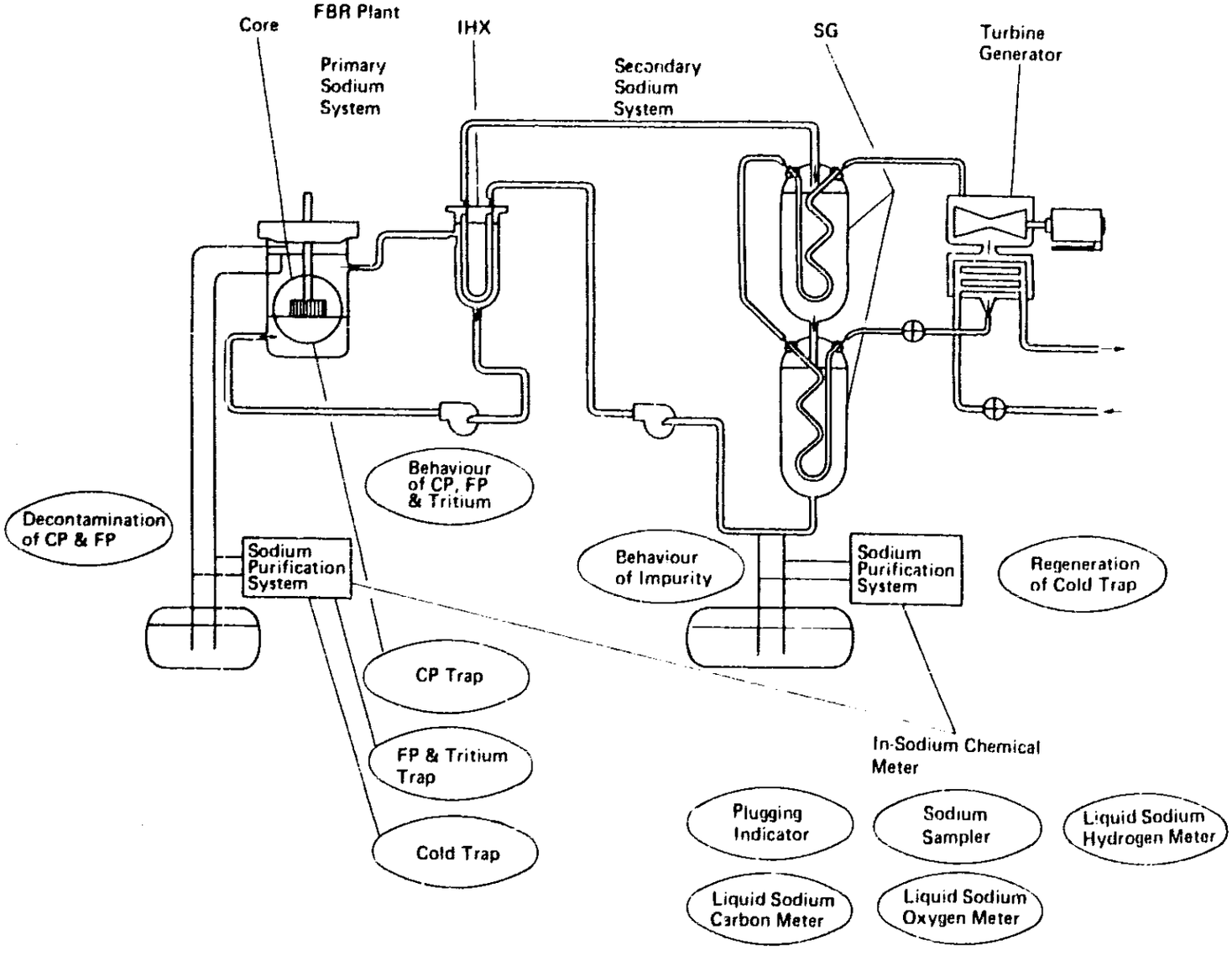
Testing items on Sodium Technology are (1) Radioactive Materials Behaviour and Control Test in Sodium and (2) Sodium Impurity Measurement and Control Test.

Testing items on Material Tests are (3) Tests on Structural Materials in air, sodium and water except for neutron irradiation and (4) Tests on Core Materials except for fuel. Data Obtained from these tests are banked in computer system and are summarized to (5) Materials Data Handbook.

The function of this section is showed as follows.



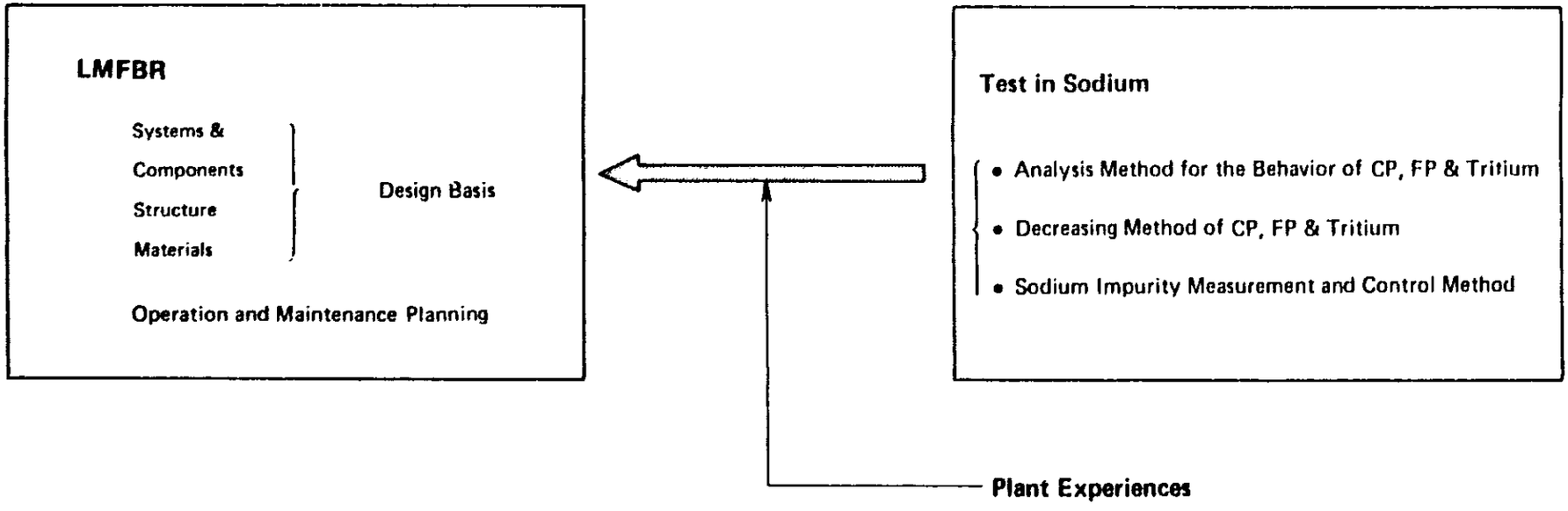
■ SODIUM TECHNOLOGY AREA



■ CHARACTERIZATION OF SODIUM TECHNOLOGY

		(CP)		(FP)	
Radioactive Material Test in Sodium (CP & FP) • To Decrease Radiation Exposure to Plant Personnel • To Prevent Contamination in LMFBR Primary System	Concerned Region	○ Primary System and Sodium Removal Facility from Exchanged Fuel Assemblies		○ Primary System and Gaseous Processing System	
	Operational Phase	○ During Normal Operation		○ During Operation with Failed Fuel	
	Source	○ Activation of Core Materials / Corrosion with Sodium		○ Nuclear Fission / Cladding Failure	
	Nuclide	○ ^{54}Mn, ^{60}Co, ^{58}Co		○ Such Many Kinds as ^{137}Cs, Rare Gase and Rare Earth etc.	
	Decreasing Method	○ CP Trap		○ FP Trap	
Sodium Impurity Measurement and Control Test (Chemical Impurities & Tritium) • To Assure Reliability of Core and Structural Material in Sodium • To Assure Reliability of LMFBR Plant Operation		(Oxygen)	(Carbon)	(Hydrogen)	(Tritium)
	Concerned Region	○ Primary and Secondary System	○ Primary and Secondary System	○ Secondary System	○ Primary and Secondary Systems and Gaseous Processing Systems
	Operational Phase	○ During Normal Operation	○ During Normal Operation and In-Leak of Pump Oil	○ During Normal Operation and Failure of Heat Transfer Tube of SG	○ During Normal Operation
	Source	○ Air Contamination	○ Carbon Transfer of Structural Materials in Sodium and In-Leak of Pump Oil	○ Corrosion in SG / Diffusion of Nascent Hydrogen and Sodium-Water Reaction	○ Fast Neutron Induced Reaction in Control Rod and Ternary Fission / Diffusion
	Control Method	○ Cold Trap	○ Cold Trap (may be)	○ Cold Trap	○ Cold Trap or Tritium/Hydrogen Chemical Trap
	Measurement Method	○ Sampler ○ Plugging Indicator (Vanadium Equilibration Method) (Oxygen Meter)	○ Sampler (Carbon Meter) (Specimen Equilibration Method)	○ Hydrogen Meter (Plugging Indicator)	

■ EVALUATION PROCESS IN SODIUM TECHNOLOGY

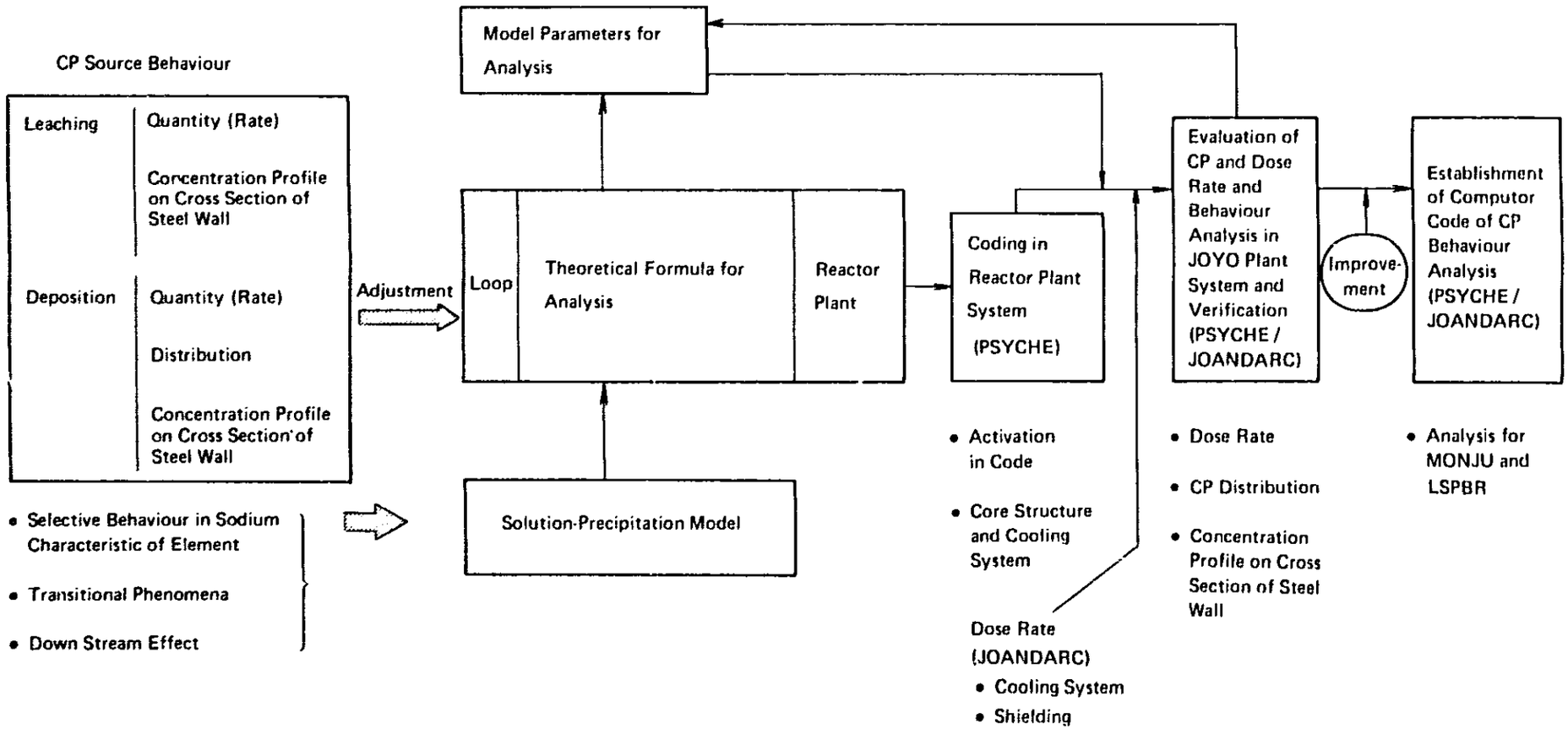


■ OBJECTIVES OF RADIOACTIVE MATERIAL TEST IN SODIUM

- To Establish Computor Code for CP Behaviour Analysis (PSYCHE / JOANDARC)
- To Develop Method of CP Trapping
- To Evaluate Method to Prevent or Control Source Rate of CP
- To Develop Method of FP Trapping —— Cesium Trap

