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ATOMICS INTERNATIONAL
A Division of North American Aviation Inc.

NAA-SR-MEMO COVER SHEET

REPORT TITLE

EVALUATION OF FERRITIC STEEL IN THE SECONDARY SODIUM SYSTEM

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NAA-SR-MEMO 11986 Rev.

(This Document Contains Pages.)
(This is Copy of Series)

CLASSIFICATION TYPE
(RD OR DI)

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I. Introduction

In the early days of sodium technology, every effort was made to get sodium systems running. With almost no background to draw upon, most early workers selected the austenitic stainless steels which had proved corrosion resistant in aqueous systems. Type 347 stainless was the most popular variety of stainless steel because some researchers believed that columbium stabilization was necessary to prevent intergranular attack.

When the need for going to less expensive steels was recognized, it was found that for long-time service below 1000°F, Type 304 stainless would be adequate. Later information showed that 304 stainless steel is adequately resistant to corrosion in sodium¹.

Historically, the austenitic stainless steels were adopted for medium service (Experimental Breeder Reactor and Submarine Intermediate Reactor) because of their known general chemical-corrosion resistance, their high-temperature mechanical properties, and the results of screening tests which indicated that sodium attacked carbon steel in dynamic systems by removal of iron, and minor alloying constituents, principally carbon, at relatively high rates. These tests further showed that oxygen additions greatly increased this attack and that diffusion welding at temperatures of 842°F (450°C) and loads of 5,000 lb/sq in. occurred readily. Whether or not deposition occurred in the cold zone of a heat transfer system was never determined in early experiments. Hot-zone weight losses, decarburization, and diffusion bonding were considered sufficiently detrimental in themselves to preclude the use of carbon steel for high-temperature service².

The ferritic chromium molybdenum steels were next considered as attractive possibilities for sodium coolant systems. These steels are less expensive pound for pound than stainless steels but the lower cost is offset by the post-weld heat treating requirements and also by the fact that piping is not available in schedules less than standard weight. The ferritic chromium steels also have higher coefficients of thermal conductivity, lower coefficients of thermal expansion and are resistant to stress-corrosion in hot water or steam contaminated with chlorides.

Studies^{3,4} have shown that all of the ferritic steels containing 2.25% chromium or more are adequately resistant to corrosion in sodium containing up to 60 ppm oxygen at temperatures at least up to 1100°F. However, steels containing 5% chromium, or less, tend to decarburize in sodium when an austenitic stainless steel is also in the system.³ This effect is only seen when large portions of the ferritic system are above 800°F.

The FFTF secondary heat transfer system is nonisothermal; the secondary system design operating temperatures vary between the loop's 300°F cold zone at the cold trap and the 845°F hot zone of the intermediate heat exchanger. Based upon these temperature conditions and component functional requirements, an evaluation has been made of carbon, chrome-moly and austenitic steels in order to select the more economical material for the application. The specific alloys selected for comparison are Type A-106, Grade B carbon steel, 2½% chromium-1 molybdenum steel, and Type 304 stainless steel. General characteristics of additional chrome-moly alloys are presented to permit evaluation

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of these materials at loop design temperatures and above. It must be borne in mind that any specific material selection must be made upon the bases of trade-offs among the following factors: mechanical properties, corrosion allowance, allowable stress, material cost, fabrication cost, and material thermal properties.

II. Summary and Recommendations

The mechanical and metallurgical properties of ferritic steels were reviewed for applicability to construction of the FFTF secondary sodium system as replacement for the more costly austenitic stainless steels. Materials selected for evaluation upon the basis of their cost, resistance to corrosion in sodium, and generally good mechanical properties were ASTM A 106, Grade B, medium carbon steel, and $2\frac{1}{4}$ chromium -1 molybdenum steel. The properties of these materials were compared with Type 304 SS.

The choice of material for construction of high temperature sodium systems is dependent upon cost, corrosion properties, carbon transfer, and mechanical strength. Environmental temperature is a determining factor in selection of a material from among plain carbon steel, chromium-molybdenum steel and austenitic stainless steel. Carbon steel above 775°F is subject to graphitization embrittlement which can cause failure as a result of mild impact loading. Use of the $2\frac{1}{4}$ Cr -1 Mo steel is normally limited to 1050°F due to the rapid scaling in air at higher temperatures. Type 304 SS has good oxidation resistance to 1650°F , but reduction in strength limits the service temperature to about 1250°F . The relative cost factors for the three materials are 1:2.4:13 for carbon steel, $2\frac{1}{4}$ Cr-1 Mo, and 304 SS, respectively. Fabrication cost penalties are imposed on the chrome-molybdenum steels by the need to heat treat weldments; these were considered in the economic evaluations.

The recommendations for the FFTF secondary sodium system construction are:

- 1) Fabricate piping from Schedule 10, Type 304 SS,
- 2) Fabricate the air-cooled heat dump exchanger with $2\frac{1}{4}$ Chrome-1 Molybdenum steel tubing having carbon steel fins,
- 3) Fabricate the purification cold trap from ASTM A 106, Grade B carbon steel.

The estimated cost savings are \$142,000 for the piping, \$128,000 for the heat exchanger, and \$5,000 per cold trap.

III. Material Properties

A. Mechanical Properties

The mechanical properties and code allowable stresses of carbon steel (Type A-106, Grade B), $2\frac{1}{4}$ chromium-1 molybdenum steel and Type 304 SS are shown in Table 1.

