AECL-6980

ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

SUMMARY OF LOOPS IN THE CHALK RIVER NRX AND NRU REACTORS

Sommaire des boucles installées dans les réacteurs NRX et NRU de Chalk River

D.T. Nishimura

Chalk River Nuclear Laboratories

Laboratoires nucléaires de Chalk River

Chalk River, Ontario

December 1980 décembre

ATOMIC ENERGY OF CANADA LIMITED

SUMMARY OF LOOPS IN THE CHALK RIVER NRX AND NRU REACTORS

by

D.T. Nishimura

Operations Division
Chalk River Nuclear Laboratories
Chalk River, Ontario K0J 1J0

1980 December

AECL-6980

L'ENERGIE ATOMIQUE DU CANADA, LIMITEE

Sommaire des boucles installées dans les réacteurs NRX et NRU de Chalk River

par

D.T. Nishimura

Résumé

Les paramètres conceptuels et opérationnels des boucles à eau légère, à haute pression et à haute température installées dans les réacteurs NRX et NRU sont présentés dans le but d'aider les expérimentateurs à passer en revue ces installations pour leurs expériences. On présente également les données relatives à la conception et à l'exploitation des réacteurs NRX et NRU susceptibles d'intéresser les expérimentateurs.

Laboratoires nucléaires de Chalk River
Chalk River, Ontario KOJ 1JO

Décembre 1980

AECL-6980

ATOMIC ENERGY OF CANADA LIMITED

Summary of Loops in the Chalk River NRX and NRU Reactors

by

D.T. Nishimura

Abstract

The design and operating parameters of the high pressure, high temperature light water loops in the NRX and NRU reactors are presented to assist experimenters reviewing these facilities for their experiments. The NRX and NRU reactor design and operating data of interest to the experimenters are also presented.

Chalk River Nuclear Laboratories
Chalk River, Ontario K0J 1J0
1980 December

AECL-6980

CONTENTS

1. INTRODUCTION

The concept of high pressure, high temperature light water loops with an in-reactor test section for fuel development, water chemistry, materials testing, etc. was introduced to the Chalk River Nuclear Laboratories by the United States Atomic Energy Commission and the Westinghouse Atomic Power Division (WAPD) in 1950. The first high pressure, high temperature water loop started operating in the central thimble of the NRX reactor in 1951 and removed in 1952. This was followed by the installation of the WAPD CR-IV and CR-V loops starting in 1954.

An in-reactor loop is a closed circuit hydraulic system that provides a coolant and radiation environment similar to that in a nuclear power reactor. It consists of pump(s) to circulate the coolant, heaters to heat the coolant, cooler(s) to remove the excess heat, pressurizer to pressurize the coolant, test section(s) for the test assembly, piping to interconnect the components, and the electrical and process control system to power and control the process.

In the following sections, the NRX and NRU reactors and their experimental loops are briefly described with figures and tabulation of design and operating parameters pertinent to anyone wishing to determine the suitability of these facilities for their experiments. A few of the more important loop parameters for each loop are tabulated in Table 1.1 to facilitate comparing these loops.

It is worth noting that design parameters are not necessarily the operating parameters. The operating pressure is always about 15% lower than design to provide the headroom required to set the overpressure protection. Cooler heat removal capacity is given for nominal operating conditions; for extreme operating conditions the heat removal capacity may be much lower. Main loop flow may be higher or lower than design depending on the test assembly pressure drop. These are details which become a concern when discussing specific experiments.

TABLE 1.1

GENERAL LOOP DATA

Loop(1)	Construction Material	Coolant or Water Op. Mode	Design Press. MPa	Design Temp. °C	Design Flow kg/s	Design Heat Rejection kW	Outlet Steam Quality % by wt.	Test Section I.D. mm	Thermal Flux(2) 10^{14} $n.cm^{-2}.s^{-1}$	Cosine Flux Length mm
X-1	SS	PW,B	17.3	330	1.14	300	~10	38	0.8	3030
X-2	CS, SS	PW	13.9	336	1.1	200	0	38	0.8	3030
X-3	SS	PW,B	17.3	330	0.77(3)	600	~10	38	0.8	3030
X-4	SS	PW,B,TPI,S	15.3	335	1.0	250	100	38	0.8	3030
X-5	SS	PW	17.3	330	1.1	550	0	38	0.8	3030
X-6	CS,SS	PW,B	18.6	359	1.14	300	20	38	0.8	3030
X-7	CS	organic	2.9	430	3.03	220	-	38	(4)	
U-1	SS	PW,B	13.9	354	17(5)	12000	100	103.9	3.0	3640
U-2	SS	PW,B	13.9	354	20(5)	8000	~10	103.9	3.0	3640
U-3	CS	organic	4.2	430	36	4500	-	103.9	(4)	
U-5	CS	PW	17.3	354	0.75(6)	140	0	63.25(7)	0.2(8)	3640

(1) X-loops in NRX, U-loops in NRU
(2) Axial maximum
(3) Through each of two parallel test sections
(4) Decommissioned
(5) Through each of two test sections in series
(6) 0.125 $kg.s^{-1}$ for each of 6 test sections in parallel
(7) Maximum fast neutron rod inside diameter
(8) Nominal fast neutron fast flux

PW pressurized water
B boiling
TPI two-phase at inlet
S steam
SS stainless steel
CS carbon steel

2. NRX REACTOR

2.1 Reactor Description

NRX is a heavy-water moderated, light-water cooled reactor with a graphite neutron reflector. The core of the reactor is contained in a cylindrical aluminum vessel known as a calandria. This vessel contains 199 vertical aluminum calandria tubes, some of different diameters, as shown on Figs. 2.1.2 to 2.1.6. Design and operating parameters of interest are tabulated on Table 2.1.1. Loop sites are shown on the core lattice diagram, Fig. 1.1.1.

The major experimental facilities in NRX are the in-reactor loops. Some low pressure low temperature experiments have been assembled into a flow tube designed to utilize the normal reactor cooling system. Metallurgical tests, requiring fast neutron flux, are installed in special fast neutron rods.

The NRX reactor power is controlled by varying the moderator level. Until equilibrium conditions are established, both the flux centerline and the peak flux change. To prevent over rating experimental fuels during this transient period, the reactor may be operated below its nominal power until equilibrium conditions are reached. The reactor operating power for any given operating cycle is determined by the requirement to maintain a nominal neutron flux at the loop sites. The reactor operating power may, therefore, vary slightly from one operating cycle to the next.

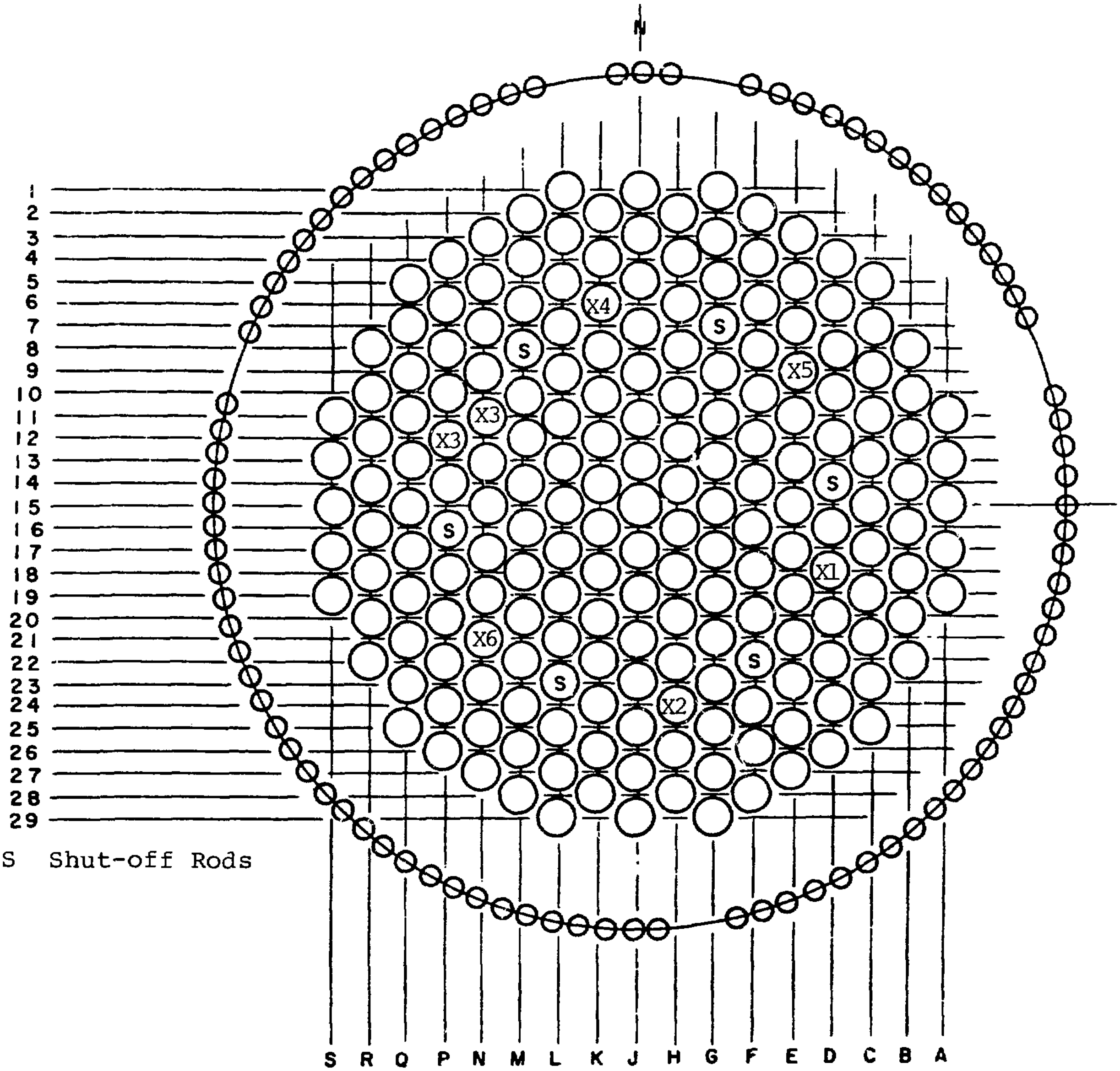
The neutron flux for a critical test may be increased or decreased by moving the test section into a lattice site located towards or away from the reactor center. The siting of a standard test section with a 38 mm pressure tube is not limited to designated loop sites but can be installed in any site suitable for driver fuels. However, reactor physics requirements, piping interference, etc. limits the sites available for such a move.

