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LMFBR SYSTEM REQUIREMENTS
FOR
SODIUM PIPING

SPAN-781-110

TECHNICAL REPORT 110

Cont. 781 Tech R. 110

PREPARED FOR

U S ATOMIC ENERGY COMMISSION
CONTRACT NO AT(04-3)-781

BRAUN PROJECT 4122-W
UNITED NUCLEAR PROJECT 2351

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C F BRAUN & CO

Engineers

ALHAMBRA CALIFORNIA 91802

October 25, 1968

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BAL-3

Gentlemen

LMFBR PIPING DESIGN GUIDE
SYSTEM REQUIREMENTS FOR SODIUM PIPING
TECHNICAL REPORT 110
AEC SAN FRANCISCO
CONTRACT AT(04-3)-781
PROJECT 4122-W

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Transmitted herewith is the task report defining system requirements for sodium piping. These requirements establish the conditions under which succeeding study tasks in developing the piping design guide will be conducted.

In accordance with instructions from your office this report is distributed to the Liquid Metal Engineering Center (LMEC), the agency responsible for technical management of the contract for the AEC, and to other agencies conducting similar work. We understand the LMEC will be given responsibility for technical coordination with other organizations.

A four-week period is allowed for review and return of comments to Braun. Comments should be mailed by November 22, 1968, to

C F Braun & Co
Dr R F Detman, Project Manager
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Yours very truly

Roger F Detman

Roger F Detman
Project Manager

RFD LH

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LMFBR SYSTEM REQUIREMENTS

FOR

SODIUM PIPING

TECHNICAL REPORT

110

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Prepared for US Atomic Energy Commission

Contract No AT (04-3) -781

Braun Project 4122-W

United Nuclear Project 2351

C F BRAUN & CO

Alhambra California

October 25, 1968

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PREFACE

This document identifies the system requirements for liquid metal fast breeder reactor plants (LMFBR), to serve as a basis for the development of a Design Guide for LMFBR sodium piping.

This first issue of the document is preliminary, and is intended primarily for review purposes. Subsequent issues will reflect changes, additions, and deletions made in the light of pertinent review comments received, and on the basis of new and better information developed as the LMFBR Program progresses.

Some of the parameters listed may subsequently prove to be inconsequential to the design of sodium piping, and will be deleted; others, not yet listed, may emerge as development proceeds, and will be added later. And some parameters, although tentatively identified, cannot yet be established with certainty and have been given provisional values, or are left blank; these will be firmed up as soon as the appropriate data are available.

C F Braun & Co
Alhambra, California
October 25, 1968

LMFBR SYSTEM REQUIREMENTS
FOR
SODIUM PIPING
TECHNICAL REPORT

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1 INTRODUCTION

C F Braun & Co has been awarded a contract⁽¹⁾ by the US Atomic Energy Commission for the development and verification of a Piping Design Guide for sodium-cooled fast breeder reactor power plants (LMFBR). The work is a Priority 1 Task under the LMFBR Program Plan⁽²⁾ prepared for the USAEC Division of Reactor Development and Technology (RDT) by the LMFBR Program Office, Argonne National Laboratory. It is identified in the Program Plan as Task 3-8.2, Development of Design Technology for Piping.

This Technical Report defines the proposed scope of the Piping Design Guide by establishing tentative LMFBR system requirements for the design of sodium piping. The requirements cover operating conditions, both steady state and transient, piping geometry, preheat, thermal insulation, leak detection, interfaces, and quality and reliability assurance.

It is anticipated that the criteria developed in this Technical Report will be subject to revision and/or expansion as the work progresses. A review procedure has been established to ensure consistency between interdependent studies currently being performed under this and other task areas of the LMFBR Program Plan.

Under the review procedure, the Liquid Metal Engineering Center, (LMEC), is the coordinating agency. Technical Reports prepared by Braun under this contract will be distributed by LMEC to appropriate Review Agencies designated by USAEC. Comments from Review Agencies will be evaluated by Braun to determine their validity. Valid comments will then be incorporated into subsequent revisions to the Technical Reports.

Figure 110-1 shows the interrelationship of tasks under Task Area 3-8, Coolant Transport and Storage Systems.

(1) AT(04-3)-781, AEC San Francisco Operation Office (SAN)

(2) Liquid Metal Fast Breeder Reactor Program Plan, LMFBR Program Office, Argonne National Laboratory - AEC R&D Report, Reactor Technology, WASH-1101, August 1968

FIGURE 110-1 INTERRELATIONSHIP DIAGRAM-TASK AREA 3- COOLANT TRANSPORT AND STORAGE SYSTEMS

2 BACKGROUND INFORMATION

2.1 PIPING TECHNOLOGY

Outside of the nuclear industry, there have been many successful large diameter thin wall piping systems in hydraulic, gas, steam, and air services operating at relatively high temperatures. However, the design parameters, such as steady state temperatures, thermal transients, reliability, and life-time have not been as severe as those required for LMFBR sodium systems.