B. General Properties

The general properties of these steels are as follows:^{5,6}

1. **Carbon Steel (0.08 to 0.20% C).** Carbon steels are the simplest in chemical compositions. These steels have adequate properties for certain applications, but are notably poor in service at elevated temperatures. Carbon steels have poor corrosion and oxidation resistance. They are subject to embrittlement by graphitization at temperatures above 775°F. They have low creep and stress-rupture strength. These steels are adequately corrosion resistant to low oxygen sodium, but tend to decarburize in sodium systems containing high chromium steels.
2. **2 $\frac{1}{4}$ Chromium-1 Molybdenum Steel.** The chromium content in this steel is sufficient to increase oxidation and corrosion resistance substantially. The molybdenum content adds significantly to creep and stress-rupture strength. It retains ductility at elevated temperatures. It is serviceable at temperatures up to 1050°F. Preheating and postheating of welded joints is required. This steel has adequate corrosion resistance, but decarburizes at temperatures above 950°F in sodium systems containing high chromium steels, thereby undergoing a reduction of mechanical strength to 80% of nominal.
3. **Austenitic Stainless Steels (Type 304).** The creep and stress-rupture strength of this alloy at temperatures above 1000°F is substantially higher than those of the ferritic chromium-molybdenum grades. Their oxidation resistance extends their useful service temperature to 1400°F. They have the disadvantage of high thermal expansion and low thermal conductivity compared with the ferritic alloys. They are subject to the precipitation of carbides at grain boundaries at temperatures above 800°F, which causes some reduction in toughness. The reduction is not sufficient, however, to bring the steels into the category of brittle materials. The precipitation of chromium carbides at grain boundaries in 304 stainless steel produces a sensitivity to selective grain boundary corrosion and oxidation. Sensitization does not make the steels subject to intergranular attack by liquid sodium, but exposure to aqueous environment produces rapid intergranular corrosion. Austenitic steels are susceptible to stress corrosion in caustic and chloride solutions.

C. Summary of Material Properties

Material characteristics of carbon steel, chromium-molybdenum ferritic steels, and austenitic stainless steels are summarized in terms of their practical temperature limitations (in Table 2) as a guide to material selection^{6,7}. The table is based upon data for pipes and tubes. The temperature limitations for avoidance of excessive scale formation, mechanical strength reduction, and graphitization are presented and the effects of chromium content and molybdenum content in the ferritic steels upon scaling resistance, graphitization and mechanical strength are made apparent. The table also provides information on relative cost data, code allowable stresses, and carburization-decarburization characteristics for multi-material systems containing appropriate carbon sinks and sources. The material costs do not reflect fabrication cost penalties of preheat and postheat requirements for welding the chromium-molybdenum alloys. The lowest temperature in the table for each material is the recommended maximum design temperature for the material in FFTF application. The final selection of a material is dependent upon the trade-off factors cited in the Introduction.

IV. Carbon Steel

A. Minimum Wall Thickness

The normal maximum operating temperature of the secondary sodium system is 845°F with a design temperature of 1000°F¹³. The greatest hoop stress in the system would be in the 18-in. piping. The code for pressure piping⁷ allows a maximum stress of 5000 psi @ 900 F for carbon steel pipe. Thus the minimum pipe wall thickness can be calculated by the following formula:

$$t_m = \frac{PD}{2S + 2 Y_p} + C$$

where:

t_m = minimum pipe wall thickness, in inches

P = maximum internal service pressure in pounds per square inch gage

D = outside diameter of pipe in inches

S = allowable stress in material due to internal pressure, at the operating temperature, in pounds per square inch

C = corrosion allowance, in inches

y = a coefficient having the following values:

$$900^\circ\text{F} - 0.4, 1000^\circ\text{F} - 0.7$$

$$\text{or } t_m = \frac{110 \times 18}{2 \times 5000 + 2 \times 0.4 \times 110}$$

$$t_m = 0.198$$

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From a code standpoint the standard pipe wall of $3/8$ in. for an 18-in. pipe would allow a 0.177 corrosion allowance at 900°F.

Actual corrosion rates¹ observed with carbon steel of 0.1 mil/yr are negligible in most system designs¹.

For short periods of time either temperature or pressure, or both, may exceed their nominal design values and the computed stress in the pipe wall, calculated for the pressure by the above formula, may be in excess of the allowable. The allowable stress, S, value may be exceeded by 15% provided it does not occur over 10% of the operating period or by 20% if it does not exceed 1% of the operating period¹.

Other reports have recommended that for carbon steel the maximum temperature for long term use is 840°F and for "temporary" use as high as 1470°F¹⁴. Oxide concentration was considered to be below 50 ppm. Mr. Stan Ekert of the DuPont Corp. stated that mild steel is used throughout most of their sodium production and processing equipment, and has continued to operate in the range of 400°C to 450°C (842°F) for periods up to 18 years in length. However, during this period some of the equipment was repaired¹⁵.

Although resistance to scale formation and mechanical strength properties indicates the useful temperature limit is 1000°F for carbon steel, the problem of graphitization embrittlement imposes a practical, safe temperature limit of 775°F where containment reliability is paramount.