TABLE 2.1.1

NRX Reactor

Reactor Power - present nominal		25 MW[1]
Moderator		heavy water
Coolant		light water
Driver Fuel Orientation		vertical
Calandria (reactor vessel)		
Internal Diameter		2,667 mm (8 ft. 9 in.)
Depth		3,200 mm (10 ft. 6 in.)
Material		aluminum
Tubes		188 - 57.15 mm (2¼ in.) I.D.
		3 - 58.74 mm (2-5/16 in.) I.D.
		7 - 88.9 mm (3½ in.) I.D.
		1 -146.05 mm (5-3/4 in.) I.D.
Lattice Spacing	hexagonal	173.0375 mm (6-13/16in.) center
Driver Fuel		
Material		U-Al alloy
Sheath		aluminum
Fuel Length	MK. I	2438 mm (8 ft.)
	MK.IV	2743 mm (9 ft.)
Core Flux	in empty hole near center	
Average Thermal		7.6×10^{13} $n.cm^{-2}.s^{-1}$
Maximum Thermal		1.2×10^{14} $n.cm^{-2}.s^{-1}$
Average Fast		2.5×10^{12} $n.cm^{-2}.s^{-1}$
Maximum Fast		4.0×10^{12} $n.cm^{-2}.s^{-1}$
Cosine Flux Length		3030 mm nominal
Control	by varying moderator level	
Minimum Moderator Level for Startup		2400 mm
Equilibrium Moderator Level		~2900 mm
Number of Shut-off Rods		6
Number of Adjuster Rods		4
Operating Cycle	6 weeks operation with about 30 hours poison shutdown at mid-cycle for changing driver fuel and experiments. A 1 week shutdown every 6 weeks for maintenance and change of driver fuels and experiments.	

(1) Reactor operating power is set as required to maintain a nominal flux at the loop sites. The power may go as high as 35 MW.