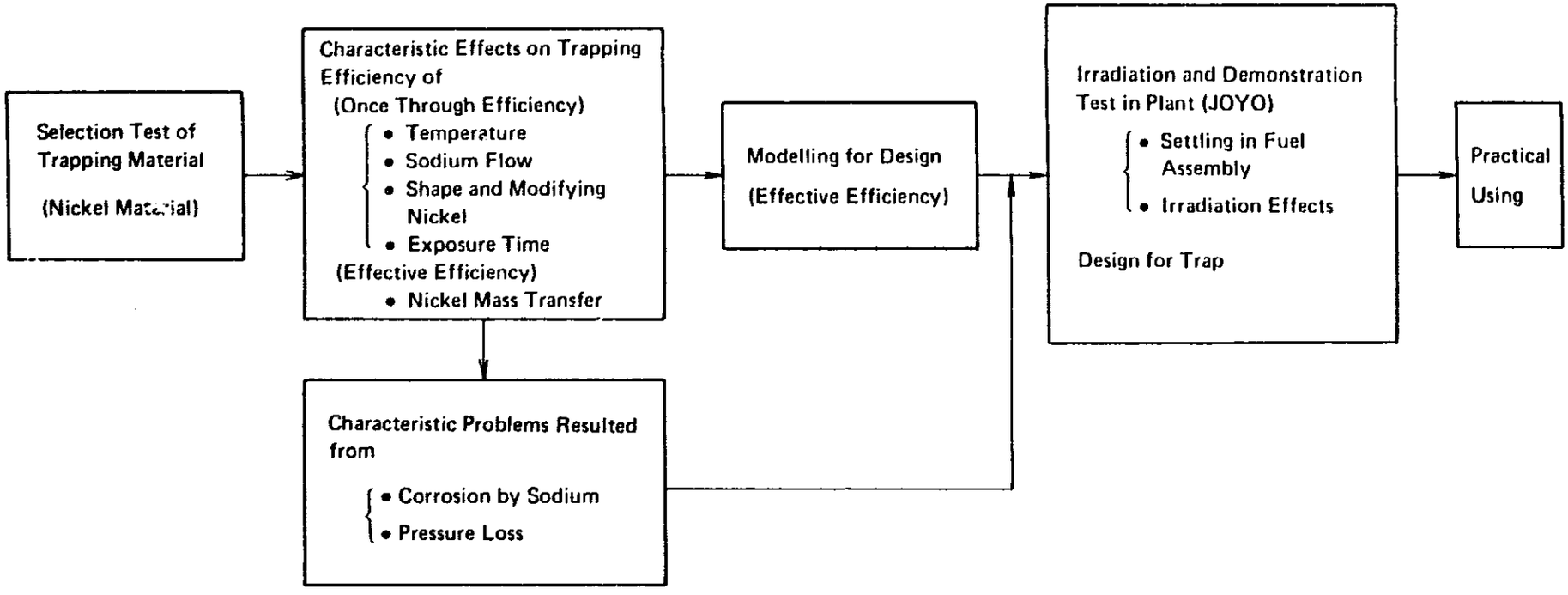
■ DEVELOPMENT OF COMPUTOR CODE FOR CP BEHAVIOR ANALYSIS

(PSYCHE / JOANDARC)



■ DEVELOPMENT OF CP TRAPPING METHOD

(Characterization Test of Trapping Material)

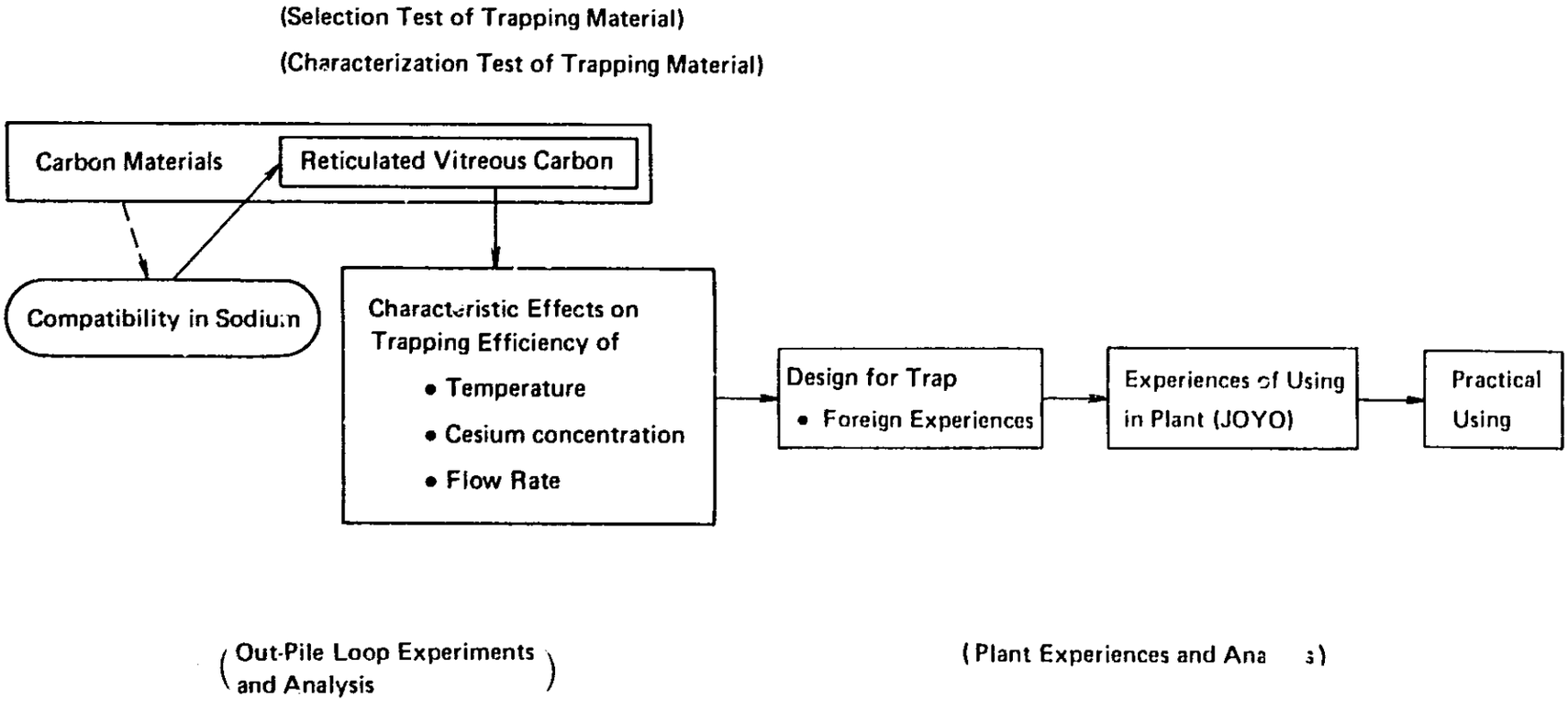


(Out-Pile Loop Experiments and Analysis)

(Design and Analysis)

(Plant Experiences and Analysis)

■ DEVELOPMENT OF FP TRAPPING METHOD – CESIUM TRAP



■ DOCUMENT OF RADIOACTIVE MATERIAL TEST IN SODIUM

Test Item	Type or Method	Content
CP Behaviour Test	Out-Pile Loop Experiment	Understanding of Characteristics of CP Behaviour (Selectivity Characteristic of Elements, Transitional Phenomena, Down Stream Effect) and Quantifying. Its Recharacterization with Advancing Core and Structural Materials is Required.
Development of Computor Code for CP Behaviour Analysis	Formulation of Solution-Precipitation Model and Its Coding (PSYCHE) and Combining with Dose Rate Analysis Code (JOANDARC)	Formulation of Theoretical Formula for Analysis. Confirmation of Model Appropriateness by Using Data from Out-Pile Loop Experiment and Foreign Data and Determination of Analytical Parameters. Coding of CP Source Term (PSYCHE) and Combining with Dose Rate Analysis in Reactor Plant Systems (JOYO and MONJU). Verification of PSYCHE/JOANDARC by Evaluation of CP and Dose Rate in JOYO. Analysis of CP Source Term and Dose Rate in MONJU. Its Analysis in Scale-Up of FBR (LSPBR) is Required.
Development of CP Trapping Method	Nickel Getter Type Settled on Core	Selection of Nickel Getter Material, Effective on ^{54}Mn and ^{51}Cr, but a Little on ^{58}Co and ^{60}Co. Characterization Test of Trapping Material (Dependency of Temperature, Sodium Flow, Shape, Exposure Time and Nickel Mass Transfer on Trapping Efficiency and Corrosion Problem). Modelling for Design. Finding Its Optimum Setting Position is Required. Irradiation and Demonstration Test Program of CP Trap is Proceeding in JOYO.
Evaluation of Methods to Prevent or Control Source Rate of CP	Evaluation by Using Analytical Model	Evaluation of Effects by Decreasing of Oxygen, Cobalt Impurity Level in Core Materials and Using Cobalt Free Hard Facing Meterials.
Development of Cesium Trap	RVC Filled Type Settled in Sodium Purification System	Selection of RVC Meterial with Fine Struct. Characterization Test of Trapping Material (Temperature, Cesium Concentration, and Pre-Processing on Trapping Efficiency and Trapping Rate). Confirmation of Nonexistence of Carburization Effect. Practical Using Program is Proceeding in JOYO.

■ APPARATUS FOR RADIOACTIVE MATERIAL TEST IN SODIUM

Utilization ; To Study CP Behaviour and To Develop Methods of CP Trapping.

Characteristics ;

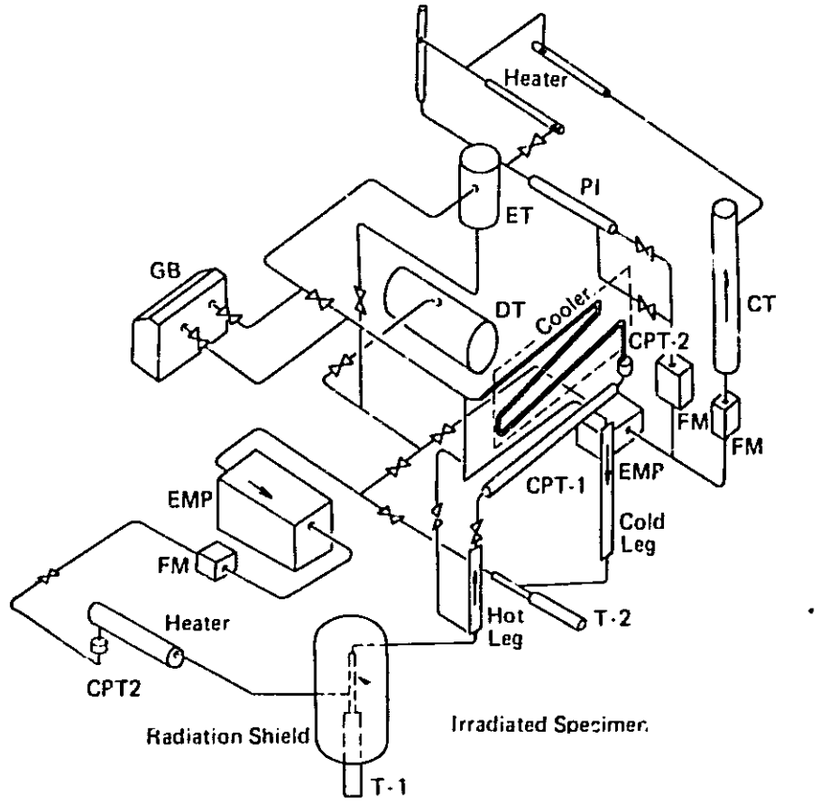
Constitution	: A Main and a Purification Circuit
Materials	: SUS316 (Heater, Cooler, Hot Leg Piping) SUS304 (Cold Leg Pinping, Other Components and Piping)
Sodium Inventory	: 20 ℓ
Maximum Temperature	: 650°C
Maximum Flow Rate	: 6.5 ℓ/min
Main Piping	: 17.3 mm O.D. X 2.0 mm thick.

Test Section ;

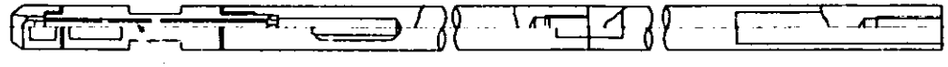
The main circuit has three test sections: a corrosion test section (T-1) in which irradiated specimens are exposed, followed by hot leg piping, CP Trap test sections (CPT), and a deposition test section (T-2) in cold leg piping.