B. Diffusion Bonding

Similar, mating alloy surfaces tends to weld together in liquid metals at temperatures much lower than those required for normal resistance or flash welding. This effect can be serious where such surfaces are designed to move occasionally, as in valves or in parts designed for periodic disassembly. The liquid metal acts first as a fluxing agent and secondly as a bridge through which atoms diffuse and are mutually attracted with energies of the same order of magnitude, as of self-diffusion and cohesion of the atoms in the base alloy.

The efficiency of the bond-per-unit area is temperature dependent. Increasing pressures merely increase the surface area of the bond and consequently the total load needed to break it. Diffusion welding is not evident until about 850°F¹⁶.

The carbon steels, and possibly the low alloy steels are subject to diffusion bonding as can be seen by the following table².

<u>Material</u>	<u>Temp. °F</u>	<u>Time days</u>	<u>Breaking Strength of bond lb/sq in.</u>
Carbon Steel on Carbon Steel	850	30	2,250
410 Stainless on 410 Stainless	932	30	None
347 Stainless on 347 Stainless	932	30	None

Although carbon steel couples appear to be more susceptible to diffusion bonding (self-welding) than the ferritic or austenitic stainless steels, it is good practice to use hard faced materials wherever static or sliding surface contact is required. Nitriding and chromium plating have been successfully employed to minimize wear and self-welding in sodium at temperatures up to 1000°F¹⁷.

C. Mass Transport

Mass transport of carbon steel is the result of the temperature dependence of solubility. In a heat transfer system iron taken into solution at a high temperature will exceed the equilibrium solubility at the lower temperature of the coolant as it gives up its heat. Tests of carbon steel in laboratory-scale static and dynamic systems showed a "hot-zone" weight loss of carbon steel, which indicated that mass transport and deposition of iron could plug the coolant passages in a carbon steel reactor system after relatively short periods of operation.

D. Decarburization

Decarburization is the loss of carbon from the surface of a ferritic alloy as a result of heating in a medium which reacts with the carbon. Austenitic stainless steels tend to decarburize adjacent ferritic steel surfaces in sodium, even to the point of "gettering" carbon from another chromium bearing steel^{16,1}. However, specific tests are required to determine this tendency in any ferritic-austenitic stainless steel sodium system.

If sodium in a circulating system is saturated with carbon, the carbon steel pipe in the system would not decarburize unless the carbon concentration is lowered by cold trapping, hot trapping, or carburization of adjacent austenitic steels. The transfer of carbon from a low-chromium ferritic steel through sodium to a high-chromium austenitic steel occurs as illustrated (even though the high-chromium steel is saturated with carbon).

The notation A_c denotes the activity of the carbon and subscripts 1, 2, and 3 denote progressively lower activity values. Thus, the low-chromium complex (Fe, Cr) carbide phase and the saturated ferrite phase in equilibrium have the same carbon activity (A_{c1}). The activity of the carbon in saturated austenitic and high-chromium complex (Fe, Cr) carbides (A_{c3}) is lower due to the higher chromium content. The activity of the carbon in sodium necessarily has some intermediate value (A_{c2}).

It is convenient to use unity for the carbon activity of graphite. On this basis, the carbon activity in low-alloy steels, saturated with carbon, is greater than unity. Gurry¹⁸ reports the activity of carbon in ferrite, saturated with carbon, to be 1.37 at 1300°F, 2.88 at 1000°F and 6.18 at 800°F. This increase in activity with decrease of temperature indicates that as the temperature is lowered there may be an increasing tendency for low-alloy steel to decarburize in sodium. The fact that the carbon activity of carbon and of low-alloy steels, containing excess carbides, is greater than unity shows that these steels will decarburize in sodium even when there is an excess of graphite in the sodium. In a plain carbon steel, decarburization can be expected to proceed until all of the carbides are removed and the carbon in the ferrite is reduced to the point where the carbon activity is unity.

Another transformation of carbon in steel is graphitization. Graphitization is a process by which the combined carbon in ferritic alloys is transferred wholly or partially to graphite or free carbon. Carbon steel is^{5,1} subject to graphitization embrittlement with time at temperatures above 775°F. Mild shock can induce brittle failure of graphitized steel. Short term exposure above 775°F will not cause immediate graphitization. For example, during stress relieving welds in heavy boiler plate, it is acceptable practice to heat the carbon steel plate to 1100°F in a furnace for one hour. Metallurgical examination of the welded plate after this heat treating has shown no evidence of graphitization.

Silicon is normally added to carbon steel to increase creep strength above 850°F. The ASME unfired pressure vessel code stipulates that carbon steel, for service temperatures above 850°F, must contain not less than 0.10 percent silicon. Silicon, however, promotes graphitization which, for reliable service, limits the use of carbon steel to a maximum of 775 - 800°F. For higher temperature application, addition of chromium and molybdenum improve mechanical properties and eliminate the graphitization problem.

V. 2-1/4 Chromium - 1 Molybdenum Steel

The 2 $\frac{1}{4}$ chromium-1 molybdenum steel alloy provides a favorable combination of strength, scaling resistance, avoidance of graphitization, and reduced decarburization rate. This alloy can be reliably used in sodium systems up to 1050°F. In duplex systems, however, where the carburizing-to-decarburizing surface area ratio is large, the material properties for purpose of design should be based upon complete decarburization of the ferritic steels having less than 5 percent chromium. For the 2 $\frac{1}{4}$ Cr-1 Mo alloy a factor of 0.8 should be applied to the allowable stress in duplex system service. For the 5 Cr- $\frac{1}{2}$ Mo alloy no reduction in the allowable stress is required. The alloys having chromium content greater than 5 percent tend to carburize instead of decarburize.