S Shut-off Rods

FIGURE 2.1.1

NRX REACTOR LATTICE DIAGRAM

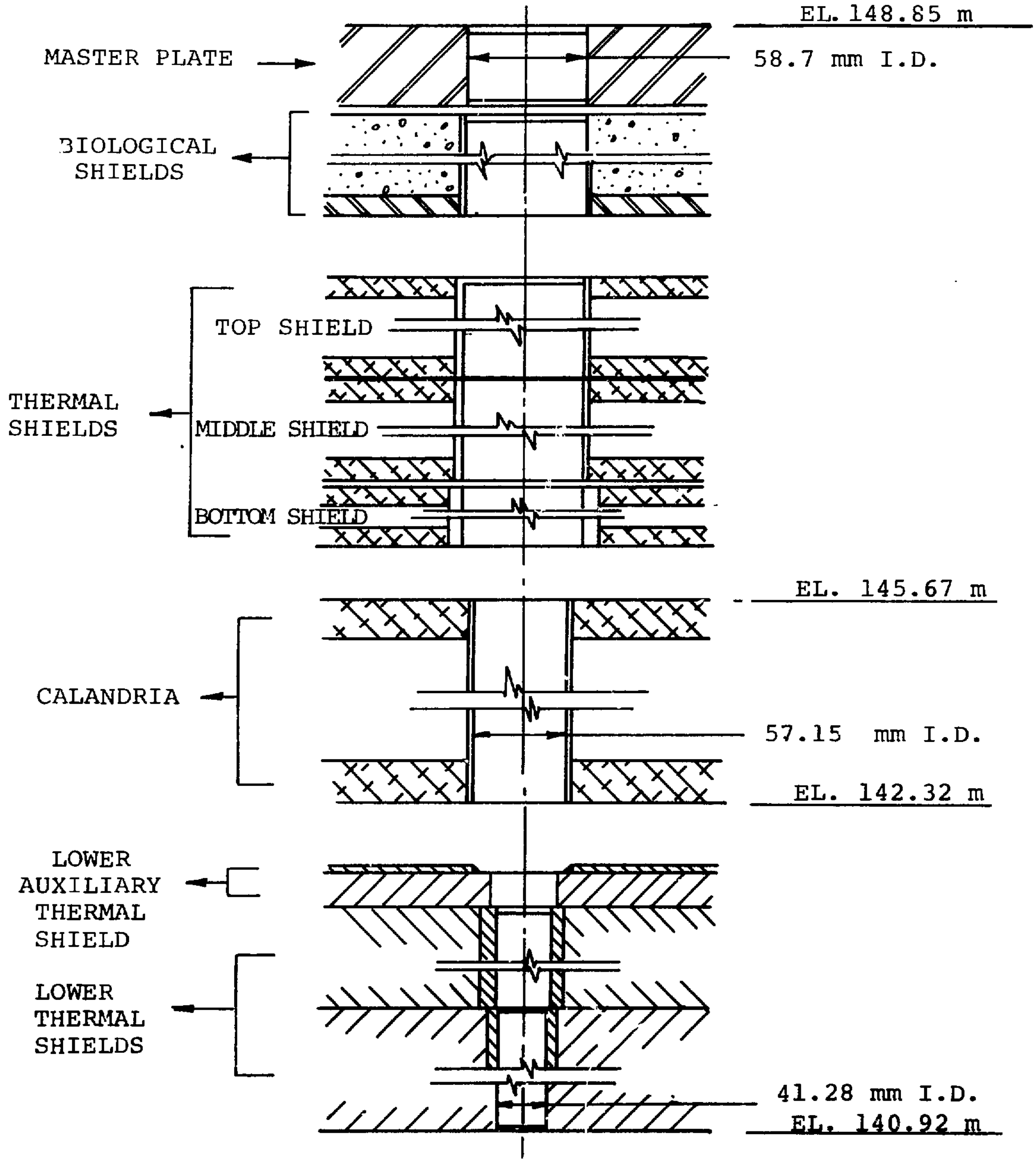


FIGURE 2.1.2

DRIVER FUEL SITE

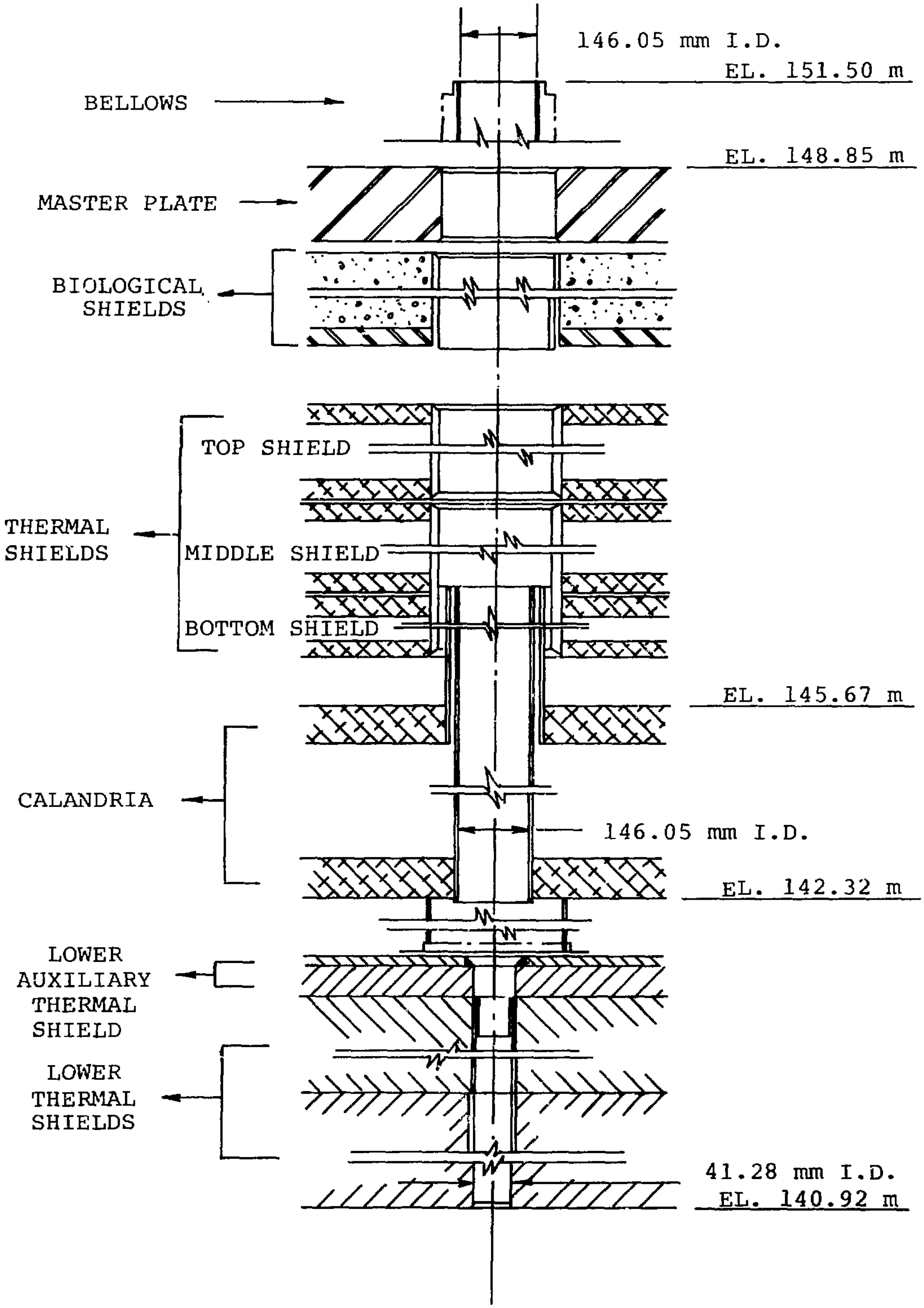
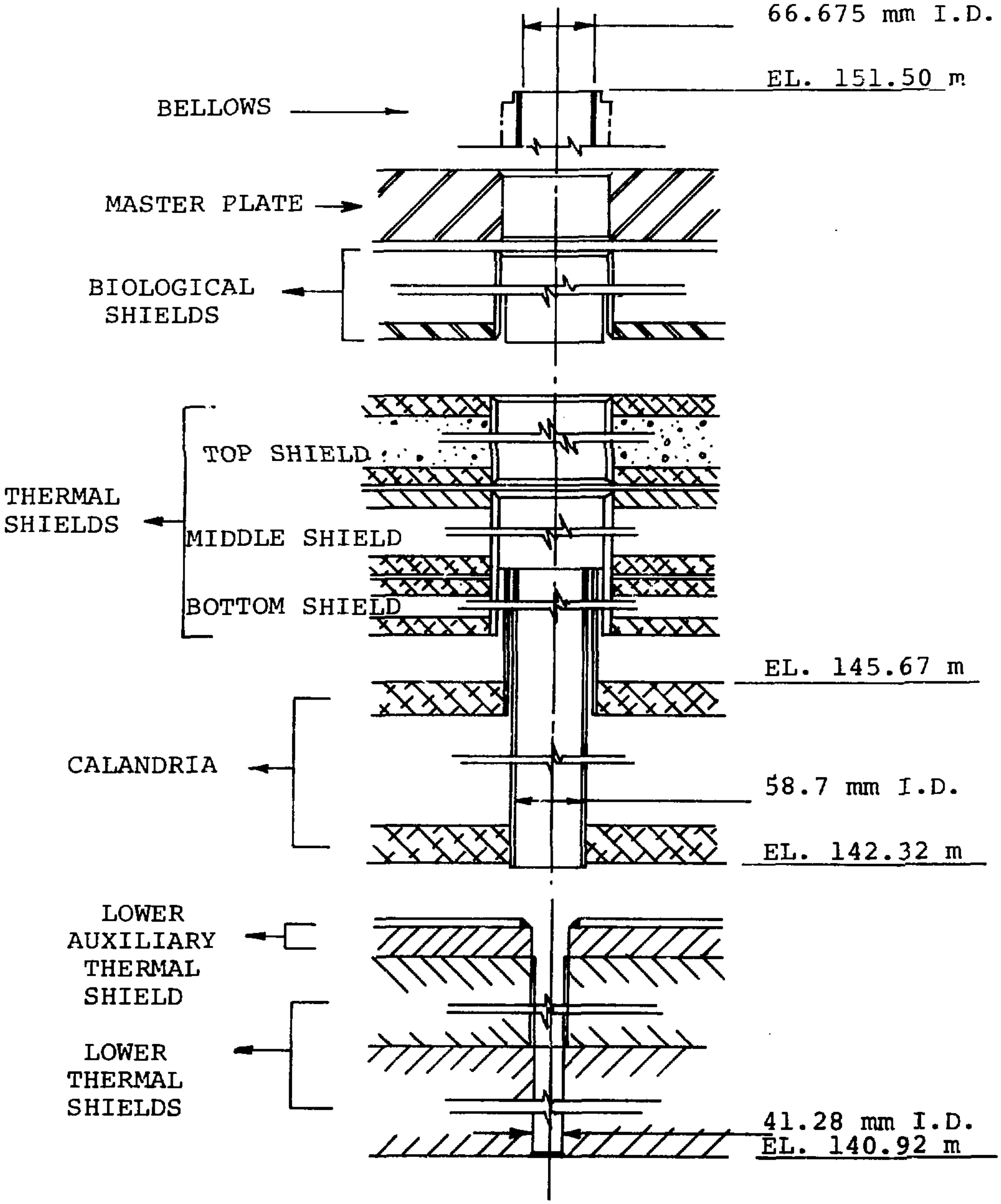