Piping as large as 30-inch diameter for sodium service has been designed, fabricated and operated. However, industrial experience is very meager. Only one FBR plant (Fermi) has used pipe this large, and that was for a run of about 70 feet. Some short runs of 16 inch pipe were used in Hallam. Twelve-inch, thin-wall austenitic piping was used fairly commonly in EBR-II, Fermi and Hallam. In each instance, the designers were forced to augment existing codes to satisfy their specific criteria and requirements.

A significant effort is being devoted within appropriate Code Committees and other interested groups to define and solve problems of piping technology. The consequences of failure in nuclear piping systems are being investigated. The USAS Code for Nuclear Power Piping has been issued in draft form, and work on piping analysis has been sponsored by the Atomic Energy Commission at General Electric and Oak Ridge National Laboratory. The Welding Research Council has sponsored an investigation of local stresses in a cylindrical shell. Undoubtedly some of the results from these activities are applicable to LMFBR piping systems, but in general, emphasis has been directed toward water systems.

Access to primary system piping for maintenance after start-up may be costly and difficult, and impossible under emergency conditions, due to the radioactivity of the coolant. Therefore, changes that usually are minor problems in most non-nuclear systems - eg, the installation of vibration dampers, and hanger adjustments - are more significant in a nuclear system, and must be precluded by adequate design where possible.

2.2 ANALYTICAL METHODS

Analytical procedures to more accurately predict the behavior and reliability of sodium coolant transport systems for the LMFBR range of operating parameters are required. As a minimum, stress analysis of the coolant systems should include the effects of (a) pressure, (b) pipe supports, (c) thermal expansion (flexibility analysis), (d) high cycle fatigue as a result of local thermal conditions in temperature mixing zones, (e) creep and incremental distortion (ratcheting), (f) conditions of instability, (g) geometric discontinuities (tees and attachments), and (h) seismic loads and other dynamic excitations.

2.3 THERMAL EXPANSION

Difficult problems of thermal expansion invariably arise in the design of large high-temperature piping systems. These difficulties are aggravated for piping of austenitic steel, the most common material of construction, because of its high coefficient of thermal expansion. With increased system temperatures, diameters, and wall thicknesses, pipe section moduli and end loads on equipment nozzles increase, making the problem more severe. Elastic and inelastic buckling under combined axial bending and transverse loads are of considerable concern. In addition, local overstrain, fatigue and creep conditions may be prevalent. Values for flexibility and stress intensification factors are uncertain. The stress range concept, although widely accepted and incorporated into existing USAS Power Piping Codes, needs to be evaluated for applicability to the large LMFBR systems. Therefore, existing procedures for determining piping stresses due to expansion must be reconsidered.

2.4 PIPE SUPPORTS

The resolution of problems of piping support in large sodium systems is an important area of development. Thin-wall pipe has the advantages of lower material cost and weight, and the ability to withstand severe thermal transients, but in large-diameter sizes, unique support problems arise. The usual support problem is caused by the heavy weight of the contents (sodium) compared with that of the pipe. The full-to-empty weight ratio for a large sodium piping system may be as high as three, whereas for the more conventional high temperature fluid systems the ratio is closer to unity.

2.4 PIPE SUPPORTS Continued

System operation at high temperature produces significant linear expansions and constant-support hangers normally are prescribed. Because of the high full-to-empty weight ratio, drainage of a sodium system produces large changes in hanger loads. However, the forces exerted by constant-support hangers remain essentially unchanged. As a consequence the system deforms until the forces developed by the stiffness of the system are in equilibrium with the hanger forces. This deformation can result in local yielding, excessive end loads and high local stresses. Local yielding may also occur at each hanger pipe attachment, because of relatively large concentrated loads applied to the thin-walled pipe, and methods of attachment must be sought to avoid geometric discontinuities.

The large mass and mass-flow rates of sodium-filled large diameter piping systems can develop high vibrational, and seismic and hydraulic forces (sodium hammer).

2.5 DOUBLE CONTAINMENT

Since safety must always be the paramount consideration, attention must be given to the consequences of pipe rupture and the resulting voiding of the system. Double containment provides some insurance against this hazard, but presents other problems. Component surveillance is more difficult to achieve, analytical methods become appreciably more complex, and the maintenance of concentricity between inner and outer pipe introduces geometric problems.