Example of Experimental Condition ;

Temperature	: 530°C (T-1), 530°C (CPT-1, CPT-2) and 400°C (T-2)
Flow Velocity	: 5.6 m/sec. (T-1, CPT-1)
Oxygen Level in Sodium	: 2.5 ppm



Schematic drawing of the Activated Material Test Loop-II



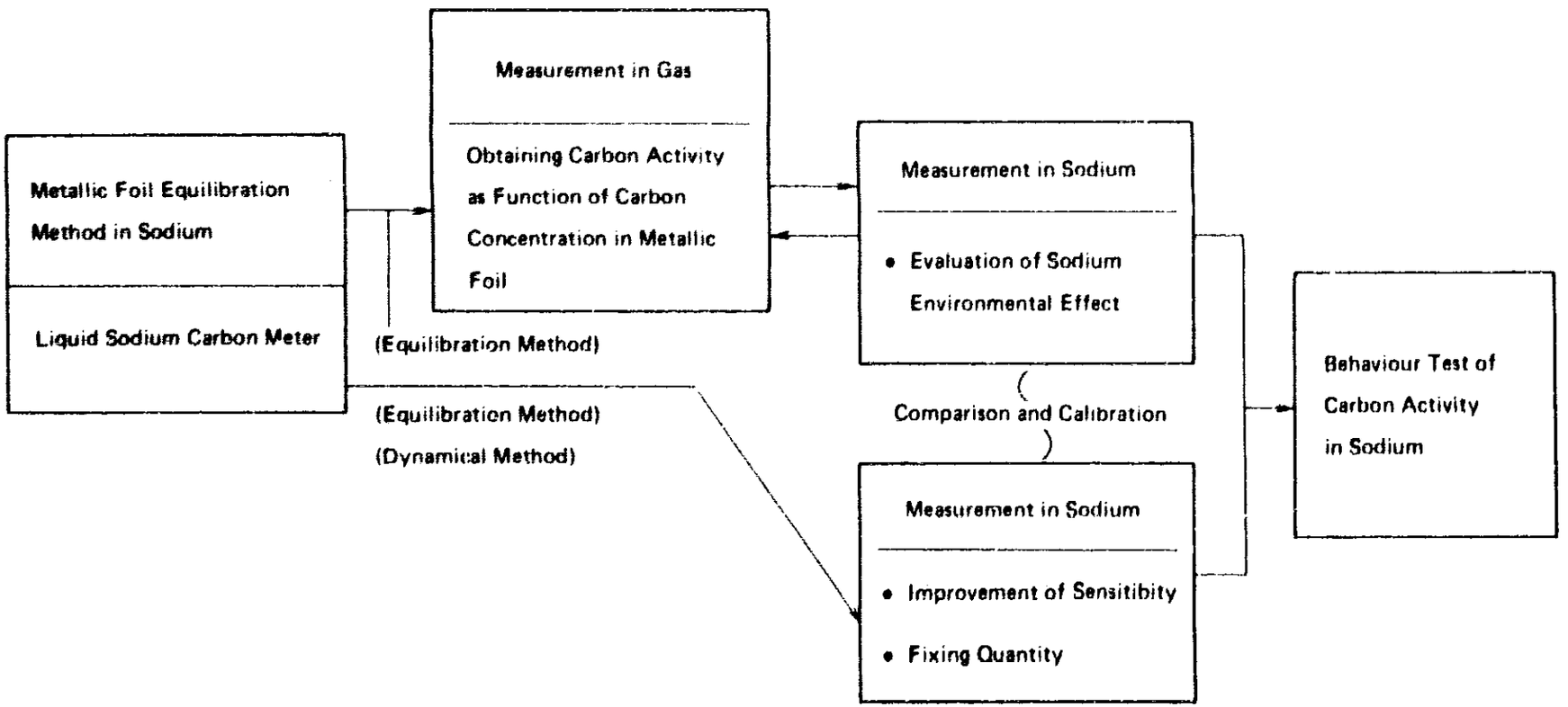
Irradiated Specimen

Test Specimen Holder (T-1)

■ OBJECTIVES OF SODIUM IMPURITY MEASUREMENT AND CONTROL TEST

- To Develop Method of Sodium Impurity Measurement
- To Understand Behaviour of Impurities in Sodium
- To Develop Regeneration Method of Cold Trap
- To Develop Tritium / Hydrogen Chemical Trap

■ DEVELOPMENT OF CARBON ACTIVITY MEASUREMENT METHOD IN SODIUM



■ DOCUMENT OF SODIUM IMPURITY MEASUREMENT AND CONTROL TEST

Test Item	Type or Method	Content
Development of Sodium Sampling Method	By-Pass Flow Through Sampling Method	Used in the Primary and Secondary System of JOYO and the Test Loops for R & D.
Development of Liquid Sodium Hydrogen Meter and Its Behaviour Test	Diffusion Type with Nickel Membrane	Confirmation of Nonexistence of Oxygen and Hydrogen Interaction in Sodium.
Development of Liquid Sodium Oxygen Meter	Electrochemical Type	Development of Long-lived Oxygen Meter is Required.
Development of Plugging Indicator	Type of Precipitation and Solution at Orifice	Development of Plugging Indicator Being Able to Identify Impurities.
Development of Liquid Sodium Carbon Meter	Diffusion Type with Thin Membrane	Higher Sensitive Carbon Meter is Required.
Impurity Measurement in Sodium with Specimen Equilibration Method	Specimen Equilibration Method	• Development of Specimen Equilibration Device. • Establishment of Measurement Method of Oxygen with Vanadium Wire Method. • Development of Carbon Measurement Method with Fe-12Mn, SUS304L, in Progress.
Development of Regeneration Method of Cold Trap in Secondary Sodium System	Method of Thermal Deconposition of Hydride and Sweeping Gas from Liquid Surface	Completion of Conceptual Design.

■ APPARATUS FOR SODIUM IMPURITY MEASUREMENT AND CONTROL TEST

Utilization ; To develop measuring and controlling techniques of impurity levels in sodium.
(1) On-line monitors, (2) Equilibration methods for measurement of impurity activities, (3) Equipments and techniques for sodium sampling.

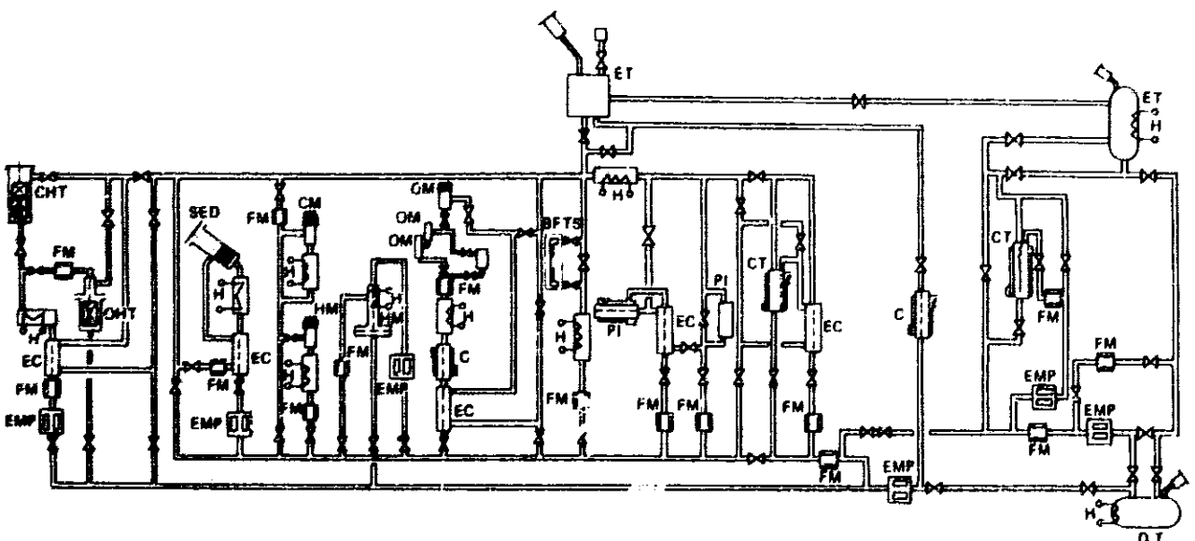
Characteristics ; This loop has been consisted of a mother and a daughter loop. Sodium is purified in the main circuit to be supplied to the test circuit, which has an electromagnetic pump, a cold trap and some devices and can be operated independently from the main circuit after sodium has been supplied.

Main Items of the Facility

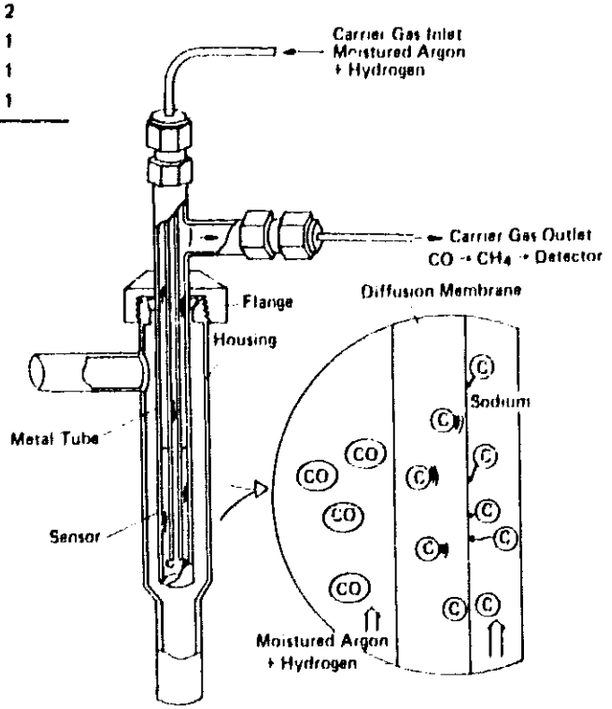
	Main Circuit	Test Circuit
Sodium Inventory (ℓ)	1800	200
Temperature (°C)	600	400-760
Flow Rate (ℓ/min)	100	20
Main Piping (mm)	60.5 O.D. x 3.5 thick	27.2 O.D. x 2.5 thick

Main Items of In-Sodium Chemical Meter Provided to the Test Circuit

Device	Mark	Number	Temperature (°C)	Flow Rate (ℓ/min)
Oxygen Meter	OM	3	max. 500	1
Hydrogen Meter	HM	1	400-500	1
Carbon Meter	CM	1	max. 760	< 1
Plugging Indicator	PI	2	120-300	0.6, 2
By-Pass Flow-Through Sampler	BFTS	1	max. 600	2
Specimen Equilibration Device	SED	1	max. 750	1
Carbon Hot Trap	CHT	1	max. 700	1
Oxygen Hot Trap	OHT	1	max. 700	1



SCHEMATIC FLOW OF SODIUM IMPURITY MEASUREMENT TEST LOOP



SCHEMATIC DRAWING OF CARBON METER AND MECHANISM

■ OBJECTIVES OF MATERIAL TESTS

1. Basic Material Property Test on Structural Materials and Core Materials
   (1) Compilation of Material Data for Design
   - Material Specifications : Product Form, Size (Thickness, Length, Width, Diameter, etc.), Chemical Composition, Grain Size, Heat Treatment Condition and others.
   - Mechanical Properties : Tensile, Creep, Fatigue, Stress-Relaxation, and others

   (2) Examination for Apolication of Modified-Type Materials
   - Structural Materials
     High Cr Ferritic Steels
     Modified Stainless Steel
   - Core Materials
     Modified SUS 316
     Modified Stainless Steels etc.
     High Cr Ferritic Steels
     Advanced Alloys (High Ni Alloys, etc.)