FIGURE 2.1.3

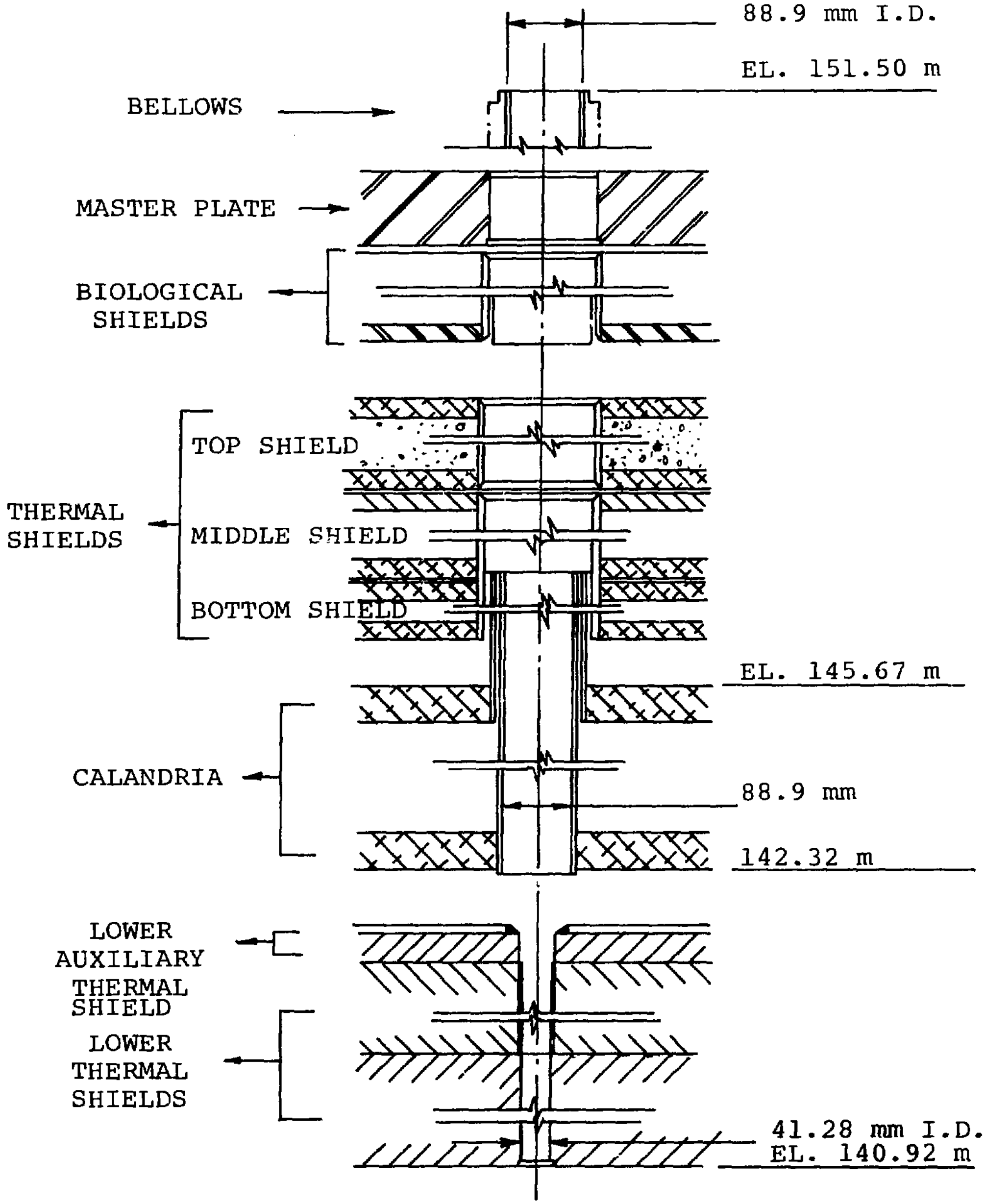
CENTRAL HOLE STRUCTURE



REACTOR POSITION H-24, E-9, Q-13

FIGURE 2.1.4

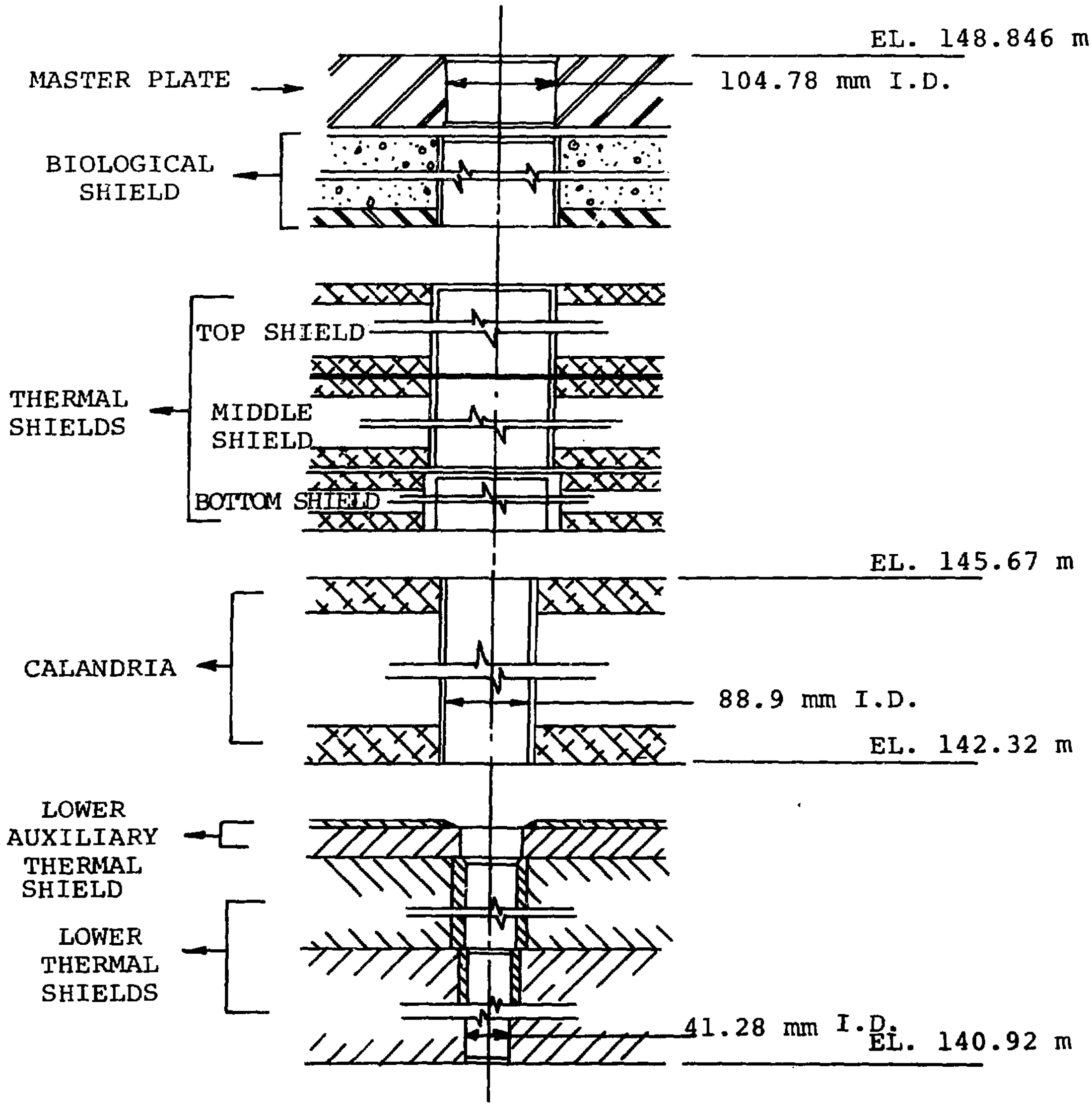
SPECIAL LOOP POSITIONS



REACTOR POSITION K-6, N-21, D-18

FIGURE 2.1.5

SPECIAL LOOP POSITIONS



REACTOR POSITION G-11, G-19, L-11, L-19

FIGURE 2.1.6

SPECIAL ENLARGED POSITIONS

2.2 LOOPS

The six NRX loops operate with completely interchangeable test sections with 38 mm I.D. pressure tubes of the design shown on Fig. 2.2.1, therefore, experimental assemblies and special in-core equipment are interchangeable from loop to loop. A larger diameter assembly could be irradiated by making minor modifications to the X-5 loop and re-installing into the central thimble an 82.5 mm I.D. pressure tube with its 62 mm I.D. flow tube.

A fuel moving machine for the 38 mm pressure tube was designed and operated in both the X-2 and X-4 loops. At present a ^{3}He fuel power cycling system is operating on the X-6 loop which provides about a 50% change in flux over a length of 67 cm.

A common data logger records both the pertinent NRX and NRU reactor data and the data from the loops in these reactors on magnetic tape for future retrieval. The data logger also assists in setting up and monitoring the various experiments.

An organic loop (X-7) was operated in the NRX reactor until 1972 when the program was terminated. The loop was then decommissioned but left as intact as possible to facilitate recommissioning when required.

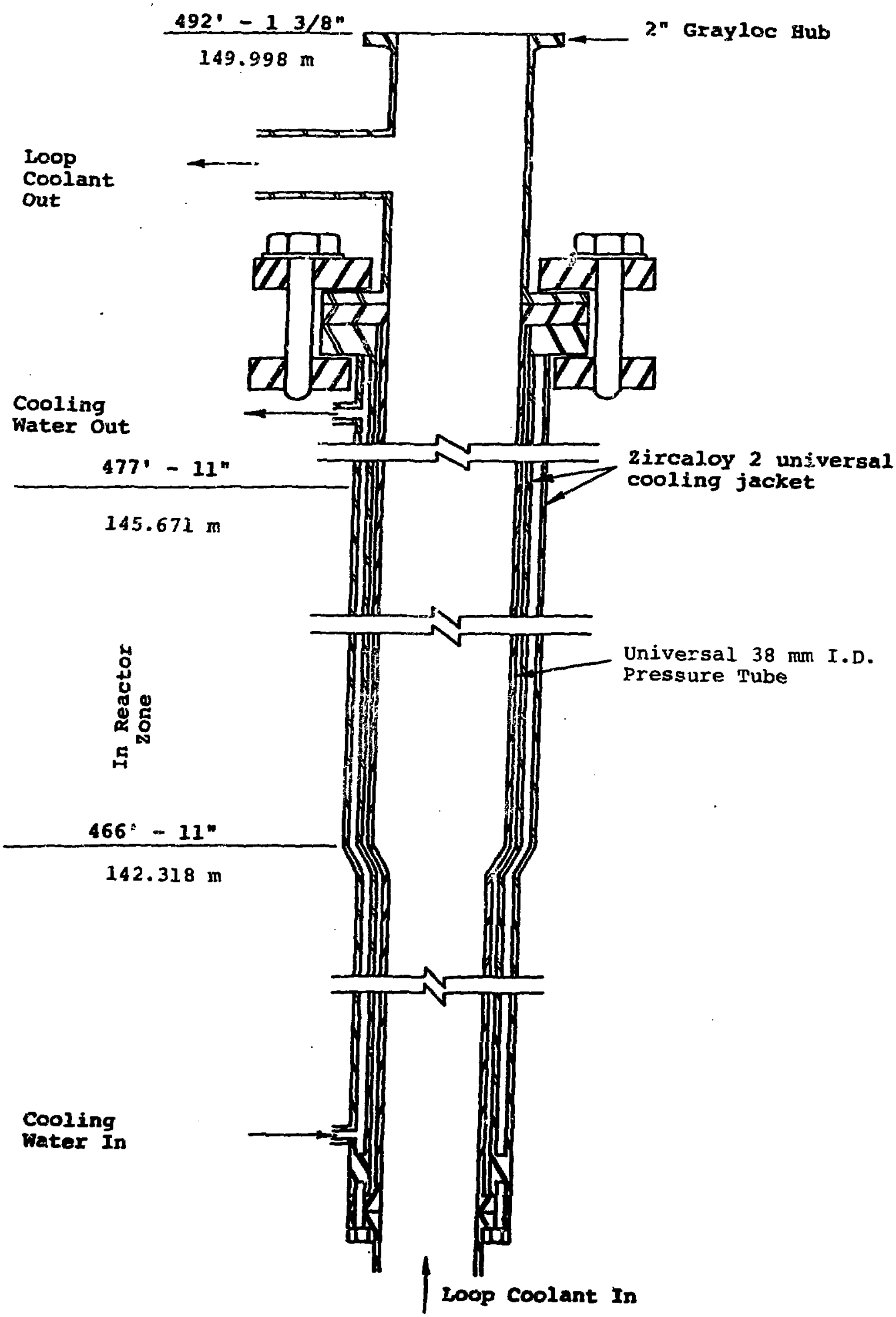


FIGURE 2.2.1

X-LOOP TEST SECTION

2.2.1 X-1 Loop

The X-1 loop is one of the Westinghouse Atomic Power Division CR-IV loops installed between 1954 and 1957. The last major modification was made in 1964 when both the main flow and the heat rejection capacities were increased.

This loop is a simple pressurized water facility, as shown on Fig. 2.2.1.1. It has sufficient pump head and pressurizer volume capacity to accommodate boiling tests with very limited outlet steam qualities. Summarized on Table 2.2.1.1 are the pertinent design and operating parameters.

Some of the past programs in this loop included fuel development, pressure tube development, minor fuel sheath defect tests, in-reactor corrosion behaviour of various materials, activity transport, water chemistry and irradiation of metallurgical samples.

TABLE 2.2.1.1

X-1 LOOP

Loop Type	Pressurized water	
Reactor	NRX	
Reactor Lattice Site(s)	D18 upflow	
Nominal Thermal Flux(1)	8×10^{13} $n.cm^{-2}.s^{-1}$	
Cosine Flux Length	303 cm	(119.3 in.)
Design:		
Pressure	17.3 MPa	(2,500 lb/in^2 gauge)
Flow	1.14 kg/s	(9,000 lb/h)
Temperature	343 °C	(650 °F)
Heater (loop)(2)	36 kW	
Boiler	N/A kW	
Heat Removal	300 kW	
Surge Tank Volume	0.095 m^3	(3.36 ft^3)
Pump Head(3)	170.7 m	(560 ft)
Construction Material	stainless steel	
Coolant		
Operating Volume	0.095 m^3	(3.36 ft^3)
Circulating Volume	0.063 m^3	(2.23 ft^3)
Total Volume	0.158 m^3	(5.58 ft^3)
Chemistry (normal)	pH 10(LiOH), 10-30 cm^3/kg H_2	
Purification:		
Flow	0.01 kg/s	(79 lb/h)
Ion-Exchange I.D.	3.175 cm	(1.25 in.)
Resin Volume	600 cm^3	(0.021 ft^3)
Monitors:		
Gamma	inlet of purification circuit	
Delayed Neutron	main loop	
γ - Spectrometer	none	
Test Section:		
Pressure Tube		
Material	cold-worked Zr-2½ wt.%Nb, other Zr alloys	
Length	9.41 m	(31 ft.)
Internal Diameter	38 mm	(1.5 in.)
Flow Tube	can be installed to decrease internal diameter.	
Out-Reactor Test Section	none	

(1) Axial peak flux at the cell boundary.
(2) Heaters for heating the coolant in the pressurized water mode - excludes heaters in the surge tank, boilers, etc.
(3) Head in metre (feet) of flowing fluid.