2.6 FABRICATION

Specifications for the manufacture of pipe bends and fittings and for the field assembly of them into a system need to be developed. These specifications include (a) fabrication techniques and processes, (b) procedures for quality control and assurance, (c) inspection and testing, (d) cleanliness standards and cleaning procedures, and (e) acceptance and manufacturing standards.

Welding substantially distorts stainless steel pipe. How much distortion is acceptable and how to control it must be determined. For ferritic materials, stress relief and the resultant oxidation are problems to be resolved.

Field fabrication problems due to poor fit and closure welds are expected. Out of round tolerances for piping as now specified - eg, ASTM A-358 - can result in a mismatch equal approximately to the wall thickness. Better fabrication processes are required to overcome this problem.

2.6 FABRICATION Continued

Closure welds for large-diameter piping systems that require inert gas back-up may also be a problem. Filling a large capacity system with inert gas is impractical. An alternative would be to isolate the closure section with pipe dams. The support and removal of such devices may be difficult and the tendency to overlook their removal must also be considered.

2.7 INSPECTION

For LMFBF piping systems, the ability to monitor and detect incipient failure and sodium leakage is required. The probability for a complete pipe rupture is low if small cracks or leakage can be detected in time. Therefore, means for reliable inspection prior to service and for continuous in-place surveillance need to be developed. This problem becomes more acute with double containment.

2.8 INTERFACE CRITERIA

The interaction between the piping system and the equipment to which it is attached must be considered. Customarily, equipment manufacturers prescribe limits to the forces and moments that their product can tolerate. Standard procedures such as those of the National Electrical Manufacturers Association (NEMA) are often adopted for this purpose. The applicability of such procedures to large LMFBF pumps and valves must be evaluated, and more reliable methods found if they should prove to be inadequate.

Other studies under the LMFBF program plan such as those related to pumps, valves, intermediate heat exchangers (IHX), steam generators, and storage tanks will provide useful sources of information in support of this effort.

2.9 SODIUM PURITY

Impurities have a significant affect on sodium corrosion characteristics. Of particular concern are interstitial impurities, oxygen, carbon, hydrogen and nitrogen. The levels of these impurities will be set by the system design. The piping design must consider these levels in establishing corrosion allowances for wall thickness and material properties of the pipe.

2.10 PLANT LIFE AND SAFETY

Besides the safety considerations already mentioned, there are other related factors that must be given attention. Among these are (a) determination of plant design life, (b) quality assurance in manufacturing, fabrication, erection, and testing, (c) in-service surveillance methods and, (d) operating history records keeping.

2.10 PLANT LIFE AND SAFETY Continued

Existing methods applied to water reactor plants must be evaluated in the light of the special needs of LMFBR plants and more exacting procedures established wherever needed.

2.11 PIPING DESIGN GUIDE

It will be the purpose of the LMFBR Piping Design Guide to establish design, fabrication, erection, testing, in-service surveillance and quality control procedures adequate to ensure the integrity of LMFBR sodium piping systems. The Guide will reflect the best proven technology in the field, extrapolated wherever necessary to meet the exacting demands of the fast breeder environment.

2.12 SYSTEM DEFINITION

As a first step towards the realization of the goals of this task, the present Technical Report attempts to define the scope of an LMFBR sodium piping system, its boundary conditions and its interfaces. Within this framework, the formulation of the Piping Design Guide can then proceed.

3 OPERATING CONDITIONS

Table 110-1 gives the range of operating conditions expected for LMFBR plants. The values given are for full load operating conditions, and have been taken from Reference (3) as the best available at this time. It must be recognized in the piping system design that the plant will not operate at full load for 100 percent of the time. It may be necessary to consider temperature, pressure, and other operating conditions at less than full load. It will also be necessary to establish operating conditions for the sodium purification systems, other auxiliary systems, and bypass branches.

The ranges of normal transient conditions affecting the piping are summarized in Table 110-2. Typical abnormal transient conditions are summarized in Table 110-3.

- (3) Liquid Metal Fast Breeder Reactor Program Plan, LMFBR Program Office, Argonne National Laboratory, WASH-1103 Reactor Technology, Volume 3, August 1968

TABLE 110-1
RANGE OF STEADY STATE OPERATING CONDITIONS

	<u>MAXIMUM VALUE</u>	<u>MINIMUM VALUE</u>
PLANT LIFE, years	30	30
PRIMARY SYSTEM		
Sodium temp		
Hot leg, F	1200	900
Cold leg, F	970	600
Loop ΔT , F	300	230
Maximum pressure		
Internal, psig	175	70
External, psig	20	0
Loop ΔP , psi	155	45
Piping pressure drop		
Number of loops	6	2
Total flow, 10^6 lb/hr	127.4	16
Flow per loop, 10^6 lb/hr	63.7	5.1
Flow per loop, 10^3 gpm	149.2	12
Pipe size		
Hot leg, in	48	24
Cold leg, in	42	18
Cover gas		
Kind	He or A	He or A
Purity, %	99.997	99.8975
Pressure, psi	30	3" H ₂ O
Sodium activity, r/hr	3.8×10^5	9.1×10^4
Radiation external to pipe, r/hr	3.8×10^5	
Sodium purity		
Oxygen, ppm	10	<10 (sat'n $<325^\circ\text{F}$)
Hydrogen, ppm	sat'n $<325^\circ\text{F}$	0.002
Carbon, ppm	20	20