The economics of using 2 $\frac{1}{4}$ chromium-1 molybdenum steel vs 304 stainless steel in the secondary piping and air dump heat exchanger is discussed under the component section of this report. This section discusses the favorable resistance to decarburization and corrosion of 2 $\frac{1}{4}$ chromium-1 molybdenum steel at the low operating temperature of 845°F.

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The corrosion characteristics of the $2\frac{1}{4}$ Cr-1 Mo alloy in sodium at FFTF conditions are satisfactory.

The following table shows the close agreement between two separate investigators on the weight loss of $2\frac{1}{4}$ chromium-1 molybdenum in a sodium system.

<u>Alloy</u>	<u>Temp.</u>	<u>Oxygen Content</u>	<u>Weight Change (Mg/cm²/Mo.)</u>	<u>Type of Test</u>
$2\frac{1}{4}$ Cr-1 Mo ¹	932°F	100 ppm	(-) 0.10	Static
$2\frac{1}{4}$ Cr-1 Mo ³	1025°F	10 ppm	(-) 0.123	Dynamic

Carburization-decarburization characteristics were also determined for the low alloy ferritic steels in reference 3. The conclusions reached were that:

- 1) Corrosion rates of the ferritic steels containing $2\frac{1}{4}$ percent chromium - 1 molybdenum were negligible when exposed at 1050°F in a low-velocity circulating sodium (0.76 ft/sec) containing 10 ppm oxygen and with a loop temperature gradient of 500°F. The loop material was 304 stainless steel. Decarburization rates were significant for the $1\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo, $2\frac{1}{4}$ Cr-1 Mo, and 5 Cr- $\frac{1}{2}$ Mo under the same conditions.
- 2) Corrosion rates of the ferritic steels containing $2\frac{1}{4}$ chromium were shown to be negligible when exposed at 1025°F in high velocity circulating sodium (13.5 ft/sec) containing 36 ppm oxygen, some carbon contamination, and without a substantial temperature gradient in the loop. The loop material was 304 stainless steel. Under these conditions the alloys having higher than 5% chromium content were significantly carburized. The $2\frac{1}{4}$ Cr-1 Mo steel decarburized slightly and the $1\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo decarburized substantially.

VI. Secondary System Components

A. Secondary Piping

Table 3 shows the comparative piping cost for carbon steel schedule 40, $2\frac{1}{4}$ chromium -1 molybdenum, and 304 stainless steel schedule 10, and schedule 40. The length of pipe and pipe size was obtained from D. R. Anderson²⁰. The piping cost which does not include field fabrication was obtained from a local piping fabricator and the figures were checked with our estimating department.

A most significant cost reduction can be realized by using schedule 10 in 304 stainless steel in place of schedule 40. The allowable stresses in the schedule 10 stainless piping are within the permissible boiler code⁷.

No analysis was made on the basis of expansion stresses. In particular, the elbows and "T's" might have to be reinforced in order to limit the stresses.

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Another advantage of schedule 10 pipe over schedule 40 is that because of the thinner wall the expansive forces are reduced on equipment and pipe supports. If we assume that the straight pipe costs amount to $1/3$ to $1/2$ the total material costs¹⁹ then a conservative estimate of the cost savings by specifying schedule 10 stainless steel piping is $2(145,000-74,000) = \$142,000$.

Many references cite the use of $2\frac{1}{4}$ chromium -1 molybdenum pipe as a method of reducing the cost of stainless steel piping. As can be seen in Table 3, the cost of $2\frac{1}{4}$ chromium -1 molybdenum is approximately 25% higher than the schedule 10 stainless steel piping. The reasons for this are twofold: One, is the extra cost of postweld treatment, furnace or local heat treating which is required in the $2\frac{1}{4}$ chromium -1 molybdenum material. The second cost factor is that schedule 10, $2\frac{1}{4}$ chromium -1 molybdenum piping is not available in the large pipe sizes. It is impossible to hot draw large diameter schedule 10 $2\frac{1}{4}$ chromium -1 molybdenum without collapsing the piping. Schedule 40 to 160 is used almost exclusively for high pressure and temperature boiler plants and process units.

Local piping fabricators state that the extra cost for full furnace stress relieving is $6\phi/\text{lb}$. They estimate that field welding is three times the cost of shop welding and that the cost for local stress relieving is a 50% premium for $2\frac{1}{4}$ chromium -1 molybdenum over stainless steel.

A local refinery states that for field stress relieving for very large piping and for a small number of welds on small piping they use "Exomet Kits" which is a thermite control process which replaces heaters, thermo-couples, and a read-out instrument control panel. The cost of an Exomet Kit for a 42-inch line is \$2,000, which would be more economical than for a conventional heat-treating method.

However, for six welds on a schedule 80 line, the cost with conventional heaters was estimated at \$1,000 labor for welding, and \$2,600 for equipment rental for heat treating. In this case the conventional heat treating method would be more economical than the Exomet Kits.