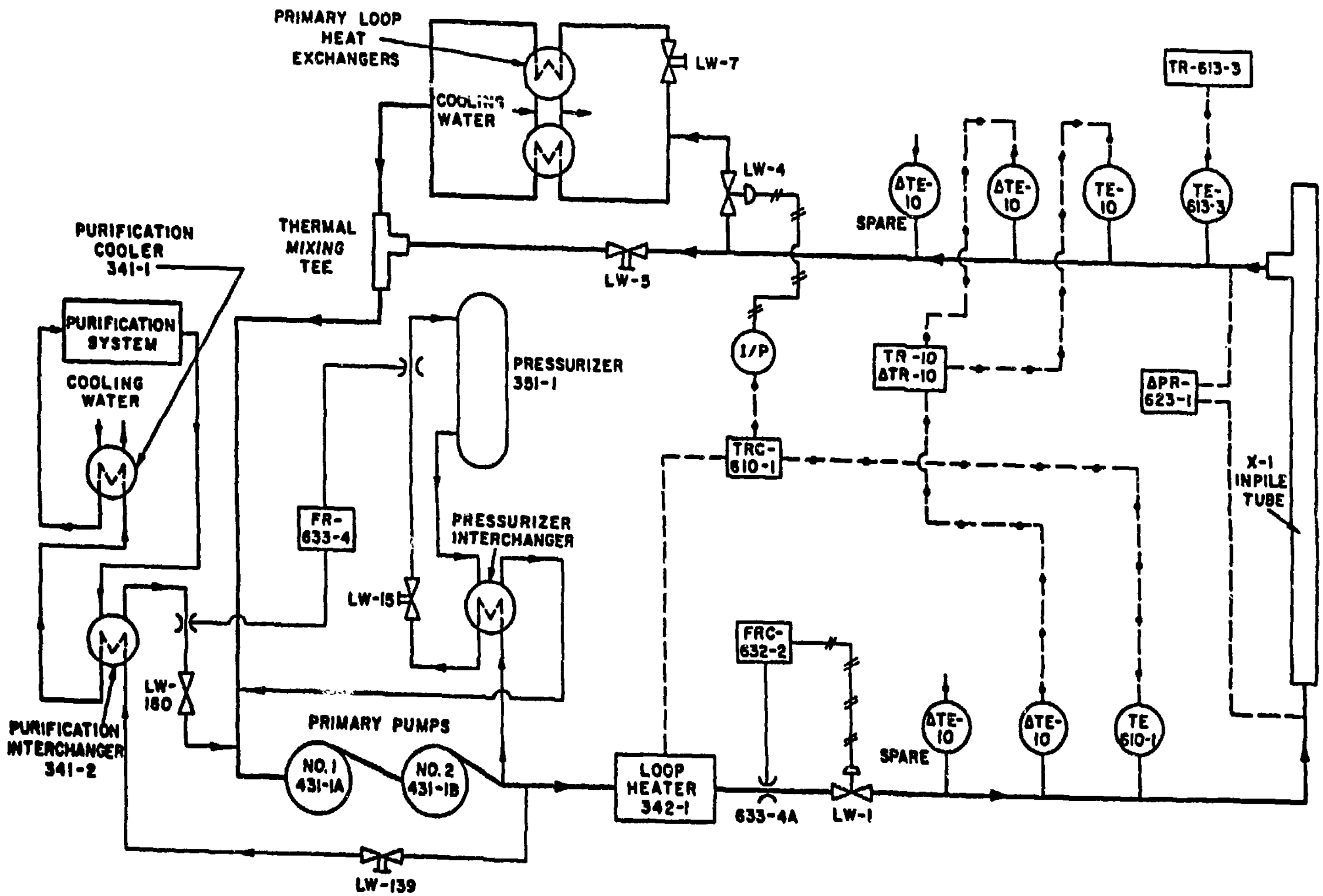


FIGURE 2.2.1.1

X-1 LOOP SIMPLIFIED FLOWSHEET

2.2.2 X-2 Loop

The X-2 Loop, although originally a WAPD CR-IV loop, was completely redesigned and rebuilt by 1977 as an extended fuel defect and safety related studies loop. As shown on Fig. 2.2.2.1, full flow filters were installed at the test section outlet to trap fuel particles released from failed fuels. Special valves and piping around the test sections were installed for safety related (LOCA) tests. Extensive on-line gamma spectrometry equipment was installed to monitor sections of main loop piping as well as sidestream tubing of different materials to study fuel failure modes and failure propagation, fission product release, fission product deposition on different materials, etc. An improved ventilation system was installed to trap radioiodines and particulates to minimize radioactive releases to the environment.

Table 2.2.2.1 summarizes the pertinent X-2 design and operating parameters.

TABLE 2.2.2.1

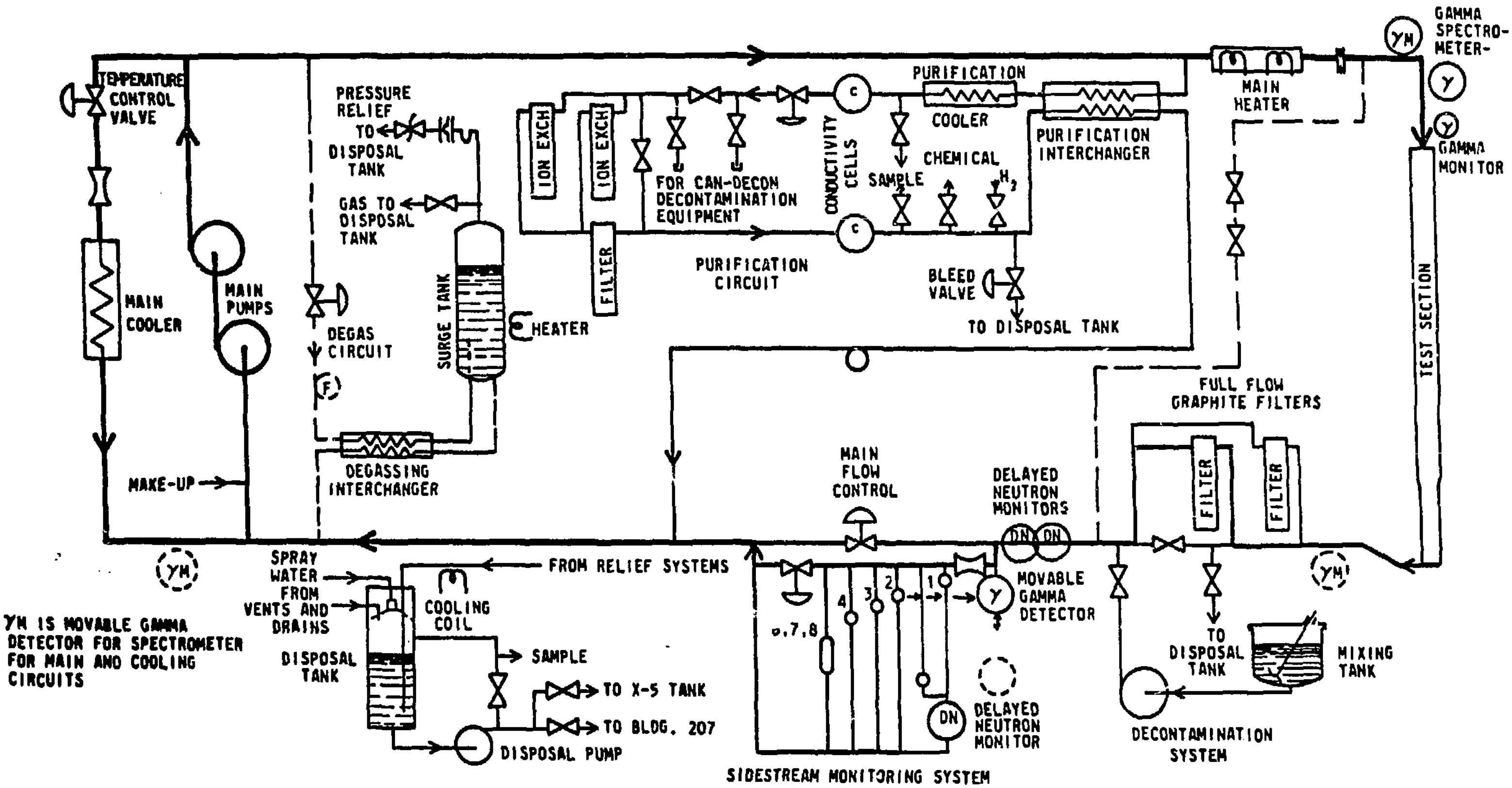
X-2 LOOP

Loop Type	Extended defect and LOCA, pressurized water	
Reactor	NRX	
Reactor Lattice Site(s)	H24 downflow	
Nominal Thermal Flux (1)	8×10^{13} $n.cm^{-2}.s^{-1}$	
Cosine Flux Length	303 cm	(119.3 in.)
Design:		
Pressure	13.9 MPa	(2,000 lb/in^2 gauge)
Flow	1.1 kg/s	(8,700 lb/h)
Temperature	336 °C	(637 °F)
Heater (loop) (2)	112 kW	
Boiler	N/A kW	
Heat Removal	200 kW	
Surge Tank Volume	0.057 m^3	(2.01 ft^3)
Pump Head (3)	170.7 m	(560 ft)
Construction Material	stainless and carbon steel	
Coolant		
Operating Volume	0.173 m^3	(6.11 ft^3)
Circulating Volume	0.146 m^3	(5.16 ft^3)
Total Volume	0.203 m^3	(7.17 ft^3)
Chemistry (normal)	pH 10(LiOH), 5-25 cm^3/kg H_2	
Purification:		
Flow	0.063 kg/s	(500 lb/h)
Ion-Exchange I.D.	7.8 cm	(3.07 in.)
Resin Volume	4200 cm^3	(0.148 ft^3)
Monitors:		
Gamma	Main pipe before the test section inlet	
Delayed Neutron	After full-flow filters	
γ - Spectrometer	See text	
Test Section:		
Pressure Tube		
Material	cold-worked Zr-2½ wt.% Nb, other Zr alloys	
Length	9.44 m	(31 ft.)
Internal Diameter	38 mm	(1.5 in.)
Flow Tube	can be installed to decrease internal diameter	
Out-Reactor Test Section	none	

(1) Axial peak flux at the cell boundary.
(2) Heaters for heating the coolant in the pressurized water mode - excludes heaters in the surge tank, boilers, etc.
(3) Head in metre (feet) of flowing fluid.