TABLE 110-1 Continued

	<u>MAXIMUM VALUE</u>	<u>MINIMUM VALUE</u>
SECONDARY SYSTEM		
Sodium Temp		
Hot leg, F	1165	800
Cold leg, F	850	500
Secondary ΔT , F	315	250
Maximum pressure		
Internal, psig	90	90
External, psig	0	0
Loop ΔP , psi	90	30
Number of loops	4	2
Total flow, 10^6 lb/hr	106.5	92
Flow per loop, 10^6 lb/hr	46	5.0
Flow per secondary loop, 10^3 gpm	110	12
Pipe size		
Hot leg, in	44	16
Cold leg, in	42	16
Cover gas		
Kind	He or A	He or A
Purity, %	99.997	99.8975
Pressure, psi	100	3" H ₂ 0
Sodium activity, r/hr	1×10^{-3}	0.25×10^{-3}
Radiation external to pipe, mr/hr	< 0.2	
Sodium purity		
Oxygen, ppm	10	
Hydrogen, ppm		
Carbon, ppm		

TABLE 110-2
RANGE OF TRANSIENT CONDITIONS

	<u>MAXIMUM VALUE</u>	<u>MINIMUM VALUE</u>
PLANT STARTUP		
Pipe preheat, dry		
Initial temp, F	Ambient	Ambient
Final temp, F	400	300
Maximum heating rate, F/hr	50	15
Pipe preheat, sodium filled		
Initial temp, F	400	Ambient
Final temp, F	800	300
Maximum heating rate, F/hr	100	15
Pump start (or valve opening)		
Initial temp, F		
Maximum initial line temp difference, F		
Initial pressure, psi		
Peak pressure (surge), psi		
Maximum impurity levels in sodium during initial heat-up		
Oxygen, ppm		
Carbon, ppm		
Hydrogen, ppm		
Time to purify, hr		
LOAD CHANGES		
Preheat to standby		
Initial temp, F	400	300
Final temp, F	Standby	Standby
Maximum heating rate, F/hr	100	15
Standby to power		
Initial temp, F	Standby	Standby
Final temp, F	Steady State	Steady State
Maximum heating rate, F/hr	100	15
Normal load changes		
10% load change (high rate)		
Initial temp, F		
Temp change, F		
Rate, F/min		
Number of changes in 30 year life		

TABLE 110-2 Continued

	<u>MAXIMUM VALUE</u>	<u>MINIMUM VALUE</u>
Normal load changes Continued		
20% load change (medium rate)		
Initial temp, F		
Temp change, F		
Rate, F/min		
Number of changes in 30 year life		
Full range load change		
100% load change (slow rate)		
Initial temp, F		
Temp change, F		
Rate, F/min		
Number of changes in 30 year life		
PLANT SHUTDOWN		
Power to standby		
Initial temp, F		
Final temp, F		
Cooling rate, F/hr		
Standby to shutdown		
Initial temp, F		
Final temp, F		
Cooling rate, F/hr		
Pump stop (or valve closing)		
Initial temp, F		
Final temp, F		
Rate of temp, change, F/hr		
Initial pressure, psi		
Final pressure, psi		
Peak pressure (surge), psi		

TABLE 110-3

RANGE OF ABNORMAL CONDITIONS

	<u>MAXIMUM VALUE</u>	<u>MINIMUM VALUE</u>
PRIMARY PUMP STOPS, SECONDARY FLOW CONTINUES		
Hot leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Cold leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Number of incidents in 30 year life		
SECONDARY PUMP STOPS, PRIMARY FLOW CONTINUES		
Hot leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Cold leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Number of incidents in 30 year life		
FEEDWATER FLOW STOPS, SODIUM FLOW CONTINUES		
Hot leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Cold leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Number of incidents in 30 year life		