The higher cost of the $2\frac{1}{4}$ chromium -1 molybdenum piping is illustrated when the relative cost ratios are compared for fabrication of 100 feet of 3-inch pipe with miscellaneous fittings²¹. The cost ratio of carbon steel is taken at unity.

<u>Pipe Material/ Schedule</u>	<u>Pipe Cost</u>	<u>Fitting and Flanges</u>	<u>Shop Fabrication</u>	<u>Total Cost</u>
Stainless Steel/10	1.6	0.5	1.2	3.3
$2\frac{1}{4}$ chromium -1 moly- bdenum/40	1.3	1.4	1.2	3.9

Here again the cost of stainless is shown to be less because the lighter schedule is available for stainless piping.

B. Air-Cooled Heat Dump Exchanger

One air-cooled heat exchanger is provided for each of the two secondary loops. These two air-cooled heat exchangers with a rating each of 850,000,000 Btu/hr are completely independent of each other except for connections to a common auxiliary furnace.

The principal area of cost reduction analysis for these exchangers was concentrated on the finned tube heat exchange sections. The proposed use of 304 stainless tubes or piping is costly from two standpoints.

1) The overall heat transfer coefficient ("U") is reduced by approximately 9% with the use of stainless steel tubes in place of $2\frac{1}{4}$ chromium -1 molybdenum tubes. Note that carbon steel is assumed to be the finning material in both cases. See cases 2 and 3, Table 4.

2) The use of stainless steel tubing with carbon steel fins is considered poor design because of the high differential expansion between the tube and finning material. $2\frac{1}{4}$ chromium -1 molybdenum tubes with carbon steel fin transfer 151 Btu/ft²/°F (based on bare tube surface area). If stainless steel tubes with stainless steel fins were used the overall "u" would be reduced to 117 Btu/ft²/°F (bare tube); see case 4, table 4. The linear length of tubing that would be required would increase to 51,300 ft, thus making the cost prohibitive.

The use of carbon steel tubing is not recommended because the cost advantage does not warrant the potential problems as described in Part IV.

Table 4 shows the use of $2\frac{1}{4}$ chromium -1 molybdenum tubes with carbon steel fins will reduce the tubing cost by $2(274,000-210,000) = \$128,000$ for both exchangers.

Additional recommendations for improved operation and more economical design are:

- 1) Use a large damper on outlet of each fan module instead of shutters in order to reduce air leakage.
- 2) There is no need to pay a premium to slope tubes for drainage.
- 3) Use parallel air flow instead of concurrent in order to prevent freezing at low heat loads. An additional 5% tubing surface is required for this parallel design.
- 4) To permit a good flow distribution across the header requires a minimum of 15 to 20 psi. The conceptual design¹³ shows only a 4 psi ΔP.

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5) Because the air film is limiting to the heat transfer, it is recommended to substitute a gas-fired heater in place of the 10,000,000 Btu/hr oil heater to prevent inadvertent fouling of the fins.

6) It is doubtful that air filters are required.

C. Secondary Pumps and Surge Tanks

The philosophy as expressed by Fedel²² still applies to carbon steel substitution for 304 stainless for the FFTF. The cost savings of utilizing carbon steel in the secondary pump for the SRE power expansion program was about 10%, but the additional cost of cleaning the pump including filters, procedure writeup, labor, and cold trapping essentially wipes out the original 10% cost reduction. It is recommended that 304 stainless be used for the pumps and secondary expansion tank.

D. Secondary Heat Transfer Valving

It is recommended that 304 stainless steel valves and trim be used in the secondary heat transfer system because the piping is 304 stainless. 2 $\frac{1}{4}$ chromium -1 molybdenum transition welds should be kept to a minimum.

E. Purification System

The main body of the cold trap should be of carbon steel such as used at Hallam (see attached Dwg 7518-078637). Carbon steel traps will cost about \$5,000 each. Stainless steel traps would increase the cost to \$10,000²³ per trap. The hot trap should also be constructed of 304 stainless steel.

F. Intermediate Heat Exchanger

The intermediate heat exchanger should be constructed of 304 stainless steel. The tube wall thickness should be a minimum of 50 mils to preclude damage by vibration²⁴.

VII. Chemical Cleaning

It is not recommended that field chemical cleaning be used on any form on any type of piping or components. The hazards of leaving a pocket of water in any of the equipment far outweigh the additional costs of cold traps that would have to be expended to clean up any oxide in 2 $\frac{1}{4}$ chromium -1 molybdenum components or piping.

VIII. Contacts with Other Facilities

A. EBR-II

Mr. W. Simmons at EBR-II was contacted to discuss the reason for installing 2 $\frac{1}{4}$ chromium -1 molybdenum piping in EBR-II's secondary system. He stated that only a limited amount of schedule 20, 2 $\frac{1}{4}$ chromium -1 molybdenum piping was installed in the headers leaving the steam generator. The 2 $\frac{1}{4}$

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chromium -1 molybdenum piping was installed in order to limit the amount of transition welds from $2\frac{1}{4}$ chromium -1 molybdenum to stainless steel. No economic analysis was made between $2\frac{1}{4}$ chromium -1 molybdenum and 304 stainless. The $2\frac{1}{4}$ chromium -1 molybdenum was used in the boiler to prevent chloride stress corrosion.