   (3) Examination for Application of Large-Scale Materials
   - SUS 304 Forging of Large Diameter and/or Thickness
   - SUS 304 Seamless Pipe of Large Diameter and Thin Thickness

   (4) Evaluation on Strength of Weldments
   - Examination for Application of Weld Material, Welding Procedure, and Non-Destructive Inspection Technique Basic Mechanical Property Tests on Welded Metals
   - Application of Inelastic Analysis and Material Tests for Welded Joints

   (5) Evaluation on Creep-Fatigue Life
   - Creep-Fatigue Test under Specified and Various Variable Load Conditions
   - Examination of Criteria on Creep-Fatigue Interaction
   - Analysis and Evaluation on Creep-Fatigue Life for Test Data

   (6) Development of Inelastic Constitutive Equation
   - Yield Condition
   - Hardening Rule on Plastic and Creep Strain
   - Flow Rule on Plastic and Creep Strain

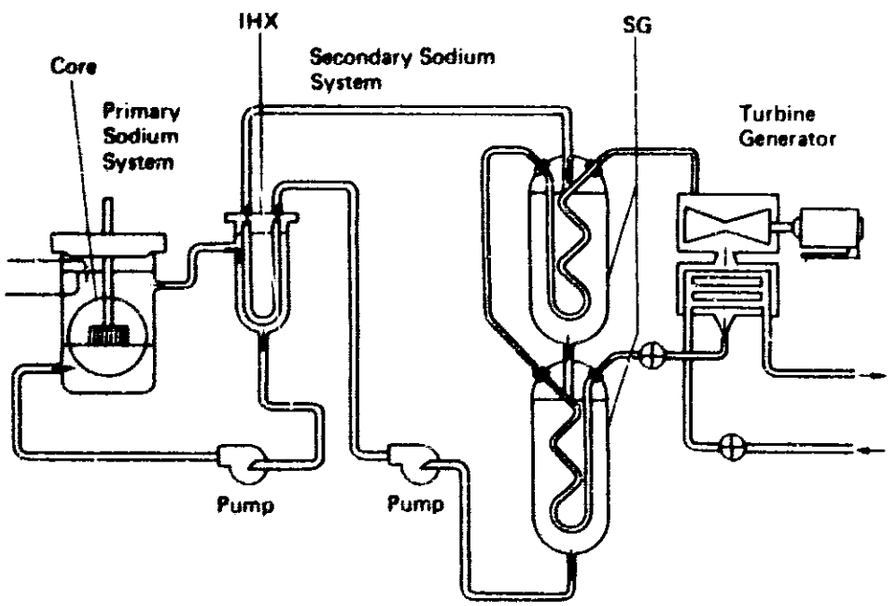
   (7) Evaluation on Crack Growth
   - Creep Crack Growth Test
   - Fatigue Crack Growth Test
   - Creep-Fatigue Crack Growth Test
   - Fracture Toughness Test

2. Environmental Effect Test
   - In Air : Basic Mechanical Properties
   - In Sodium : Corrosion, Mass Transfer, Aging Effect, and Material Strength Tests in and after Immersion
   - Under Neutron Irradiation : Mechanical Properties
   - In H_2O, In NaOH, etc. : Corrosion, Oxidation, Stress Corrosion Cracking, Wastage, and Hydrogen Penetration Tests

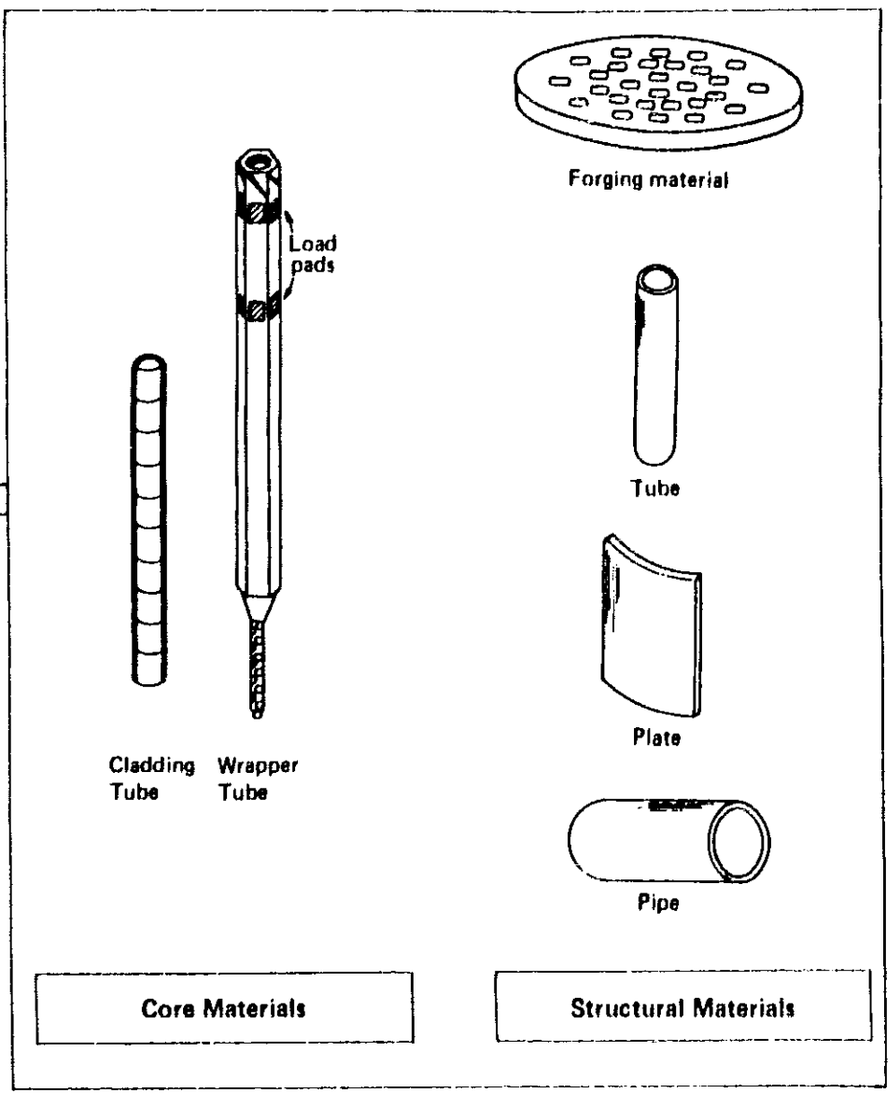
3. Tribological Test
   (1) Development and Selection of Co-Free Alloys for Maintenance Cost Reduction
   (2) Evaluation of Tribological Properties for Sliding and Vibrating Parts of Demonstrating Reactor

4. Development on Material Data Handbook
   (1) Development on Material Specification for FBR
   (2) Formulation on Basic Mechanical Properties for FBR
   (3) Recommendation to Regulator on Material Strength Standard (Including Design Allowable Stresses) for FBR Design Code
   (4) Compilation of Material Data Handbook on the above all Results

■ SCOPE OF R&D ON MATERIALS



- Reactor Vessel
- Core Structure
- Primary Coolant Circuit Pipe
- Intermediate Heat Exchanger (IHX)
- Secondary Coolant Circuit Pipe
- Steam Generator (SG)
- Turbine Generator



■ MATERIALS

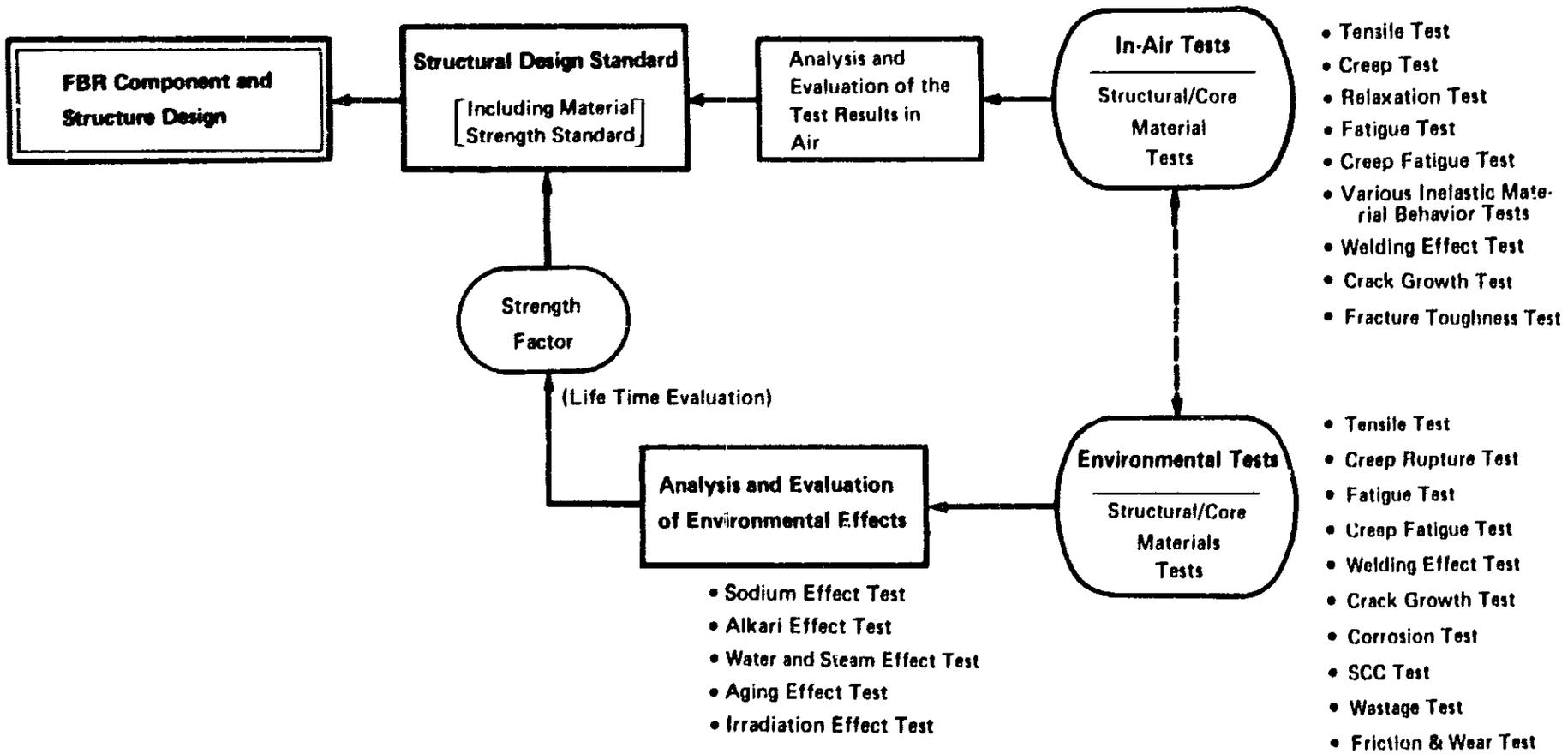
■ Structural Materials

Service Life	• Life Time of Plant (for Parmanent Structure)
Concerning Components	• R/V, C/I, Pump, IHX, SG, Primary and Secondary Pipe, etc.
Tests	• Metallurgical and Mechanical Tests in Air, Sodium, Water and Caustic Environment • Tribology Tests in Sodium Environment for Pump, IHX and SG

■ Core Materials

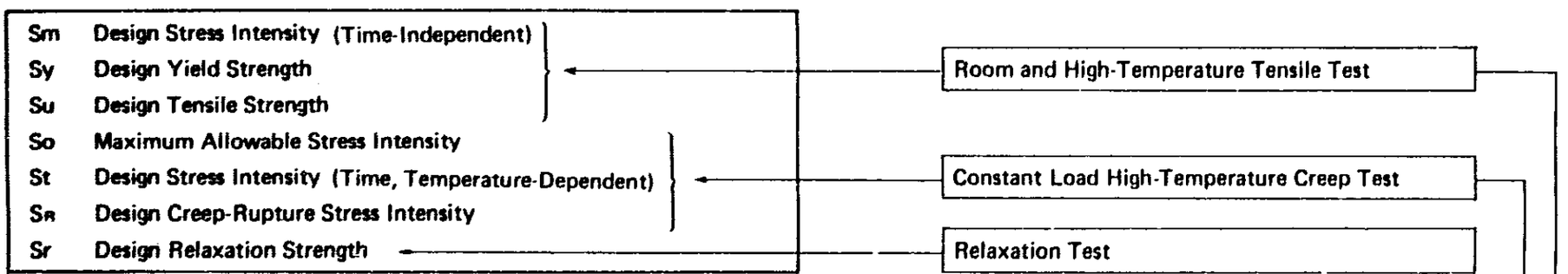
Service Life	• About 2 Years (for Changeable Structure)
Concerning Components	• CRD, Fuel Cladding Tube, Wrapper Tube, etc.
Tests	• Metallurgical and Mechanical Tests in Air, Sodium and Neutron Irradiation Environments • Tribology Tests in Sodium Environment for CRD, Fuel Cladding Tube and Wrapper Tube