TABLE 110-3 Continued

	<u>MAXIMUM VALUE</u>	<u>MINIMUM VALUE</u>
REACTOR SCRAMS		
SODIUM FLOW CONTINUES		
Hot leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Cold leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Number of incidents in 30 year life		
LOSS OF LOAD		
Hot leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Cold leg		
Initial temp, F		
Final temp, F		
Maximum rate, F/sec		
Number of incidents in 30 year life		
SODIUM-WATER REACTION IN STEAM GENERATOR		
Secondary system hot leg		
Initial temp, F		
Maximum temp, F		
Max rate of temp rise, F		
Final temp, F		
Duration of transient, sec		
Peak pressure, psi		
Temp at peak pressure, F		
Maximum oxygen in sodium, ppm		
Maximum hydrogen in sodium, ppm		
Number of incidents in 30 year life		

TABLE 110-3 Continued

	<u>MAXIMUM VALUE</u>	<u>MINIMUM VALUE</u>
SODIUM-WATER REACTION IN STEAM GENERATOR Continued		
Secondary system cold leg		
Initial temp, F		
Maximum temp, F		
Max rate of temp rise, F		
Final temp, F		
Duration or transient, sec		
Peak pressure, psi		
Temp at peak pressure, F		
Maximum oxygen in sodium, ppm		
Maximum hydrogen in sodium, ppm		
Number of incidents in 30 year life		
SEISMIC ACCELERATIONS		
Horizontal, ft/sec ²	16	3.2
Vertical, ft/sec ²	10	2.2
FISSION PRODUCTS (Xe + Kr) IN SODIUM		
(1 % of fuel pins fail)		
Release rate, curies/hr		2400
Max activity released, curies		1.35x10 ⁶

4 INTERFACE REQUIREMENTS

The design of LMFBR sodium piping shall take into account constraints imposed by the design requirements for the main components of the LMFBR system. Attention shall be given to the following interface compatibility considerations.

- 1) Materials
- 2) Welding, including weld preparation
- 3) Dimensions
- 4) Loads, from all causes
- 5) Radiation
- 6) Mass transport
- 7) Fill and drain
- 8) Supports
- 9) Hydrostatic testing
- 10) Nondestructive testing
- 11) In-service surveillance

Tentatively identified as interfacing system components are the following.

PRIMARY SYSTEM

Reactor
IHX
Pump
Valves
Purification system components
Emergency cooling system components
Storage tank
Cover gas system components
Radiation shielding

SECONDARY SYSTEM

IHX
Steam generator
Pump
Valves
Purification system
Storage tank
Cover gas system

5 PIPING

5.1 PIPE GEOMETRY

5.1.1 SIZE AND THICKNESS RANGE Selected pipe sizes shall be limited to a maximum outside diameter of 48 inches. Wall thicknesses shall be sufficient to ensure adequate protection against failure at the maximum temperature and pressure attainable by the system under the most severe predictable service conditions. Wall thickness calculations shall take into account the following.

- 1) Internal pressure
- 2) External pressure
- 3) Inside metal temperature
- 4) Outside metal temperature
- 5) Allowances for corrosion and/or erosion
- 6) Mill tolerances
- 7) Method of fabrication (eg seamless, welded)
- 8) Instability

5.1.2 FITTINGS It is anticipated that LMFBR sodium pipe systems will be of all-welded construction. Fittings shall be of forged or formed and welded construction having a wall thickness at least equal to that of the matching pipe. Changes in wall thickness shall be achieved by a gradual transition, to avoid abrupt discontinuities.

Acceptable fittings are

- 1) Elbows
- 2) Tees
- 3) Mixing tees
- 4) Instrument fittings

Many failures have been experienced with bellows-type expansion joints in sodium service, and further investigation will be necessary before satisfactory design standards can be established. Meanwhile, such devices shall be considered for use only in the outer wall of double containment piping, and in no case shall they be used in the pressure containing pipeline.

Expressly excluded from use in the pressure containing parts of LMFBR sodium piping systems are the following.

- 1) Flanged joints
- 2) Mechanical joints
- 3) Mitered bends
- 4) Reducing elbows
- 5) Corrugated or creased elbows

5.1.3 DOUBLE CONTAINMENT Double containment may be specified for certain primary sodium systems to guard against uncontrolled dispersion of radioactive sodium or radioactive impurities in the sodium. The secondary container or jacket must contain the sodium after a major pipe failure. Containment integrity must be maintained until corrective actions are completed. Leak detectors should be provided to warn of any sodium accumulation in the space between the pipe and the jacket. This space should be filled with a non-reacting gas to avoid excessive temperatures in case of a sodium leak.

5.1.4 SUPPORTS The adequate design of the supporting system for LMFBF sodium piping shall be given special attention. The term "supports" shall include rigid hangers, spring hangers, and supports which carry the weight in compression. In some cases a supporting element may be a combination of these.

In addition to the weight effects of piping components, consideration shall be given to other load effects introduced by service pressure and temperature, earthquakes, etc. Hangers and supporting elements shall permit the free or controlled movement of piping caused by thermal expansion and contraction.