FIGURE 2.2.2.1

X-2 LOOP SIMPLIFIED FLOWSHEET



2.2.3 X-3 Loop

The X-3 loop is one of the original WAPD CR-IV pressurized water loop. In 1964 the flow and heat rejection capacity was uprated. Recently the loop was modified to operate with two parallel in-reactor test sections as shown on Fig. 2.2.3.1. Tabulated on Table 2.2.3.1 are the pertinent design and operating data for this loop.

At present this loop is dedicated to the Westinghouse Bettis fuel program.

TABLE 2.2.3.1

X-3 LOOP

Loop Type	pressurized water
Reactor	NRX
Reactor Lattice Site(s)	N11, P12 upflow on both
Nominal Thermal Flux(1)	8×10^{13} $n.cm^{-2}.s^{-1}$
Cosine Flux Length	303 cm (119.3 in.)
Design:	
Pressure	17.3 MPa (2,500 lb/in^2 gauge)
Flow	0.77 kg/s (6,100 lb/h)
Temperature	343 °C (650 °F)
Heater (loop)(2)	92 kW
Boiler	N/A kW
Heat Removal	600 kW
Surge Tank Volume	0.12 m^3 (4.24 ft^3)
Pump Head(3)	256 m (840 ft)
Construction Material	stainless steel
Coolant	
Operating Volume	0.170 m^3 (6.0 ft^3)
Circulating Volume	0.130 m^3 (4.59 ft^3)
Total Volume	0.250 m^3 (8.81 ft^3)
Chemistry (normal)	pH 10(NH_4OH), 40-70 cm^3/kg H_2
Purification:	
Flow	0.01 kg/s (79 lb/h)
Ion-Exchange I.D.	3.175 cm (1.25 in.)
Resin Volume	600 cm^3 (0.021 ft^3)
Monitors:	
Gamma	inlet to purification
Delayed Neutron	none
γ - Spectrometer	none
Test Section:	
Pressure Tube	
Material	cold-worked Zr-2½ wt.% Nb, other Zr alloys
Length	9.44 m (31 ft.)
Internal Diameter	38 mm (1.5 in.)
Flow Tube	installed to decrease internal diameter in both test sections
Out-Reactor Test Section	none

(1) Axial peak flux at the cell boundary
(2) Heaters for heating the coolant in the pressurized water mode - excludes heaters in the surge tank, boilers, etc.
(3) Head in metre (feet) of flowing fluid.

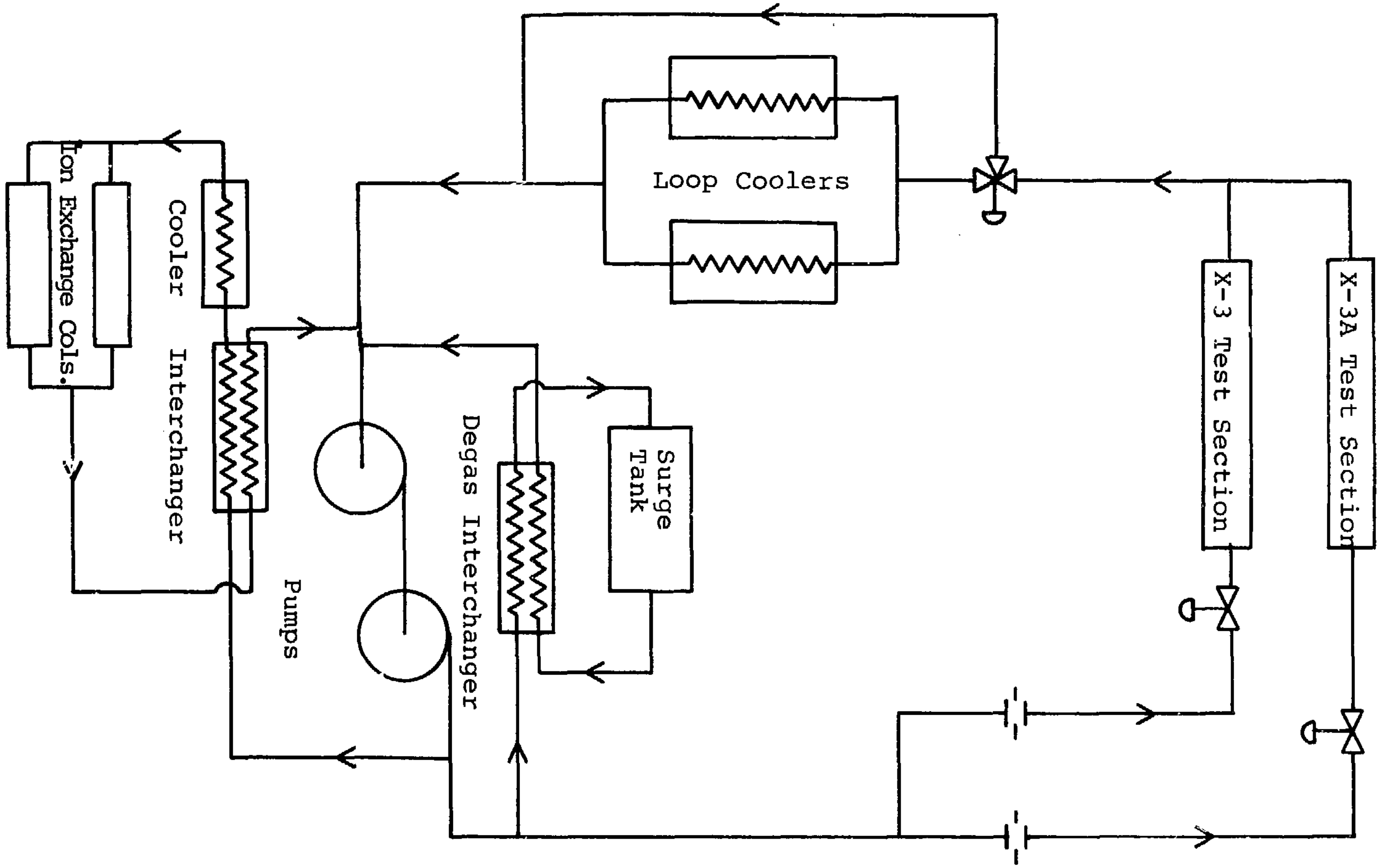


FIGURE 2.2.3.1

X-3 LOOP SIMPLIFIED FLOWSHEET

2.2.4 X-4 Loop

The original X-4 loop was a carbon steel pressurized water loop designed and built by the English Electric Company Ltd. and installed in 1957. It was modified in 1960 for superheated steam tests and further modified as a multi-mode (pressurized water, boiling, steam-water inlet, steam) water loop in 1962. In 1966 the loop was uprated to extend the operating range to that tabulated on Table 2.2.4.1. New and replacement components of stainless steel were installed during each modification so that the present loop has very little carbon steel surfaces remaining.

This loop, shown on Fig. 2.2.4.1, does not require the operation of the boiler in the pressurized water and boiling mode; therefore, volatile chemistry control is not required in these modes.

Some of the past programs in this loop included: fuel irradiation in pressurized water, boiling water, steam-water inlet, and steam inlet modes, critical heat flux, corrosion in- and out-reactor, coolant chemistry, fuel moving, metallurgy irradiations, pressure tube development,LOCA instrument development, and activity transport.

TABLE 2.2.4.1

X-4 LOOP

Loop Type	pressurized water, boiling, two-phase inlet, steam
Reactor	NRX
Reactor Lattice Site(s)	K6 upflow
Nominal Thermal Flux[1]	8 x 10^{13} $n.cm^{-2}.s^{-1}$
Cosine Flux Length	303 cm (119.3 in.)
Design:	
Pressure	15.3 MPa (2,200 lb/in^2 gauge)
Flow	1 kg/s (7,920 lb/h)
Temperature	335 °C (635 °F)
Heater (loop)[2]	100 kW
Boiler	250 kW
Heat Removal	250 kW
Surge Tank Volume	0.419 m^3 (14.8 ft^3)
Pump Head[3]	310.9 m (1020 ft)
Construction Material	stainless steel
Coolant	
Operating Volume	0.655 m^3 (23.1 ft^3)
Circulating Volume	0.270 m^3 (9.5 ft^3)
Total Volume	0.850 m^3 (30.0 ft^3)
Chemistry (normal)	pH 10(NH_4OH), 1-5 cm^3/kg H_2
Purification:	
Flow	0.019 kg/s (150 lb/h)
Ion-Exchange I.D.	5.7 cm (2.25 in.)
Resin Volume	1,600 cm^3 (0.056 ft^3)
Monitors:	
Gamma	main loop spray water circuit
Delayed Neutron	after loop pumps
γ - Spectrometer	none
Test Section:	
Pressure Tube	
Material	cold-worked Zr-2½ wt.% Nb, other Zr alloys
Length	9.44 m (31 ft.)
Internal Diameter	38 mm (1.5 in.)
Flow Tube	can be installed to reduce internal diameter

Out-Reactor Test Section

Location	Length cm	Length in.	Internal Diameter cm	Internal Diameter in.
After Superheater	221	87	3.22	1.27
After Pump	221	87	3.27	1.29
Separated Steam	147	58	3.27	1.29
After Test Section	226	89	2.29	0.90
Across Pump	209	82	2.31	0.91

(1) Axial peak flux at the cell boundary.
(2) Heaters for heating the coolant in the pressurized water mode - excludes heaters in the surge tank, boilers, etc.
(3) Head in metre (feet) of flowing fluid.
(4) Pressurized water mode only, in all other modes the circulating volume is the operating volume.