Mr. G. E. Deegan was telephoned to discuss the operating experience with $2\frac{1}{4}$ chromium -1 molybdenum in the secondary system. He stated that they had an initial problem of "rusty" 14-inch piping which caused plugging of cold traps. After the initial cleanup they have not experienced any problems with the $2\frac{1}{4}$ chromium -1 molybdenum.

Reference 25, quoted below, describes the initial cleanup of the $2\frac{1}{4}$ chromium -1% molybdenum piping.

"The primary system which has a low surface-to-volume ratio, is constructed almost entirely of austenitic stainless steel (Type 304). During the initial heatup of this system and subsequent operations, the plugging temperature (oxide content) remained at very low levels (below 250°F). This attests to the original cleanliness of the system and subsequent care in operation.

"The secondary system, which has a much greater surface-to-volume ratio, is constructed of about 20% stainless steel (Type 304) and the remainder of Croloy ($2\frac{1}{4}$ chromium -1% molybdenum ferritic steel). Unfortunately, this piping had been installed without the mill scale (magnetite) being completely removed. The system was estimated to contain 400 lb of this material which could react with the sodium to produce 370 lb of sodium oxide.

"In late September 1963 the secondary piping system was filled from the storage tank and heated to 575°F. This was the maximum temperature allowable based on the design operating pressure in the steam drum (1250 psi). The rate of rise in plugging temperature indicated the formation of 0.95 lb/hr of sodium oxide. Since this was greater than the removal capability of the cold trap, the plugging temperature was only allowed to rise to about 550°F and the system drained to the storage tank. The storage tank was then heated to 600°F and cold trapped until the plugging temperature approximated 250°F. The piping system was refilled and the cycle repeated a total of five times before the system plugging and temperature ceased increasing after filling and heating to 575°F.

"By cold trapping in batches, it was possible to keep a rather accurate account of the amount of sodium oxide removed. The initial cold trap plugged after it had a calculated 100 lb of sodium oxide removed. A temporary cold trap was then installed, and it is estimated that with it a total of 140 lb of sodium oxide was removed during the cleanup operation.

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"The balance of the magnetite and that which was reduced to iron is believed to be in the cold traps and in the form of a sludge on the bottom of the storage tank. When the system was heated, thermal expansion probably caused much of the brittle magnetite to flake off of the walls and be introduced into the coolant. An inspection of the filter in the line to the plugging meter showed the presence of considerable magnetite, and a magnet lowered to the bottom of the storage tank also indicated the presence of a quantity of magnetic material therein.

"Just prior to filling the secondary piping system, the hydrogen content of the argon cover gas was 50 ppm. After the first sodium fill and heatup, it increased to 1500 ppm. This hydrogen is believed to have come from moisture adsorbed on the mill scale. Purging with fresh argon reduced the concentration to less than 50 ppm, where it remained. During the yard piping work (tie to the intermediate heat exchanger) and pump repair work, the system became contaminated with air and moisture. After filling the system with sodium, the hydrogen content rose to about 200 ppm. This was reduced by purging with fresh argon to less than 50 ppm.

"Prior to the approach to power, the entire secondary system was evacuated to a pressure of 1/10 torr and filled with fresh argon. Since that time, the hydrogen-helium concentration has remained below 10 ppm."

B. Enrico Fermi Power Plant

R. H. Anderson of United Engineers and Construction was telephoned to discuss materials of construction of the Fermi Reactor. Mr. Anderson said that $2\frac{1}{4}$ chromium -1 molybdenum schedule 40 piping was used in the secondary cold leg at 520 F to 820 F. He did not believe any economic analysis was made comparing 304 stainless with chromium -1 molybdenum. $2\frac{1}{4}$ chromium -1 molybdenum tubing was used in the steam generator and he believed the piping was simply an extension of the tubing specifications.

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TABLE 1

Mechanical Properties of Steels 8,9,10,11,12

Properties	304 Stainless Steel			2-1/4 Chromium -1 Moly.			Carbon Steel (0.08 to 0.20%C)		
	1050°F	850°F	650°F	1050°F	850°F	650°F	1050°F	850°F	650°F
Linear Thermal Expansion $\alpha \Delta T$ 75° (in./in.)	0.0103	0.0078	0.0055	0.0078	0.0060	0.0041	-	.0060	0.0041
Conductivity $\frac{\text{Btu}}{\text{Hr} \times \text{ft}^2 \times \frac{^\circ\text{F}}{\text{in.}}}$	160	148	140	195	195	195	240	257	273
Tensile Strength (psi)	57,000	62,000	64,000	48,000	63,000	68,000	27,000	42,000	60,000
Yield Strength (psi)	18,000	21,000	26,000	27,000	34,000	37,000	13,000	20,000	26,000
Maximum Allowable Stress (psi)	8,000	10,000	11,500	5,300	14,400	15,000	(900°F) 5,000	7,800	15,000
Elongation Before Fracture (%)	36	37	40	40	22	22	51	41	33
Reduction of Area Before Fracture (%)	62	70	72	75	59	60	83	72	63
Modulus of Elasticity (10 ⁶ psi)	21	22	24	21	23	25	-	23.7	25.7
Charpy Impact Strength (ft-lb)	86	98	98	30	31	43	51	-	-
Creep Strength 1% in 100,000 hr (psi)	10,000	23,000	-	6,000	32,000	-	2,000	10,000	-
Stress for Rupture in 100,000 Hr (psi)	15,000	22,000	-	8,000	-	-	2,000	9,600	-