The design of elements for supporting or restraining piping systems or their components shall be based on all the concurrently acting loads transmitted into the supporting elements.

When imposed vibration or other dynamic loads occur during operation, suitable dampers, restraints, anchors, etc, shall be added to relieve or remove these effects.

The required strength of all supporting elements shall be based on the loading prescribed in the design data for the system, including the weight of the fluid transported, or the fluid used for testing, whichever is heavier (the specific gravity of sodium is less than that for water).

The design of the supporting elements shall be such as to prevent complete release of the piping load in the event of spring failure or misalignment. All parts of the supporting element shall be fabricated and assembled so that they will not be disengaged by movement of the supported piping.

Pipe hangers shall be designed to permit adjustment after erection, while supporting the load. Particular attention shall be given to the provision of means for adjustment of supporting elements attached to radioactive primary coolant systems. Consideration shall be given to the provision of remotely controllable servomechanisms.

The general design requirements for supporting elements not otherwise defined above shall be in conformity with USAS B31.7, Paragraph 1-721.

5.1.5 FILLING AND DRAINING LMFBR sodium piping systems shall be designed to permit free draining of the contents. Horizontal pipe runs shall be sloped to a minimum fall of 1:50 towards the drain tank or sodium pool. High points shall be provided with means of venting to the cover gas system. There shall be no pockets in which liquid sodium or nonsoluble gases can accumulate. In drain lines, provision shall be made to maintain an atmosphere that is free of oxygen or water.

5.2 MATERIALS

5.2.1 PIPING MATERIALS

5.2.1.1 COMPOSITION Composition should be the same as specified for vessels and other sodium containing components in each system.

Primary System	Type 304 or 316 stainless steel (Allowing for selection of carbon content and alloy composition in their permissible ranges.)
Secondary System	Type 304 or 316 stainless steel, 2-1/4 Cr - 1 Mo steel (Allowing for selection of carbon content and alloy composition in their permissible ranges.)

Modifications of these steels to inhibit carbon transfer are desirable, but will require development and code acceptance.

5.2.1.2 FABRICATION AND INSTALLATION METHODS

Acceptable	Forgings, weldments, welding
Not Acceptable	Castings, bolted flanges or other mechanical joints

5.2.2 SODIUM PURITY The maximum levels of metallic impurities in sodium are listed in Table 110-4. Interstitial impurities, which depend on operating conditions, are given in Section 3. Maximum levels of radioactivity are given in Table 110-5.

TABLE 110-4

Maximum Levels of Metallic Impurities, ppm
(For Primary and Secondary Systems)

Aluminum	10	Manganese	5
Antimony		Mercury	35
Barium		Molybdenum	
Beryllium		Nickel	5
Bismuth		Palladium	
Boron	1	Potassium	150
Cadmium	2	Rare Earths	
		Rhenium	100
Calcium	20	Rhodium	30
Cerium		Samarium	0.2
Cesium	15	Silver	15
Cobalt	1	Strontium	
Copper	10	Sulfur	100
Dysprosium	0.02	Tantalum	5
Europium	0.2	Tin	
Gadolinum	0.02	Titanium	
Gold		Tungsten	
Indium	25	Uranium	
Iron	10	Vanadium	
Lead	7	Zinc	
Lithium	5	Zirconium	
Magnesium		Hafnium	

TABLE 110-5

Maximum Levels of Radioactivity, c/gNa
(For Primary System Sodium)

	After Years of Operation				
	1	5	10	20	30
^{110}Ag					
^{140}Ba (La)					
^{141}Ce					
^{144}Ce					
^{58}Co					
^{60}Co					
^{134}Cs					
^{137}Cs					
^{59}Fe					
^{131}I					
^{54}Mn					
^{24}Na					
^{22}Na					
^{103}Ru					
^{89}Sr					
^{90}Sr					
^{182}Ta					
^{65}Zn					
^{95}Zr (Nb)					

5.2.3 PREHEATER MATERIALS Preheater materials must

- 1) Withstand temperatures reached at full heater power and pipe temperature of 800°F,
- 2) Withstand the maximum anticipated system operating temperatures (with preheat power off),
- 3) Withstand radiation (if present),
- 4) Not deteriorate with time to the extent of impairing the required performance,
- 5) Withstand thermal cycling and pipe movement, including vibration.

External surface materials must be compatible with pipe materials, support or structural materials, insulation, leak detector materials, and atmospheric environment and must not react violently with sodium in case of a leak.

Electric insulating materials must have and maintain high resistance to prevent short-circuiting arcs.