■ FLOW DIAGRAM ON DEVELOPMENT OF STRUCTURAL DESIGN STANDARD

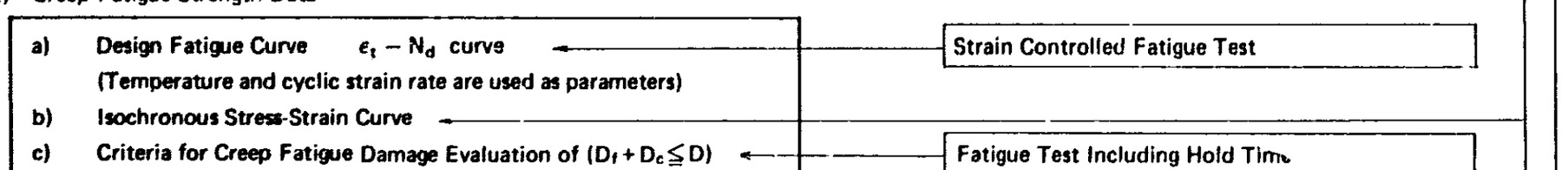


■ RELATIONSHIP OF BASIC MATERIAL PROPERTY TESTS TO MATERIAL STRENGTH STANDARD

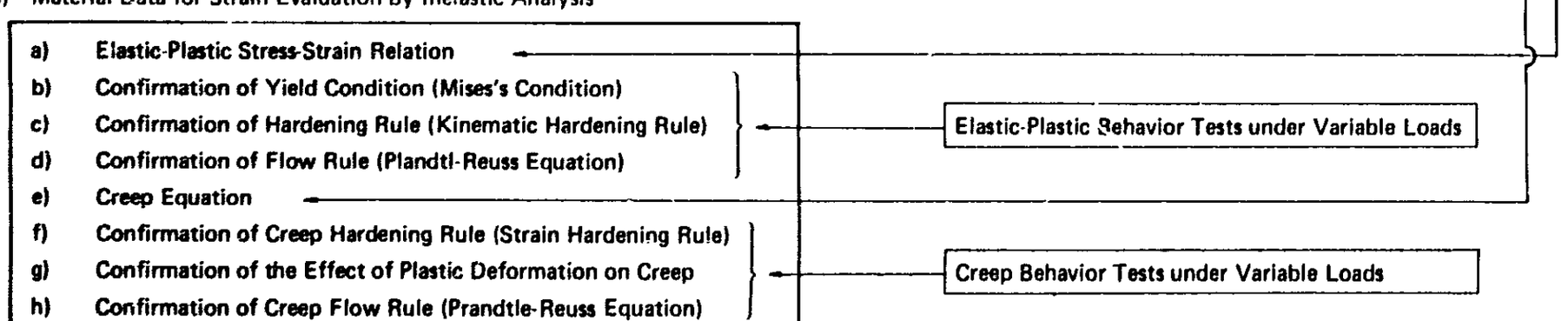
(1) Allowable Stress Data



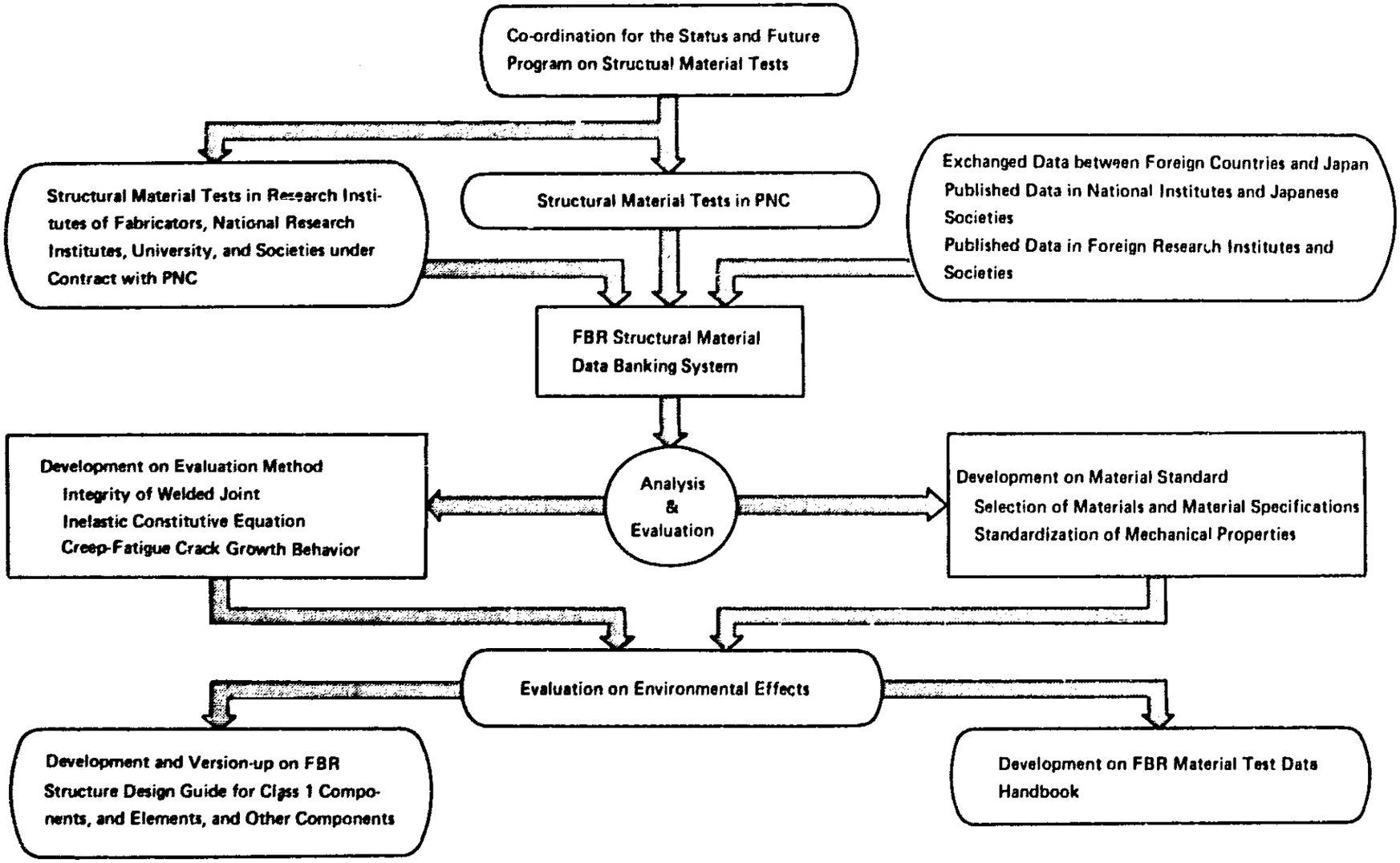
(2) Creep Fatigue Strength Data



(3) Material Data for Strain Evaluation by Inelastic Analysis



■ FLOW DIAGRAM OF RESEARCH AND DEVELOPMENT ON FBR STRUCTURAL MATERIALS



■ R&D SUBJECTS FOR STRUCTURAL MATERIAL IN AIR

Subject	Test Item	Contents	Material
Standardization of Basic Mechanical Properties on Base Metal	Tensile Test	Tensile Test under the Condition of Strain Rate 0.3 %/min.	SUS 304 SUS 316 SUS 321 2¼Cr–1Mo Inconel 718 Modified Stainless Steels High Cr Ferritic Steels
	Creep Test	Creep Test under the Condition of Constant Load Condition	Ditto
	Low Cycle Fatigue Test	Low Cycle Fatigue Test under the Condition of Strain-Controlled Reversed Loading including Strain Rate Effects	Ditto
	Relaxation Test	Relaxation Test under the Condition of Constant Strain	Ditto
Development of Evaluation Methods on Strength of Welded Joints	Basic Mechanical Property Tests	Same as the Content in case of Base Metal	Welded Metals
	Verification Test of Welded Joint	Verification Test of Welding Procedures and Application Test of Non-Destructive Inspection-Techniques	Similar and Dissimilar Welded Joints Welded Metals for Large Scale Forged SUS 304 Large Scale 2¼Cr–1Mo Pipe and High Cr Ferritic Steels
Development of Creep-Fatigue Life Evaluation Method	Creep Fatigue Test under Specified Load Conditions	Creep-Fatigue Test under the Condition of Strain Hold Time including Long Life (More than 1 year)	SUS 304 SUS 316 SUS 321 2¼Cr–1Mo High Cr Ferritic Steels

■ R&D SUBJECTS FOR STRUCTURAL MATERIAL IN AIR (CONTINUE)

Subject	Test Item	Contents	Material
Development of Inelastic Constitutive Equation	Elastic-Plastic Behavior Test under Uniaxial and Multiaxial Loading	Elastic-Plastic Behavior Test under Uniaxial Various Cyclic Loading for Development of Hardening Rule and Multiaxial Cyclic Loading for Development of Flow Rule	SUS 304 2¼Cr–1Mo High Cr Ferritic Steels
	Creep Behavior Test under Uniaxial and Multiaxial Loading	Creep Behavior Test under Uniaxial Variable Loading for Development of Hardening Rule and Multiaxial Variable Loading for Development of Flow Rule	Ditto
Development of Evaluation Method on Various Creep-Fatigue Strength Reduction	Pre-Strain Effect Test	Creep and Fatigue Damage Estimation Test on Pre-Strained (Max. 5%, by Tensile Test) Material	SUS 304 2¼Cr–1Mo High Cr Ferritic Steels
	Notched Effect T st	Creep-Fatigue Test on Notched Specimens	
	Mean Stress and Mean Strain Effect Test	Creep-Fatigue Test with Mean Stress and/or Mean Strain	
Development of Evaluation Method on Crack Growth	Creep Crack Growth Test	Creep Crack Growth Test for Development of Prediction and Evaluation on Crack Growth under Constant Loading at Elevated Temperature	SUS 304 2¼Cr–1Mo High Cr Ferritic Steels Welded Metal Welded Joint
	Low Cycle Fatigue Crack Growth Test	Crack Growth Test under Uniaxial Various Cyclic Loading with/without Strain Hold Time for Development of Prediction and Evaluation on Low Cycle Fatigue Crack Growth	
	Fracture Toughness Test	Static and Dynamic Fracture Toughness Test at Elevated Temperature	2¼Cr–1Mo High Cr Ferritic Steels Welded Metal

■ R&D SUBJECTS FOR STRUCTURAL MATERIAL TESTS IN VARIOUS ENVIRONMENTS

Subject	Test Item	Material	Condition
Evaluation of Basic Strength on Domestic Materials in Sodium	Tensile, Creep, and Fatigue Test	SUS 304, SUS 316, SUS 321, 2¼Cr–1Mo, High Cr Ferritic Steels, Modified Stainless Steels, Inconel 718	As-Received, Sodium-Exposed Thermally Aged
Evaluation of Corrosion and Mass Transfer Behaviour	Metallurgical Examination	Welded Joints of SUS 304, 316, 321 and Ni Base Alloys	As-Received
Evaluation of Carbon Transfer Behaviour in Secondary Circuit of Prototype FBR	Ditto	SUS 304, 321, and 2¼Cr–1Mo	As-Received
Evaluation of Sodium Impurity Effect	Ditto	Ditto	Ditto
Evaluation of Corrosion and Mass Transfer Behaviour of Advanced Materials	Metallurgical Examination, Tensile Test	• Base Metal and Welded Joints • High Cr Ferritic Steels and Modified Stainless Steels	As-Received, Sodium-Exposed
Evaluation of Basic Strength on Advanced Materials	Tensile, Creep, and Fatigue Test	High Cr Ferritic Steels and Modified Stainless Steels	As-Received, Sodium-Exposed, Thermally Aged, In Sodium
Evaluation of Time-Dependent Change of Mechanical Properties of Materials by Surveillance Tests for "JOYO"	Metallurgical Examination, Tensile and Creep Test	SUS 304, 2¼Cr–1Mo	As-Received, Sodium-Exposed
Evaluation of Environmental Effect for Crack Growth	Fatigue Test (In Planning)	SUS 304, 2¼Cr–1Mo and High Cr Ferritic Steels	Sodium-Exposed In Sodium
Evaluation of Corrosion and Cracking Behaviour in Alkaline Environment	Metallurgical Examination, SERT Test	SUS 304 and High Cr Ferritic Steels	As-Received
Evaluation of Tribology on Contact and Sliding Parts	Self-Welding, Friction and Wear Test	Stellite, Colmonoy, High Cr Ferritic Steels etc.	As-Received, Sodium-Exposed

■ R&D SUBJECTS FOR CORE MATERIAL

Subject	Test Item	Material	Condition	Remark
Generation of Basic Strength Data on Fuel Cladding Tube and Duct Materials	Tensile, Biaxial Creep, Biaxial Creep Rupture, etc.	Cold-Worked SUS 316 Modified Stainless Steels	As-Received Sodium-Exposed	In-Air In-Sodium
Evaluation of Material Behavior on Advanced Alloys for Fuel Cladding Tube and Duct Materials	Tensile, Biaxial Creep Rupture and Mass-Transfer, etc.	High Cr Ferritic Steels ODS Ferritic Steels Other Advanced Alloys	As-Received Sodium-Exposed	In-Air In-Sodium
Evaluation of Corrosion Behavior on Fuel Cladding Tube and Duct Materials	Metallugical Examination	Cold-Worked SUS 316 Modified Stainless Steels	As-Received	In-Sodium
Evaluation of Corrosion Behavior with High Heat Flux on Fuel Cladding Tube	Metallugical Examination	Cold-Worked SUS 316	As-Received	In-Sodium
Generation of Fatigue and Creep-Fatigue Strength Data on Cold-Worked Material	Fatigue, Creep-Fatigue	Cold-Worked SUS 316 Modified Stainless Steels	As-Received	In-Air
Evaluation of Thermal Aging Effect on Tensile Strength of Cold-Worked Fuel Cladding Tube	Tensile	Cold-Worked SUS 316 Cold-Worked Modified Stainless Steel	As-Received Thermally Aged	In-Air In-Inert Gas
Evaluation of Tribology on Hard-Facing Materials for Duct Road Pads	Self-Welding, Friction and Wear, Thermal Cycle, Sodium Compatibility, etc.	Chrome-Carbide/Nichrome Hard Cr Plating, etc.	As-Received Sodium-Exposed	In-Sodium
Evaluation of Tribology on Hard-Facing Materials for Control Rod Drive Mechanism	Self-Welding, Friction and Wear, Sodium Compatibility, etc.	Inconel 718, Fukudalloys, Metco, etc.	As-Received	In-Sodium