TABLE 2

Summary of Material Characteristics - Temperature Limitations

<u>Type of Steel</u>	<u>Relative Material Cost</u>	<u>Scale Formation Limiting Temp. F</u>	<u>Mechanical Strength⁽¹⁾ Limiting Temp. F</u>	<u>Graphiti- zation⁽²⁾ Limiting Temp. F</u>	<u>Carburization-⁽³⁾ Decarburiza- tion</u>	<u>Allowable Stress, 900 F, psi</u>
Carbon (ASTM 106)	1.00	1000	1000	775	Decarb.	5,000
1/2 Cr	N.A.	1050	N.A.	975	"	N.A.
1/2 Mo	1.45	1000	1050	875	"	12,500
1/2 Cr - 1/2 Mo	1.70	1050	1050	975	"	12,500
1 Cr - 1/2 Mo	1.77	1050	1075	-	"	13,100
2 1/4 Cr - 1 Mo	2.38	1050	1150	-	"	13,100
5 Cr - 1/2 Mo	2.39	1150	1075	-	Carburize	11,500
304 S.S.	9.52	1650	1250	-	"	9,400
316 S.S.	12.92	1050	1350	-	"	16,000

* N.A. - Not available.

- (1) - Based upon a 1 percent creep in 10,000 hrs at a stress level of 5,000 psi.
- (2) - Where temperature is not given, graphitization does not occur.
- (3) - Decarburization rate decreases with increasing chromium content.

TABLE 3

Piping Cost

Pipe Size	Feet	Carbon Steel (Schedule 40) Cost \$/Ft		2-1/4 Chrom.-1 Moly (Schedule 40) \$/Ft		304 Stainless Steel**			
						Schedule 10		Schedule 40	
1"	2000	0.2	\$ 400	1.3	\$ 2,600	1.5***	\$ 3,000	1.7	\$ 3,400
1½"	320	0.3	96	1.6	512	1.7	544	2.1	672
2"	3170	0.5	1,585	2.0	6,340	2.3	7,291	2.7	8,559
3"	530	1.0	530	3.8	2,014	4.0	2,120	7.1	3,763
4"	910	1.4	1,274	4.5	4,095	5.1	4,641	10.0	9,100
6"	730	2.1	1,533	9.1	6,643	7.5	5,475	18.0	13,140
14"	200	7.5	1,500	45.7	9,140	22.9	4,580	51.0	10,200
18"	1120	20	<u>22,400</u>	61(3/8"Wall)	<u>68,320</u>	41.0	<u>45,920</u>	88(3/8")	<u>98,500</u>
Totals		\$29,318		\$99,664		\$73,663*		\$145,034*	

* Note: This is the cost of a straight pipe. A review of material cost of the main heat transfer system indicates that the price of all straight pipe amounts to one-third the material cost, while two-thirds covers the cost of the fitting material, predominantly 90° elbows. (18)

** Includes 100% X-ray and partial data reports

*** Hot finish seamless tubes from 1" to 4"

TABLE 4

Tubing Cost for Air Dump Heat Exchanger

Type of Tube -14 Gage 0.085 Wall Thickness	Cost Per Ft of Bare Tube \$/Ft	Cost of Fin \$/Ft	Cost of Finning Tube \$/Ft	Total Cost \$/Ft	Tubing, Required Length (ft)	Total Material Cost (\$)	Total Labor and Fabrica- tion, Tubing Only
1) Carbon Steel Tube with Carbon Steel Fins	0.34	0.28	0.06	0.68	36,000	\$24,500	\$167,000
2) 2-1/4 Chrome-1 Mo-Tube with Carbon Steel Fins	0.50	0.28	.08	0.86	36,000	31,000	210,000
3) 304 Stainless Tube with Carbon Steel Fins	0.70	0.28	.10	1.08	37,400	40,400	274,000
4) 304 Stainless Tube with Stainless Steel Fins	0.70	0.63	.13	1.46	51,300	74,700	507,000

NOTES

1 VESSEL TO BE DESIGNED AND BUILT PER ASME UNIFORM PRESSURE VESSEL CODE, SECTION VIII, MEL CASE 18734, CUDF, CASE 18704 AND NATIONAL BOARD STAMPING REQUIRED

2 DESIGN PRESSURE 100PSIG AT 850F PNEUMATIC TEST PER CODE WITH CLEAN DRY AIR FREE AIR SCAP SUBBLE ALL PRESSURE CONTAINING WELDS

3 ESTIMATED WEIGHT 160 LBS EMPTY

4 ALL OPERATING

5 ALL PRESSURE CONTAINING WELDS 100% RADIOGRAPHED

6 UNIT SHALL BE HELDING LEAK TESTED AFTER ASSEMBLY PER AT SPEC NAHS CODE 05 BY PRESSURE METHOD

7 THIS SHALL BE WELDED ON ALL ALTERNATING SURFACES PROVIDING MINIMUM 1/8" DISTORTION TO THE FINISHED VESSEL AS AN ALTERNATE, FINS MAY BE TACK WELDED IN PLACE AND FURNACE BRAKED WITHIN 2400F MAXIMUM TEMPS ON APPROVED EQUAL BRACKET ALIGNED CENTERING FOR WELDING OR BRACKET OF FINS SHALL BE SATISFACTORY CONTINUOUS THERMAL RAMP BETWEEN STEEL AND FINS