5.2.4 INSULATING MATERIALS The insulation must

- 1) Withstand the maximum anticipated system operating temperature (or, if higher, preheater surface temperatures),
- 2) Withstand radiation (if present),
- 3) Not deteriorate with time,
- 4) Withstand thermal cycling and pipe movement, including vibration,
- 5) Be compatible with pipe materials, supports or structural materials, preheater materials, leak detector materials and atmospheric environment (not absorb moisture or other gases).

In case of a liquid metal leak, the insulating materials must not react violently with the liquid metal, not form reaction products which cannot be removed or are corrosive, and not emit noxious or corrosive fumes.

5.2.5 LEAK DETECTOR MATERIALS All materials must

- 1) Withstand the maximum anticipated system operating temperature (or higher temperatures which may result from preheating),
- 2) Withstand radiation (if present),
- 3) Not deteriorate with time to the extent of impairing the required performance.

External surface materials must be compatible with piping materials, insulation, preheater materials, and the atmospheric environment and must not react violently with sodium, in case of a leak.

5.2.6 CLEANING MATERIALS Cleaning materials must

- 1) Be free of chlorides and halogens to avoid stress corrosion,
- 2) Be free of boron to avoid reactivity effects,
- 3) Not leave any harmful residues,
- 4) React with sodium in a controllable manner.

Purge gases must

- 1) Not contain impurities which react with sodium or pipe materials
- 2) Meet the following purity standards...(table of suggested gas versus impurity limits)

5.2.7 EXTERNAL ENVIRONMENT The environmental atmosphere for piping is either air or oxygen depleted gas. The gas may be helium, argon, or nitrogen with a maximum oxygen content of per cent and a dew point of F. Environmental conditions for pool type systems are given in Section 6.0.

5.3 PREHEAT AND COOLDOWN

Sodium piping preheat requirements are as follows.

- 1) To prevent excessive thermal shock by the introduction of sodium into an empty system during filling operations
- 2) To provide for steady increases in pipeline temperatures under transient flowing conditions
- 3) To provide means of melting frozen resident sodium after a shutdown
- 4) To provide means for melting or redissolving precipitated impurities in the sodium
- 5) To provide means for controlling the rate and sequence of sodium cooldown.

Preheaters shall be designed to raise the system temperature from ambient to an average temperature of 400 F within a minimum time of hours. Temperature differences during heat up must be considered in the piping design. At the end of preheat, pipe temperature differences shall not exceed F.

5.4 INSULATION

LMFBR system requirements for thermal insulation are as follows.

- 1) To prevent excessive heat losses from the outer surface of the piping
- 2) To afford protection to operating personnel
- 3) To maintain a satisfactory thermal environment in areas adjacent to the piping.

The temperature at the outside surface of the insulation shall not exceed 150F when the system is at maximum operating temperature.

Insulation materials requirements are listed in 5.2.4. Selected materials shall be free of adsorbed water, and the method of application shall include means for preventing moisture from entering the insulation during periods of shutdown.

Insulation shall be attached to the pipe and in-line components by external straps. Methods of attachment which require the welding of studs or support rings to the pipe wall shall be excluded.

5.5 LEAK DETECTION

Provisions shall be made in the piping system for the inclusion of suitable leak detection devices. Such devices may include shorting wires or probes, photocells, or ionization gages.

The system for detecting leaks shall be capable of identifying leaks greater than cc/hr in the primary system or cc/hr in the secondary system. Consideration must be given to compatibility of the leak detection system with insulation, double containment, and the preheat system. Leak detector material requirements are described in 5.2.5.

6 POOL TYPE SYSTEMS

In some LMFBR plant designs, the complete primary coolant system is submerged in a sodium pool within the reactor vessel. The piping design for such a primary system must meet unique requirements which do not exist in the more conventional loop-type arrangements. They are as follows.

6.1 OPERATING CONDITIONS

The pipe external environment is primary system sodium at temperatures, pressures, etc, which are listed for normal operation in Table 110-1. The pipe will be exposed to significant neutron and gamma radiation levels which have to be established by the plant design.

6.2 INTERFACES

Since the IHX is located in a relatively high neutron flux environment, the secondary sodium will become radioactive to some extent. Maximum activity levels for the secondary sodium are curies/g of or r/hr at the surface of a 36 inch pipe.

6.3 PIPING

Minimum leakage slip joints and other suitable mechanical joints are acceptable for pool-type, primary system piping connections.

Thermal insulation on the reactor outlet-to-IHX₂ inlet pipe is required to reduce surface heat flexes to Btu/hr-ft² maximum, under steady state conditions. Thermal insulation on this and all other piping is required to maintain stress levels within allowable limits during transient conditions.

Secondary containment, leak detection and preheat (other than for the reactor vessel) are not required.