■ OUTLINE OF IN-AIR TEST MACHINES FOR STRUCTURAL MATERIALS

Testing Machine	Specification	Unit	Remarks
Tensile Testing Machine	Max. Load : 25 ton / 5 ton Iristoron type	3	5 ton : 1 25 ton : 2
Creep Testing Machine (Uniaxial Tensile)	Max. Load : 5 ton	104	Single Type : 104
Relaxation Testing Machine	Max. Load : 10 ton Max. Temp. : 800 °C	2	Lever Type : 2
Low Cycle Fatigue & Creep Fatigue Testing Machine (Uniaxial Push-Pull)	Max. Load : ±10 ton	11	Furnace Type : 4 Induction Heating : 7
High Cycle Fatigue Testing Machine (Uniaxial Push-Pull)	Max. Load : ±10 ton	1	Induction Heating : 1 (Strain Controll Type)
Long Life Creep Fatigue Testing Machine (Uniaxial Push-Pull)	Max. Load : ±5 ton	5	Mechanical Load : 4 Thermal Expansion Load : 1
Biaxial Fatigue Testing Machine (Internal Pressure-Tension)	Max. Load : 75 ton Max. Temp. : 700 °C	1	Electric Furnace Type
Biaxial Fatigue Testing Machine (Tortion-Tension)	Max. Axial Load : ±20 ton Max. Tortional Load : 200 kg·m	1	Induction Heating Type
Biaxial Creep Testing Machine (Tortion-Tension)	Max. Axial Load : 3 ton Max. Tortional Load : ±10 kg·m	1	
Impact Testing Machine (Charpy)	Max. Load : 30 kg·m	1	

■ LIST OF SODIUM LOOPS FOR STRUCTURAL MATERIAL TESTS

Facilities / Particulars	Material Test Sodium Loop-1	Material Test Sodium Loop-2	Structural Materials Sodium Exposure Test Pots	Carbon Transfer Test Loop	Fatigue Test Loop-1	Fatigue Test Loop-2	Sodium Exposure Test Loop-1	Sodium Exposure Test Loop-2	Creep Test Loop	Self-Welding & Wearing Test Loop
Maximum Using Temperature (°C)	700	700	750	600	700	600	700	560	600	700
Main Piping Diameter (in.)	3/4	3/4	1/2	1/2	1/2	3/4	3/4	3/4	3/4	3/4
Maximum Flow Rate (ℓ/min.)	30	30	10	9.8	30	35	38	38	35	About 5
Sodium Inventory (ton)	About 1.0	About 1.8	0.4	0.3	1.3	0.4	0.4	0.4	0.52	About 0.8
Loop Material	SUS 304 SUS 316	SUS 304 SUS 316	SUS 304 SUS 316	SUS 304/ 2¼Cr–1Mo	SUS 304	SUS 304	SUS 304 SUS 316	SUS 304/ 2¼Cr–1Mo	SUS 304	SUS 304 SUS 316
Test Items Concerning Studies on Material Behavior	Test of Materials in Sodium (Mass-Transfer, Creep, etc.)	Test of Materials in Sodium (Mass-Transfer, Creep, etc.)	Sodium Compatibility Test of Materials in Sodium	Test on Carbon Transfer Between Austenitic Stainless Steel and Ferritic Steel	Fatigue Test in Flowing Sodium	Fatigue Test in Flowing Sodium (FIGURE 1)	Sodium Exposure, Simulating the Primary System (FIGURE 2)	Sodium Exposure, Simulating the Secondary System	Creep Test in Flowing Sodium	Self-Welding & Wearing Test in Flowing Sodium

■ OUTLINE OF IN-SODIUM TEST MACHINES FOR STRUCTURAL MATERIALS

Testing Machine		Specification	Unit
Tensile Creep Testing Machine	Single Type	Max. Load : 0.75 ton Max. Temp. : 700 °C	9
	Multiple Type	Max. Load : 0.75 ton Max. Temp. : 700 °C 6 Levers	6 × 1
Fatigue Testing Machine (Uniaxial Push-Pull)		Max. Load : ±10 ton Max. Temp. : 650 °C Wave Form : Triangle, Sine, etc	2
Creep Fatigue Testing Machine		Max. Load : ±10 ton Max. Temp. : 650 °C	2
Friction and Wear Testing Machine		Max. Load : 0.5 ton Max. Temp. : 650 °C Max. Slide Velocity : 50 mm/sec	3
Self-Welding Testing Machine		Max. Load : 1 ton Max. Temp. : 700 °C	3
Alkaline Cracking Testing Machine		Max. Load : 1 ton Max. Temp. : 550 °C Strain Rate : 0.0005 ~ 0.01 mm/mm	1

■ LIST OF SODIUM LOOPS FOR CORE MATERIAL TESTS

Particulars \ Facilities	Material Test * Sodium Loop-1	Material Test * Sodium Loop-2	Sodium Exposure Test Pots	Self-Welding and * Wearing Test Loop
Max. Using Temperature (°C)	700	700	730	700
Main Piping Diameter (in.)	3/4	3/4	1/2	3/4
Max. Flow Rate (ℓ/min.)	30	30	About 1	About 5
Sodium Inventory (ton)	About 1.0	About 1.8	About 0.4	About 0.8
Loop Material	SUS 304, 316	SUS 304, 316	SUS 304, 316	SUS 304, 316
Test Items Concerning Studies on Material Behavior	Tests of Materials in Flowing Sodium Corrosion & Mass-Transfer Test, Creep & Creep-Rupture Test	Tests of Materials in Flowing Sodium Corrosion & Mass-Transfer Test, Creep & Creep Rupture Test	Sodium Compatibility Test of Materials in Flowing Sodium	Tribology Tests of Hard-Facing Materials in Flowing Sodium Self-Welding, Friction and Wear Test

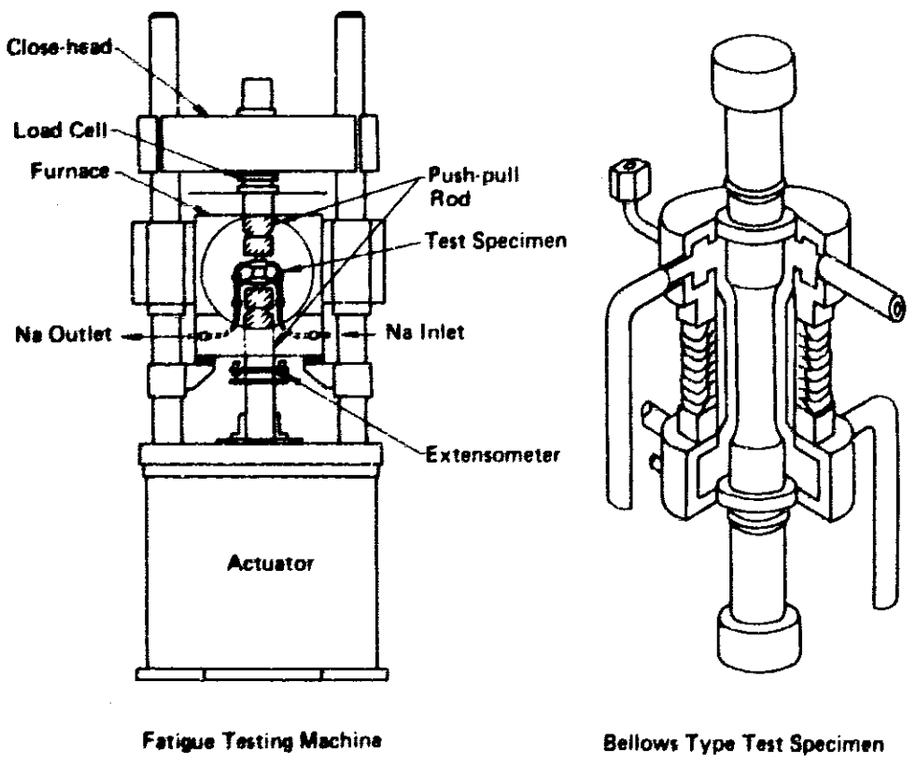
* Common Use to Structural Material Tests

■ OUTLINE OF TEST MACHINES FOR CORE MATERIAL

Environment	Testing Machine	Specification	Unit	Remark
In-Air	• Tensile Testing Machine	Max. Load : 25 ton Max. Temp. : 900 °C Instron Type	3*	5 ton x 1 25 ton x 2
	• Biaxial Creep/Creep Rupture Testing Machine (Internal Pressure Type)	Max. Pressure : 700 kgf/cm² Max. Temp. : 800 °C Pressure Line (system) : Total 22 Electric Furnace Type	4	
	• Fatigue/Creep-Fatigue Testing Machine (Uniaxial Push-Pull)	Max. Load : ±10 ton Max. Temp. : 800 °C Strain Rate : 10^{-3} sec^{-1}	1*	
In-Sodium	• Biaxial Creep Rupture Testing Machine	Max. Pressure : 700 kgf/cm² Max. Sodium Temp. : 700 °C Pressure Line (system) : Total 60	4	FIGURE 3
	• Corrosion and Mass-Transfer Test Section	Max. Sodium Flow Velocity : 700 cm/sec Max. Sodium Temp. : 700 °C	4	FIGURE 4
	• Sodium Exposure Test Section	Max. Sodium Temp. : 730 °C Sodium Flow Rate : about 0.5 ℓ/min. Vessel Type	5	FIGURE 5
	• Friction and Wear Testing Machine	Max. Load : 0.5 ton Max. Sodium Temp. : 700 °C Max. Sliding Velocity : 20 mm/sec Angle of 120° Oscillating Rotation and Vertically Reciprocating Sliding Motion, Pin & Plate Type	2	FIGURE 6
	• Self-Welding Testing Machine	Max. Load : 1 ton Max. Sodium Temp. : 700 °C Ring & Disc Type	3	FIGURE 6