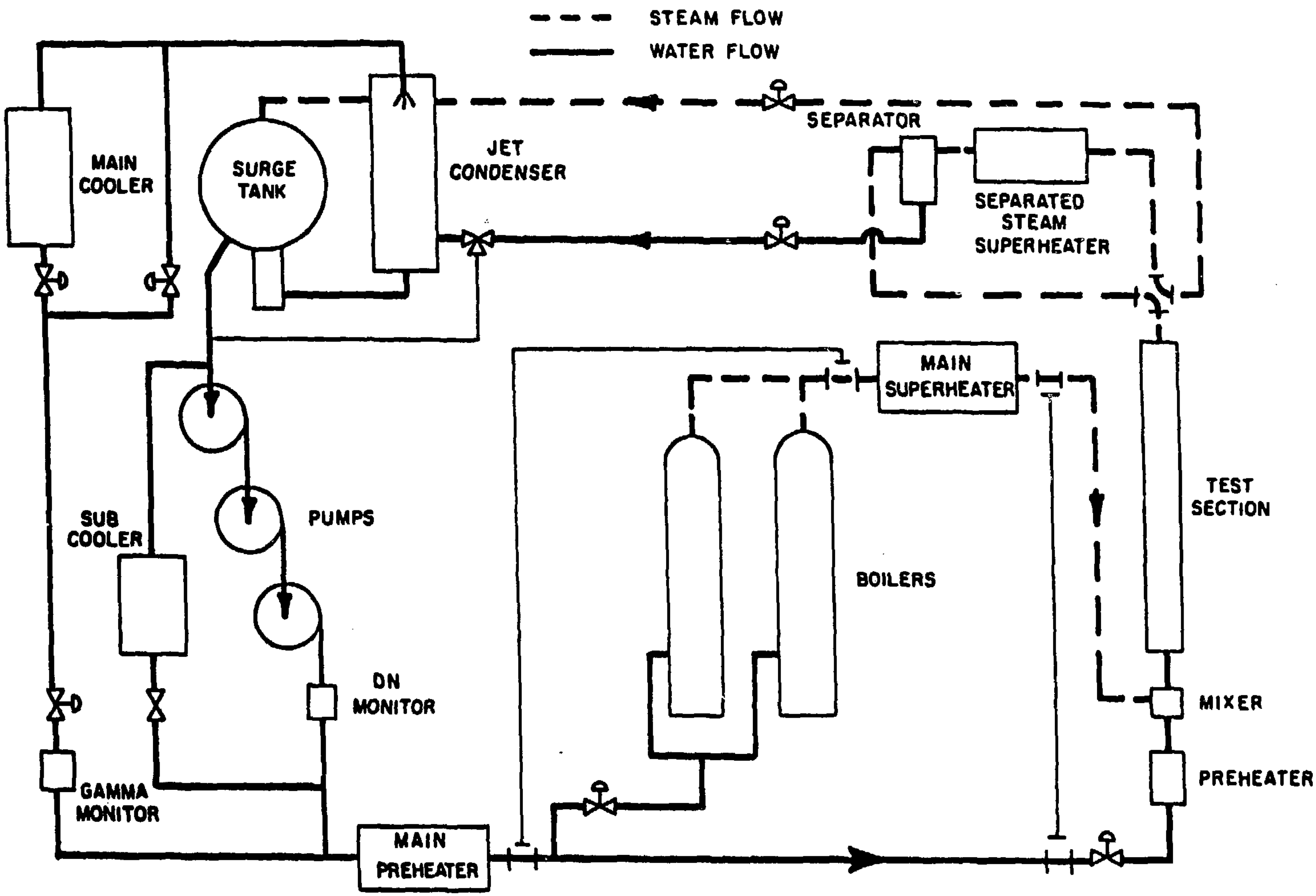


FIGURE 2.2.4.1

X-4 LOOP SIMPLIFIED FLOWSHEET

2.2.5 X-5 Loop

The X-5 pressurized water loop is the largest loop in the NRX reactor. It was designed and fabricated for Westinghouse Atomic Power Division as the CR-V loop and installed in 1955. Until 1979 a flow of about 4.8 kg/s was circulated through a re-entrant test section with a 62 mm internal diameter flow tube. Recent program changes were such that the smaller through-flow test sections were found more useful than the large re-entrant test section. Minor modifications to the X-5 loop were therefore made and it was returned to service with a test section containing a 38 mm pressure tube. The loop flowsheet is shown on Fig. 2.2.5.1 and a tabulation of the design parameters and the present capabilities are given in Table 2.2.5.1.

Some of the past programs in this loop included fuel development, in- and out-reactor corrosion, minor fuel sheath defect tests, activity transport, water chemistry and metallurgy irradiations.

TABLE 2.2.5.1

X-5 LOOP

Loop Type	pressurized water
Reactor	NRX
Reactor Lattice Site(s)	E-9 upflow
Nominal Thermal Flux(1)	8×10^{13} $n.cm^{-2}.s^{-1}$
Cosine Flux Length	303 cm (119.3 in.)
Design:	
Pressure	17.3 MPa (2,500 lb/in^2 gauge)
Flow	1 kg/s (7,920 lb/h)
Temperature	330 ^{o}C (625 ^{o}F)
Heater (loop)(2)	50 kW
Boiler	N/A kW
Heat Removal	550 kW
Surge Tank Volume	0.129 m^3 (4.55 ft^3)
Pump Head(3)	207 m (680 ft)
Construction Material	stainless steel
Coolant	
Operating Volume	0.32 m^3 (11.3 ft^3)
Circulating Volume	0.25 m^3 (8.8 ft^3)
Total Volume	0.38 m^3 (13.4 ft^3)
Chemistry (normal)	pH 10(LiOH), 5-15 cm^3/kg H_2
Purification:	
Flow	0.03 kg/s (230 lb/h)
Ion-Exchange I.D.	7.8 cm (3.07 in.)
Resin Volume	4,200 cm^3 (0.148 ft^3)

Monitors:
- Gamma (1) purification inlet and (2) after the main pump
- Delayed Neutron after main pumps
- γ - Spectrometer none

Test Section:	
Pressure Tube	
Material	Zr alloy
Length	9.44 m (31 ft.)
Internal Diameter	38 mm (1.5 in.)
Flow Tube	can be installed to reduce internal diameter

Out-Reactor Test Section

Location	Length cm	Length in.	Internal Diameter cm	Internal Diameter in.
After Test Section	150	59	4.87	1.92

(1) Axial peak flux at the cell boundary.
(2) Heaters for heating the coolant in the pressurized water mode - excludes heaters in the surge tank, boilers, etc.
(3) Head in metre (feet) of flowing fluid.