Materials for pipe support and thermal insulation shall preferably be the same as that of the pipe to minimize thermal expansion and sodium compatibility problems.

7 QUALITY AND RELIABILITY ASSURANCE REQUIREMENTS

The piping design guide shall define the quality and reliability assurance measures to be implemented in accordance with the requirements of the LMFBR Program. In general these requirements dictate that quality management is maintained over engineering, construction, and operation.

7.1 ENGINEERING

The quality assurance requirements for engineering include, as a minimum, the following provisions.

- 1) Independent design review
- 2) Validation of computer codes
- 3) Certification of mathematical analysis

7.2 CONSTRUCTION

Construction of piping systems, including fabrication, erection, and static testing shall be in accordance with an approved quality control program. The quality control program shall be in accordance with applicable provisions of the following standards, specifications, and codes.

- 1) RDT-S-903, tentative RDT Standard for Quality Control System Requirements
- 2) MIL-Q-9858A and NASA NPC 200-1A
- 3) ASME Code, Section III and USAS B31.7

7.2.1 MATERIALS Materials tests and inspections shall be in accordance with approved standards. Typical standards are as follows.

- 1) RDT-MA-182 Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High Temperature Service, February 7, 1968
- 2) RDT-MA-193 Alloy-Steel Bolting Materials for High Temperature Service, April 4, 1968
- 3) RDT-MA-213 Seamless Austenitic Stainless Steel Tubes, January 30, 1968
- 4) RDT-MA-240 Chromium and Chromium-Nickel Stainless Steel Plate, Sheet and Strip for Fusion-Welded Unfired Pressure Vessels, February 6, 1968

7.2.1 MATERIALS Continued

- 5) RDT-MA-298 Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes, February 6, 1968
- 6) RDT-MA-336 Alloy Steel Forgings for High Temperature Service, December 13, 1967
- 7) RDT-MA-358 Electric-Fusion Welded Austenitic Chromium Nickel Alloy Steel Pipe, Preliminary Draft
- 8) RDT-MA-376 Seamless Austenitic Stainless Steel Pipe, January 31, 1968
- 9) RDT-MA-403 Factory-Made Wrought Seamless Austenitic Steel Welding Fittings, February 19, 1968
- 10) RDT-MA-479 Stainless and Heat-Resisting Steel Bars and Shapes for Use in Boilers and other Pressure Vessels, February 5, 1968

7.2.2 MANUFACTURING PROCESSES Manufacturing processes shall be in accordance with approved standards, such as the following.

- 1) RDT-S-902 Tentative RDT Standard for Welding, June 18, 1968
- 2) RDT-S-910 Tentative RDT Standard for Preparations for Sealing, Packaging, Packing, and Marking of Components for Shipment and Storage, October 14, 1967
- 3) RDT-S-922 Proposed Standard - Material Fabrication Requirements, June 21, 1967
- 4) RDT-S-973 Cleaning and Cleanliness Requirements for Sodium Systems and Components, March 1, 1968

7.2.3 INSPECTIONS Inspection of in-process and final assemblies shall be in accordance with approved standards such as the following.

- 1) RDT-S-904 Tentative RDT Standard for Inspection System Requirements, April 25, 1967
- 2) RDT-S-905 Tentative RDT Standard for Calibration System Requirements, September 14, 1967

7.2.3 INSPECTIONS Continued

- 3) RDT-S-908 Tentative Draft-Nondestructive Test Methods, April 8, 1967
- 4) RDT-S-916 Tentative RDT Standard for Requirements for Identification Marking of Reactor Plant Components and Piping, September 12, 1967
- 5) RDT-S-928 Tentative RDT Standard for Continuous Identification Marking of Wrought Metal Products, September 7, 1967
- 6) RDT-S-934 Draft - Material, Equipment, Process Standard Weld Examination Standard, Water-cooled Nuclear Power Plants, April 28, 1967

7.2.4 TESTS Subassemblies and final assemblies shall be tested to prove their integrity and leak-tightness. Consideration shall be given to type and purity of test fluid to avoid contamination of the system or the introduction of substances having a deleterious affect on the piping material.

7.3 RELIABILITY ASSURANCE

Requirements for continual monitoring of the system to assure integrity during operation shall be defined, and requirements for repair, inspection, and test shall be specified.

7.3.1 MONITORING Piping system monitoring shall include the following.

- 1) Sodium purity
- 2) Material surveillance coupons exposed to process sodium
- 3) Strain measurement
- 4) Remote or semi-remote inspection
- 5) Operating records

7.3.2 MAINTENANCE AND REPAIR Requirements for replacement or repair of piping systems shall be defined, including the following provisions.

- 1) Accessibility
- 2) NDT and inspections
- 3) Testing