* Common Use to Structural Material Tests

■ SCHEMATIC DRAWING OF TEST EQUIPMENTS FOR STRUCTURAL MATERIALS



Fatigue Testing Machine

Bellows Type Test Specimen

FIGURE 1. Fatigue Testing Machine and Bellows Type Specimen

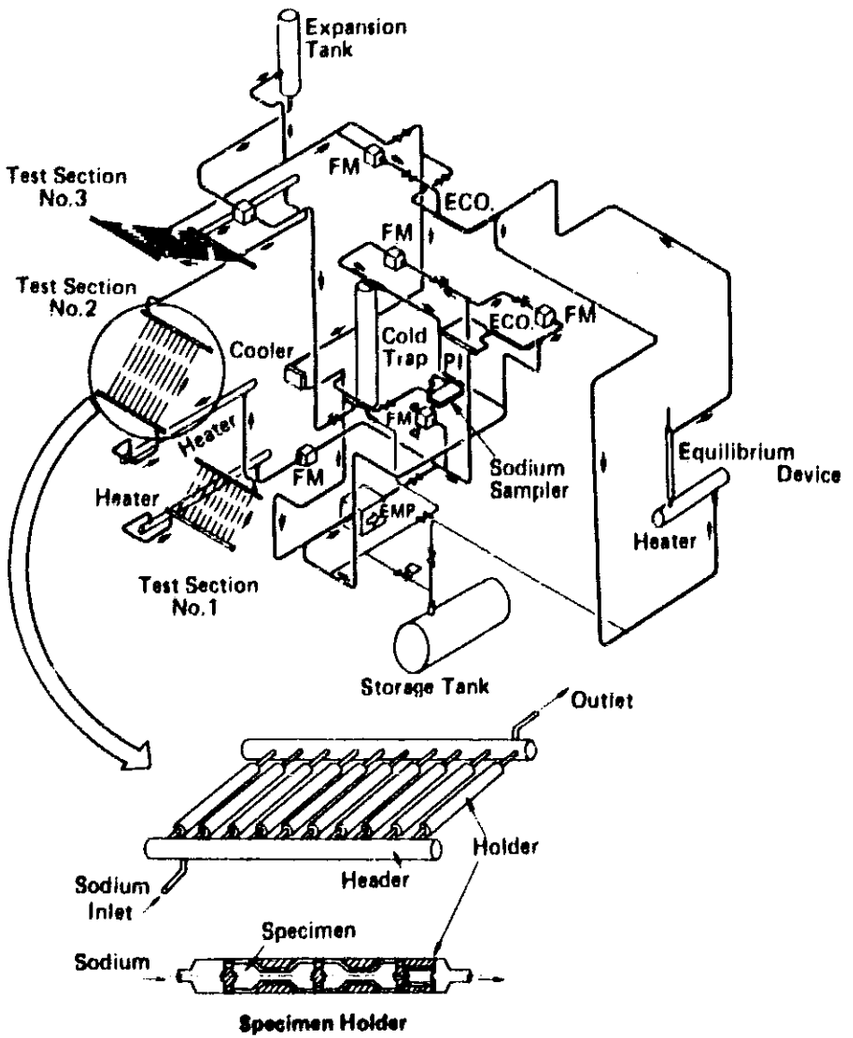


FIGURE 2. Sodium Exposure Test Loop 1

■ SCHEMATIC DRAWING OF TEST EQUIPMENTS FOR CORE MATERIALS

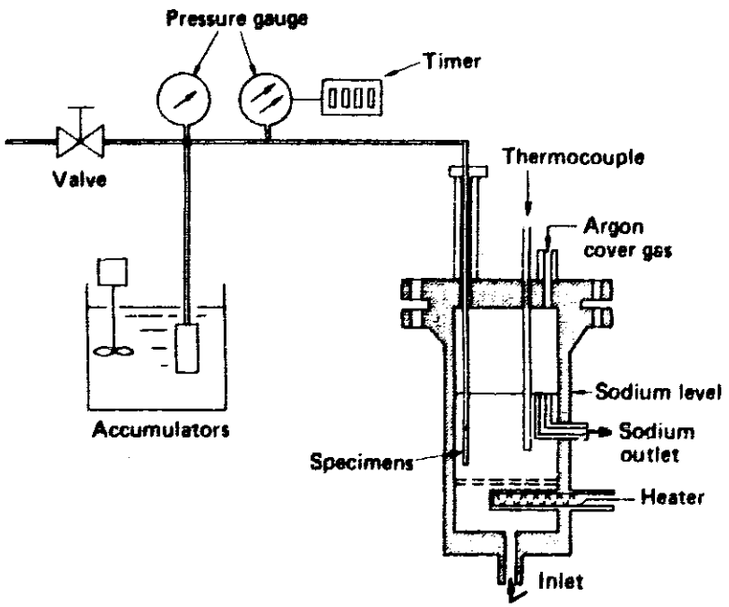


FIGURE 3. Biaxial Creep Rupture Test Section

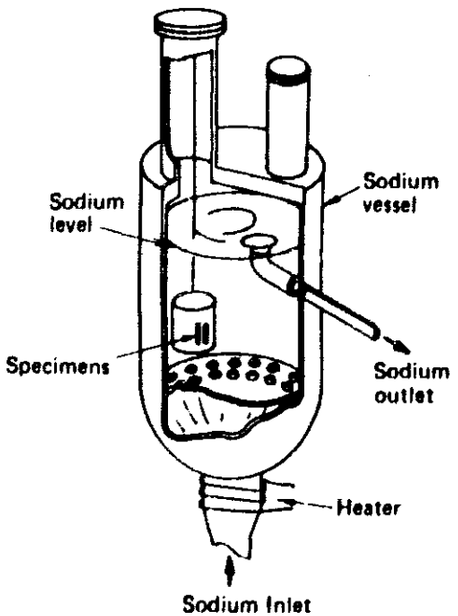


FIGURE 5. Sodium Exposure Test Vessel

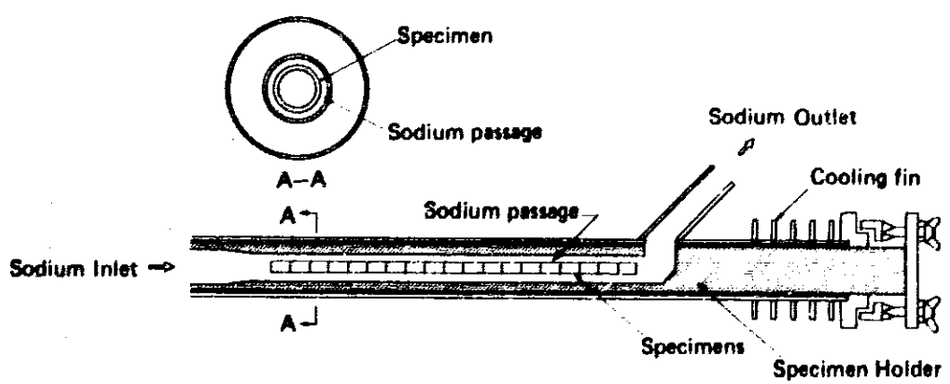
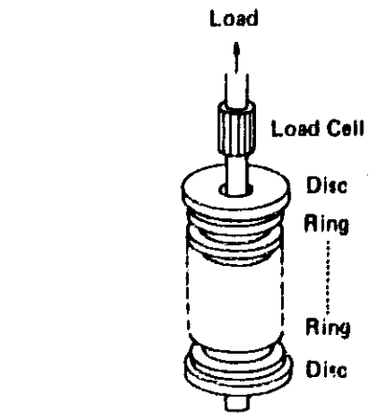
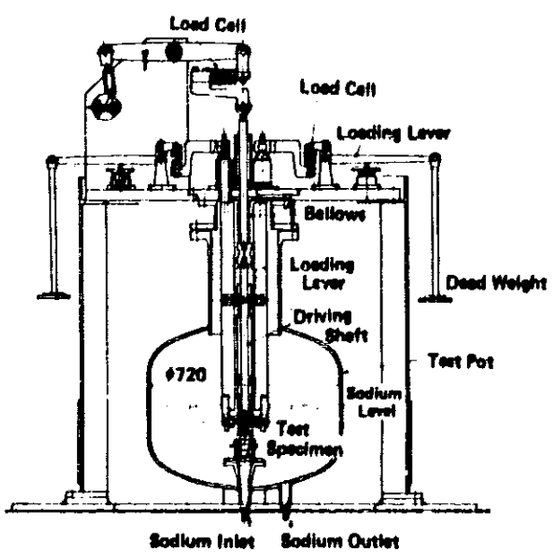


FIGURE 4. Corrosion and Mass-Transfer Test Section



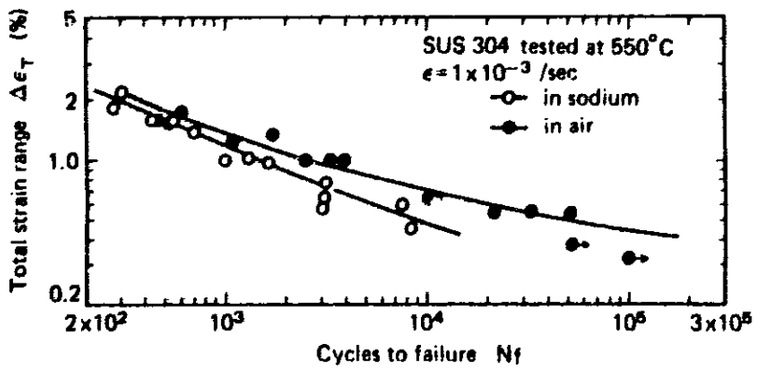
(a) Self-Welding



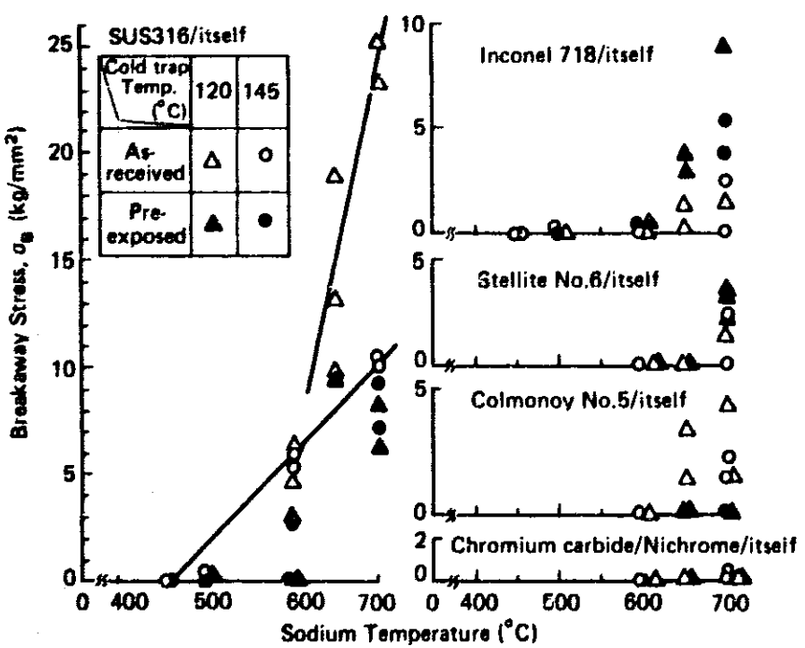
(b) Friction and Wear

FIGURE 6. Self-Welding and Friction Test Sections

■ EXSAMPLE OF TEST RESULT



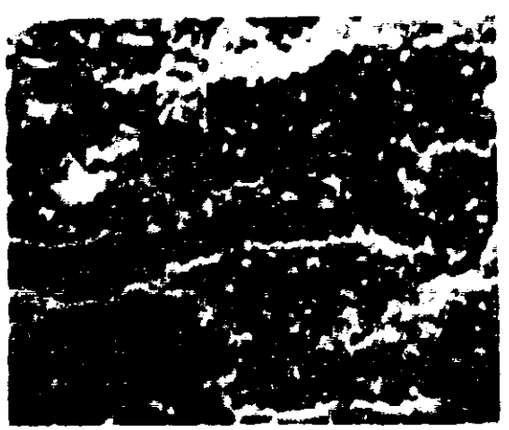
Comparison of Low Cycle Fatigue Data for SUS304 Tested in Air and Sodium at 550°C



Relation Between Breakaway Stress and Sodium Temperature on the Combinations on Material/itself