8 1) WELD P/W SHALL BE TYPE 304 STAINLESS STEEL WIRE 2) BRACKET DESIGN AND DIMS 0.125" TO 0.1875" AND 0.061" OR APPROVED EQUAL

9 2) THERMOCOUPLE ASSEMBLY COMPLETE WITH WIRE SHALL BE THERMOCOUPLE MODEL 2077 OR APPROVED EQUAL

9 INTERIOR OF VESSEL AND ALL INTERIOR PARTS, SHALL BE CLEANED FREE OF ALL DETECTABLE DIRT DUST MILK SCALE, OIL GREASE FROM FINS AND ALL OTHER SURFACE CONTAMINANTS PRIOR TO FINAL ASSEMBLY, PROOFING CLEANING

10 CLEANING SHALL BE PERMITTED ON ALL SURFACES

11 CLEANING FOR APPROVAL VESSEL SHALL BE DRYED AND SEALED WITH AN INERT APPROPRIATE METHOD, DESIGN OR INSTRUCTIONS PRIOR TO SHIPMENT OR EXPOSURE TO AMBIENT CONTAMINATING AGENTS SHALL BE PERMITTED

10 FLAME CUTTING OF PARTS SHALL NOT BE PERMITTED

11 PARTS IN GENERAL, INCLUDING, BUT NOT LIMITED TO, FLAME CUTTING WILL BE PERMITTED IF CUT TO SIZE AND CAPERIFIED

5 FALS AS GROUND EGT AFTER CUTTING

11 BRACKET FINGS SHALL NOT BE USED WITHOUT WRITING PER MISSION OF AT

Q	-55	T/L ASSY	% AMT. USED FROM IN.
	-54		
	-49		
1	-50	SPLINE	5% 0.0 - 5% 0.66
1	-51	SLEEVE	5% 0.0 - 5% 0.00 5' 0.6
1	-52	RING	0% - 5% 1.5 5% 1.6
2	-53	ROD	1" DIA. 25 LG
	-54		
3	-55	LUB ASSY OF	
	-56	BASE PLATE	3% .1 - 3% .1
1	-57	SCU PORT PLATE	4 = 5% 5% 5%
3	-57	SCU NO SET SCR	1.2 0.3 4.5
	-48		
1	-38	NORRLE ASSY OF	
1	-39	BLIND FLANGE RING	1% 0.000 4" 300" 3
1	-40	GASKET TONAL TYP	1% 0.5
1	-41	PIPE NOZZLE (IN)	2" SCH 40 12.6 LG
1	-42	PIPE NOZZLE (OUT)	2" SCH 40 7 LG
	-43		
1	-34	GUIDE ASSY OF	
1	-35	GUIDE RING	1% DIA = 4.16
4	-36	GUIDE RIB	1% = 4" 2.8 66
	-37		
1	-19	MOWER COLD TRAP ASSY OF	
1	-20	UPPER PLATE	4 (STK) 12 DIA 12 LG
1	-21	LOWER PLATE	4 (STK) 12 DIA 12 LG
1	-22	BAFFLE	4 (STK) 12 DIA 12 LG
3	-23	BAFFLE	4 (STK) 12 DIA 12 LG
3	-24	ROD	1/2 DIA = 7.0 LG
6	23	HEX NUT	1/2 - 13
24	-24	SPACER PIPE	1/2 SCH 40 = 9.6 LG
1	-25	UPPER PIPE CAP	1/2 SCH 40 = 9.6 LG
1	28	LOWER PIPE CAP	1/2 SCH 40 = 9.6 LG
1	-30	WIRE MESH	1/2 DIA 10 LG 10 30
1	-31	PIPE NOZZLE	6" SCH 40 = 0.6
1	-31	FLANGE	1/2 DIA 4" 300" 3

1	- 9	COIL ASSY OF					
	- 10	PIPE	6 5/8" 40 - 8 9 EG		2150 LBS		
	- 11	PIPE	8 5/8" 40 - E EG		3150 LBS		
	- 12	180° ELBOW (L R)	MALE 7" 40 2 5/8" 40		4350 LBS		
1	- 13	PIPE COIL	2 5/8" 40 10 L		1800 LBS		
1	- 14	90° ELBOW (L R)	2 5/8" 40 10 2 5/8" 40		1800 LBS		
1	- 15	PIPE	1 5/8" 40 3 16		2000 LBS		
1	- 16	COLPIPE	MALE 2 5/8" 40 1/2" 5W		2000 LBS		
1	- 17	1/2" GROUND (B N)	2 5/8" 40		2150 LBS		
-	- 18						
		COIL TRAP ASSY OF					
1	- 3	PIPE CAP	20 5/8" 20		2150 LBS		
1	- 4	PIPE	20 5/8" 20 8 1/2 L		2150 LBS		
40	- 5	FINS	2 1/2" 40 6 5/8" 1/2		2000 LBS		
1	- 6	SHROUD	20 10" 16 6 5/8" 1/2		2000 LBS		
	- 7						
	- 8						
ITEM NO	QTY	PART NO.	DESCRIPTION	UNIT	WT	PRICE	TOTAL AMT

[illegible]

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BE CHANGED WITHOUT NOTICE