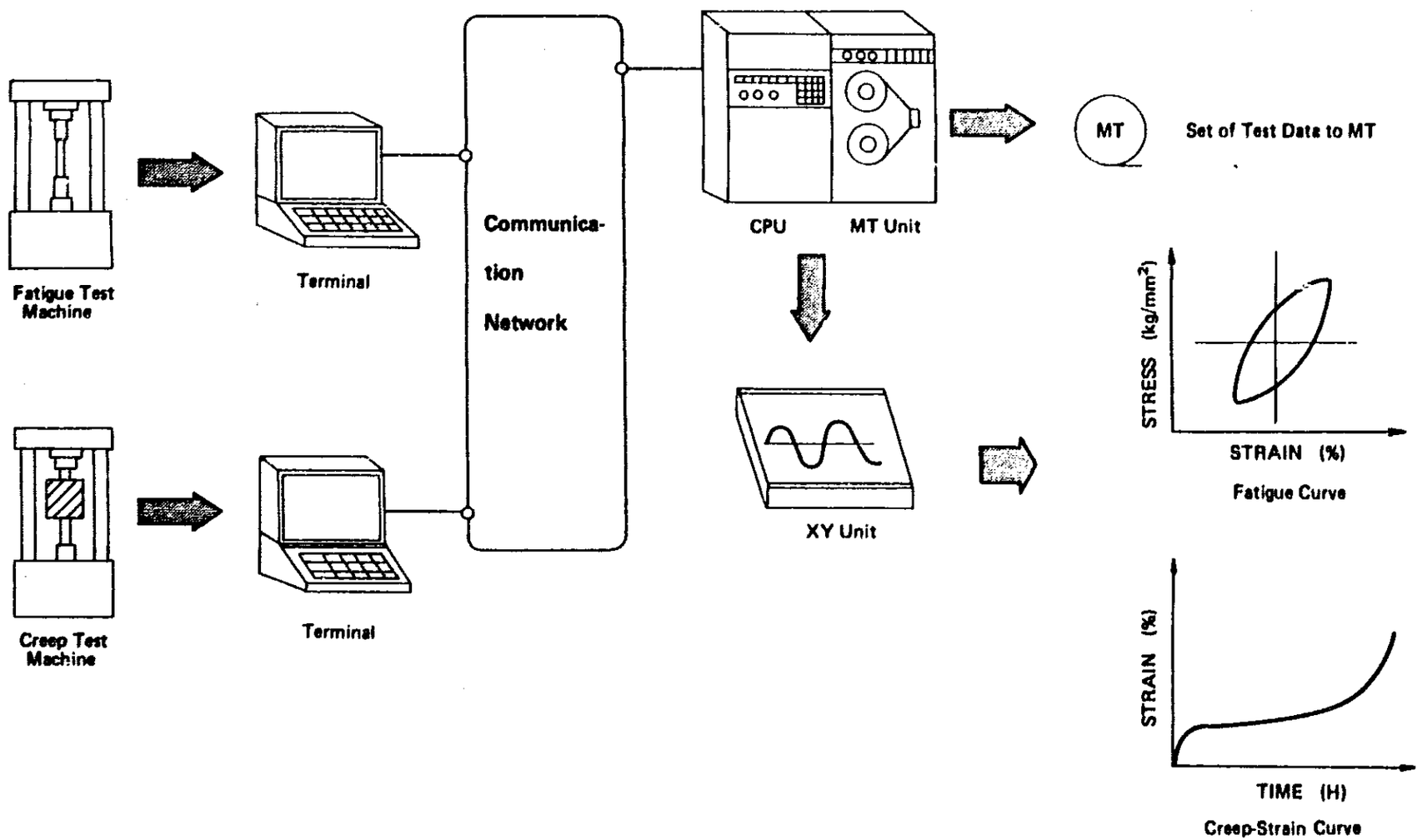
Sodium Side

Microstructure of Ferrite Layer of SUS304 Exposed to Flowing Sodium

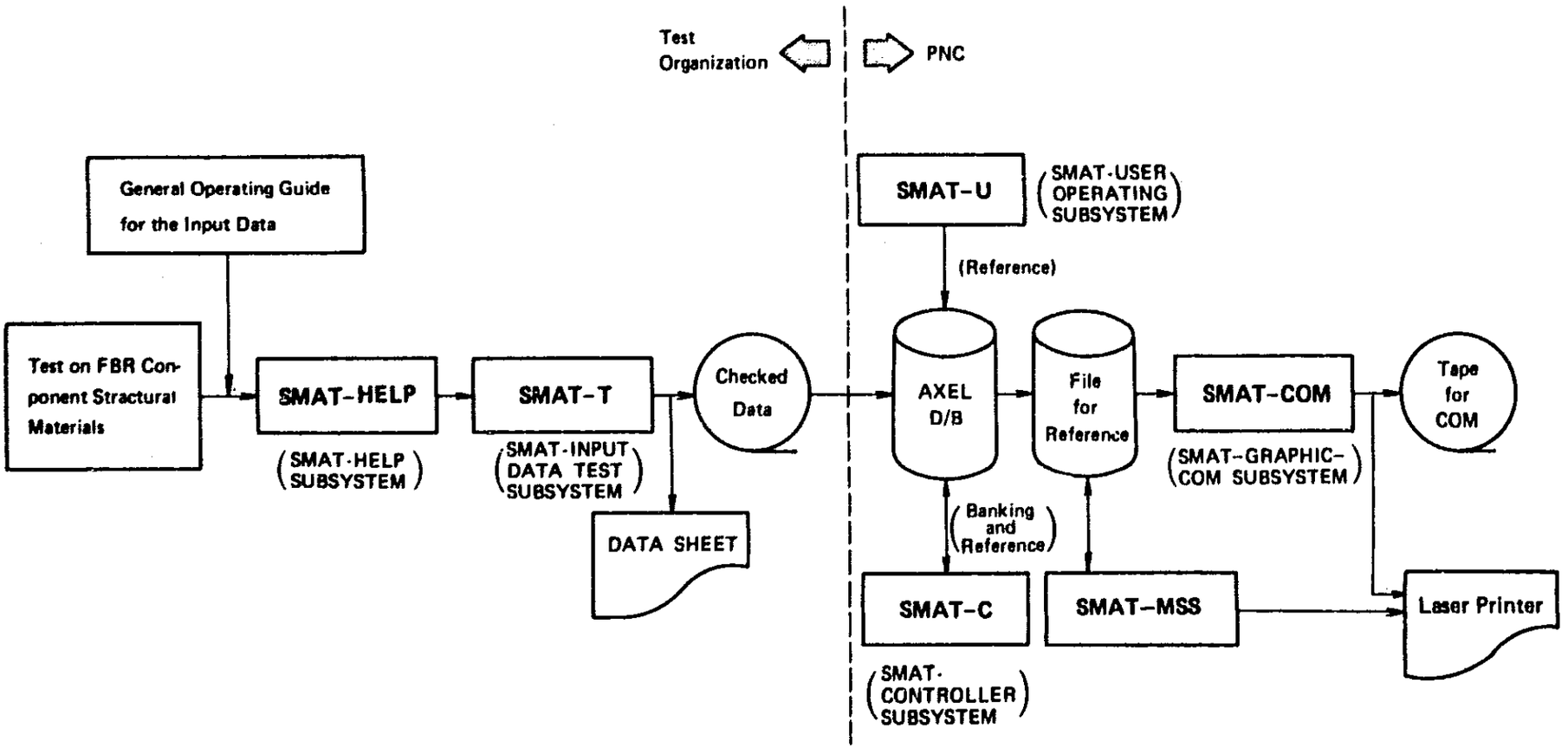


Scanning Electron Micrographs of the Surface of SUS304 after Exposure to Flowing Sodium

■ REAL-TIME SYSTEM FOR MATERIAL



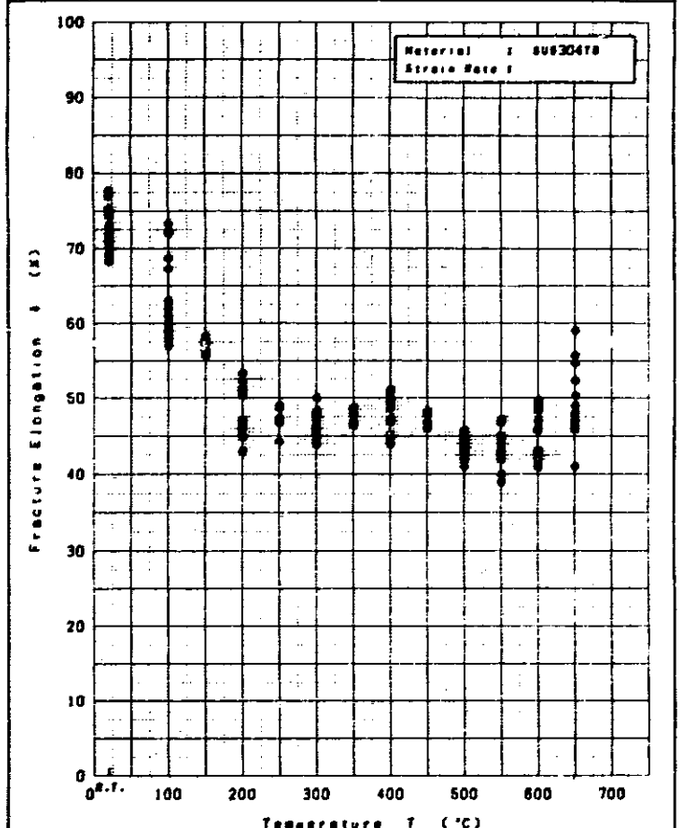
■ FLOW DIAGRAM OF FBR STRUCTURAL MATERIALS DATA BANKING SYSTEM



■ FORMAT OF DATA HANDBOOK

FBR Metallic Material Test Data Handbook

PART 1 - STRUCTURAL MATERIALS	GROUP 1 - HIGH ALLOY STEELS	SECTION 2 - 304 SS ANNEALED
REVISION : 0, 04-01-80 PREVIOUS REVISION :	PROPERTY : Elongation	



DATA SOURCE :	ENVIRONMENT	EXPOSURE	TEST
	ENVIRONMENT	AS RECEIVED	IN AIR
NOTE :			

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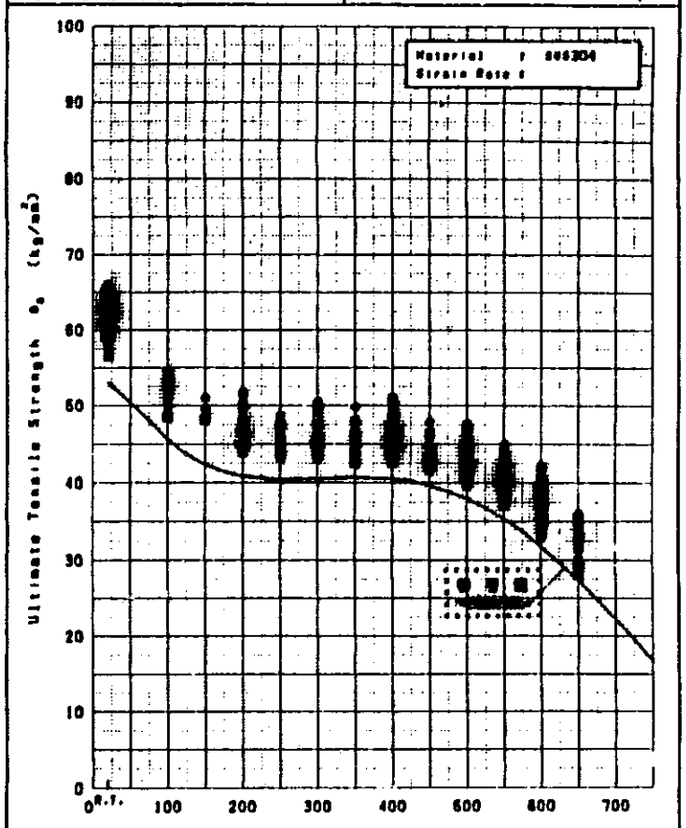
FBR Metallic Material Test Data Handbook

PART 1 - STRUCTURAL MATERIALS	GROUP 1 - HIGH ALLOY STEELS	SECTION 2 - 304 SS ANNEALED
REVISION : 0, 04-01-80 PREVIOUS REVISION :	PROPERTY : Ultimate Tensile Strength	



DATA SOURCE :	ENVIRONMENT	EXPOSURE	TEST
	ENVIRONMENT	AS RECEIVED	IN AIR

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■ EQUIPMENTS FOR METALLUGICAL EXAMINATION AND INSTRUMENTAL ANALYSIS

Apparatus	Main Specification	Unit	Remark
Scanning Electron Microscope	Resolution; 60 Å, Max. Magnificent; X 180,000, Max. Accelerating Voltage; 39 KV	1	JSM-35C
Scanning Electron Microscope	Resolution; 60 Å, Max. Magnificent; X 80,000, Max. Accelerating Voltage; 30 KV	1	S-450 Only for Radioactive Material Test
Transmission Electron Microscope	Resolution; 2.04 Å, Max. Magnificent; X 300,000, Max. Accelerating Voltage; 200 KV	1	JEM-200C
Energy Dispersive Spectro-Scopy	Si(Li) Ditector, Resolution; 146 eV, Energy; $_{11}$Na ~ $_{92}$U	1	Addition to JSM-35C
Energy Dispersive Spectro-Scopy	Si(Li) Ditector, Resolution; 146 eV, Energy; $_{11}$Na ~ $_{92}$U	1	Addition to S-450
Energy Dispersive Spectro-Scopy	Si(Li) Ditector, Resolution; 148 eV, Energy; $_{11}$Na ~ $_{92}$U	1	Addition to JEM-200C, Equipped with CPU
Wave Dispersive Spectro-Scopy	Energy Resolution; Less than 15 eV Range of Measurable Wave Length; 5.8 ~ 88 Å, $_{5}$B ~ $_{15}$P	1	Addition to JSM-35C
Ion Microanalyzer	Diameter of Minimum Beam; 2 μm, Detectability; 50 ppb (for Si/B) $_{1}$H ~ $_{92}$U	1	IMA-2, Equipped with CPU, be Possible to Automatic Analysis
X-ray Diffraction Apparatus	Resolution; $\Delta(2\theta)$ Less than 0.12° for Si (220)	1	Equipped with Micro Diffractmeter
Metallurgical Microscope	Max. Magnificent; X 2,000, Automatic Exposure Meter	1	In Addition, Three Ones
High Temperature Micro Vickers Hardness Tester	Max. Temperature; 1,600 °C, Load; 50 ~ 1000 g	1	In Addition, a Micro Vickers Hardness Tester
Rockwell Hardness Tester	Automatic Load; 60, 100 and 150 kg	1	
Vickers Hardness Tester	Load; 10 to 1,000 g, Minimum Measurable Scale; 0.5 μm	1	
Surface Roughness Gauge	Range of Measurement; 0.01 ~ 600 μm, Max. Magnificent; X 100 ~ 100,000	1	
Precision Balance	Range of Measurement; 1 μg, Standard Error; 1 μg	2	In Addition, Four Direct-Reading Balances
Inert-Gas Heating Furnace	Max. Heating Temperature; 600 °C, Standard Error; ±5 °C	5	

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