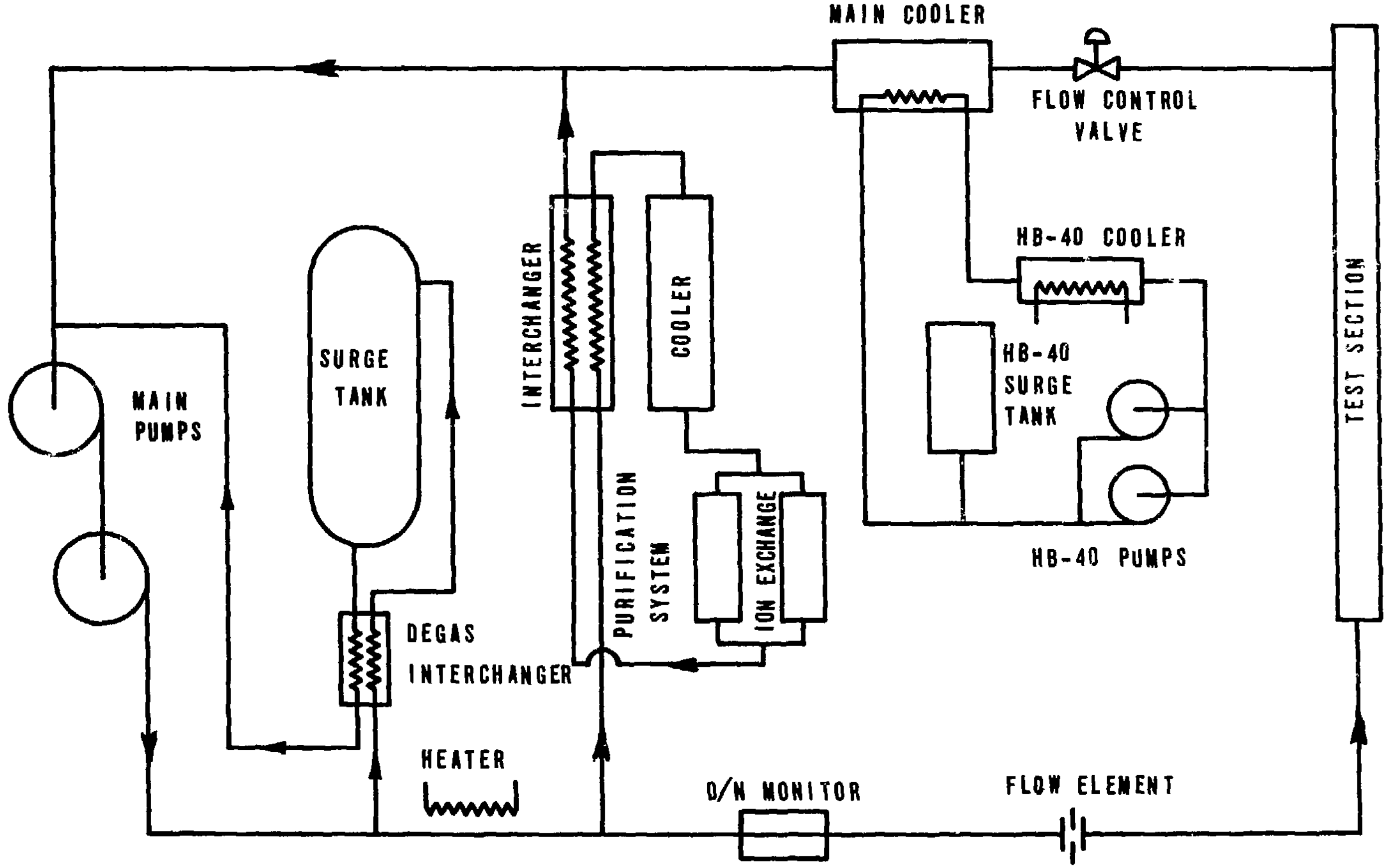


FIGURE 2.2.5.1: X-5 LOOP SIMPLIFIED FLOWSHEET

2.2.6 X-6 Loop

The X-6 loop installed in 1956 was similar to the other WAPD-IV loops except the construction material was carbon steel instead of stainless steel. In 1963 the loop was modified and uprated as a boiling water loop as shown on Fig. 2.2.6.1. The design and operating parameters of interest are tabulated on Table 2.2.6.1.

Some of the past programs included fuel development in the pressurized and boiling water modes, water chemistry, in- and out-reactor corrosion, pressure tube devleopment, heat transfer, fission product release rate, and activity transport.

TABLE 2.2.6.1

X-6 LOOP

Loop Type	pressurized water, boiling		
Reactor	NRX		
Reactor Lattice Site(s)	N21 upflow		
Nominal Thermal Flux(1)	8×10^{13} n.cm^{-2}.s^{-1}		
Cosine Flux Length	305 cm	(	120 in.)
Design:			
Pressure	18.6 MPa	(	2,680 lb/in^2 gauge)
Flow	1.14 kg/s	(	9,000 lb/h)
Temperature	359 °C	(	678 °F)
Heater (loop)(2)	60 kW		
Boiler	N/A kW		
Heat Removal	300 kW		
Surge Tank Volume	0.102 m^3	(	3.60 ft^3)
Pump Head(3)	170.7 m	(	560 ft)
Construction Material	carbon steel		
Coolant			
Operating Volume	0.150 m^3	(	5.30 ft^3)
Circulating Volume	0.095 m^3	(	3.35 ft^3)
Total Volume	0.196 m^3	(	6.93 ft^3)
Chemistry (normal)	pH 10(LiOH), 5-25 cm^3/kg H_2		
Purification:			
Flow	0.011 kg/s	(	87 lb/h)
Ion-Exchange I.D.	3.175 cm	(	1.25 in.)
Resin Volume	600 cm^3	(	0.021 ft^3)
Monitors:			
Gamma	piping before the test section inlet		
Delayed Neutron	after the pumps		
γ - Spectrometer	none		
Test Section:			
Pressure Tube			
Material	cold-work Zr-2½ wt.% Nb, other Zr alloys		
Length	9.44 m	(	31 ft.)
Internal Diameter	38 mm	(	1.5 in.)
Flow Tube	can be installed to decrease internal diameter		

Out-Reactor Test Section

Location	Length		Internal Diameter	
	cm	in.	cm	in.
Before Test Section	152	60	2.31	0.91
After Test Section	197	76	2.36	0.93
Separated Steam	98	38	2.33	0.92
Purification	113	44	~2.3	0.9

(1) Axial peak flux at the cell boundary.
(2) Heaters for heating the coolant in the pressurized water mode - excludes heaters in the surge tank, boilers, etc.
(3) Head in metre (feet) of flowing fluid.

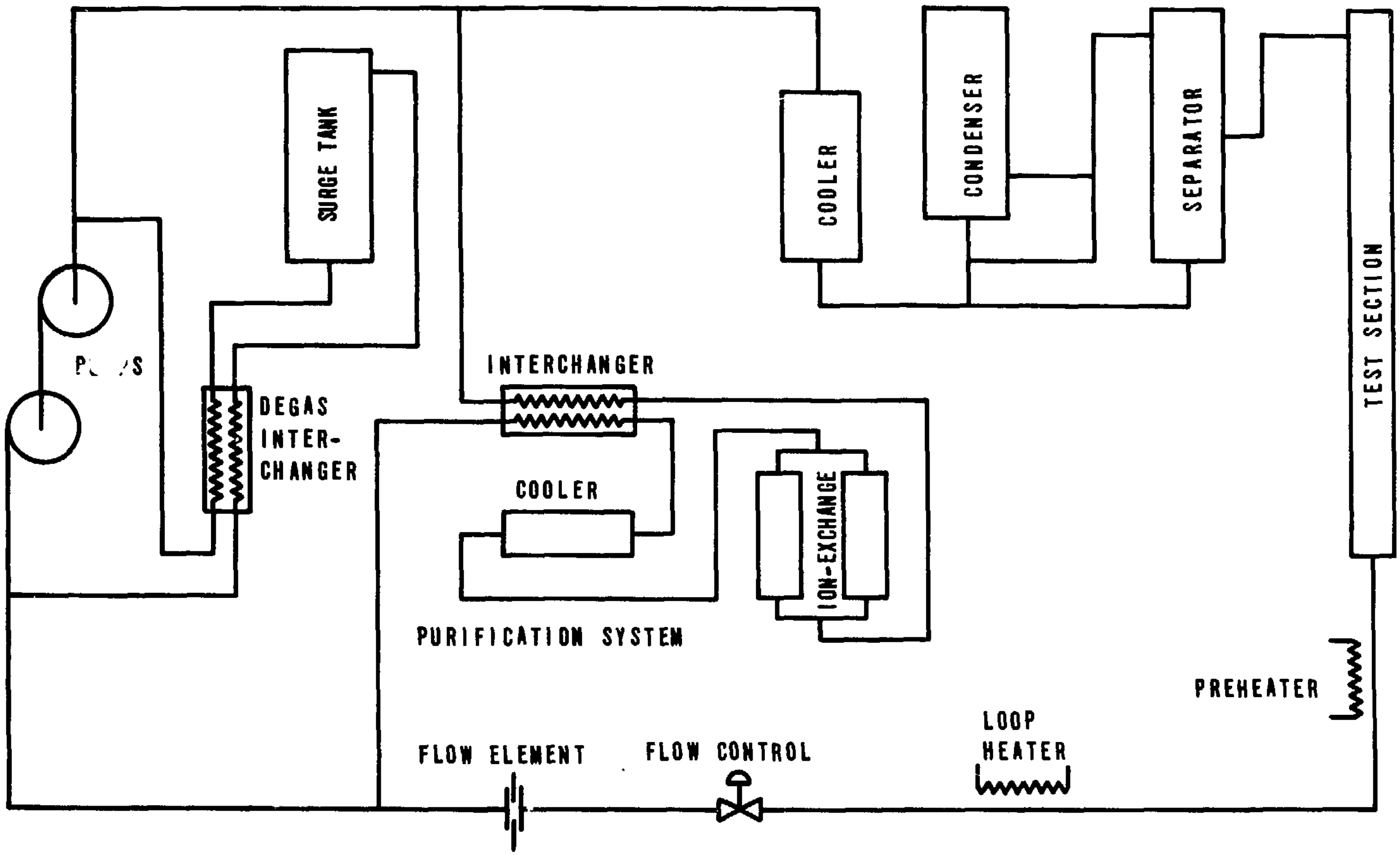


FIGURE 2.2.6.1: X-6 LOOP SIMPLIFIED FLOWSHEET

3. NRU REACTOR

3.1 Reactor Description

NRU is a heavy-water moderated and cooled reactor. The reactor vessel consists of a stainless steel top and bottom header and a cylindrical aluminum side wall. Of the 227 lattice positions, 7 positions have penetrations through the upper section of the lower thermal shield which permits converting these to loop sites. As shown on Fig. 3.1.1 these sites are: C18, E12, E20, J16, L8, L24 and (17. Tabulated on Table 3.1.1 are the pertinent reactor design and operating data. Figure 3.1.2 shows a vertical section through a reactor site prepared for loop installation.

Loops are the major experimental facilities in the NRU reactor. Some low pressure, low temperature experimental assemblies have been designed to utilize the normal reactor cooling system. Fast flux irradiation of metallurgical samples are provided inside fast neutron rods.

The NRU power is modulated by inserting or withdrawing control rods No. 12 to 18 in sequence. The reactor power is varied as required to maintain the highest priority loop fuel within its operating range. Since NRU is an "on-power" fueled reactor, driver fuels are moved or changed while operating to bring as many of the loops as practical within their operating range.

TABLE 3.1.1

NRU Reactor

Reactor Power - present nominal	130 MW
Moderator	heavy water
Coolant	heavy water
Driver Fuel Orientation	vertical
Reactor Vessel	
Outside Diameter	3505 mm (11 ft. 6 in.)
Depth	3658 mm (12.0 ft.)
Material - wall	aluminum
- top, bottom header	stainless steel
Lattice - number	227
- spacing hexagonal	196.85 mm (7.75 in.) center
Driver Fuel	
Material	U-Al alloy
Sheath	aluminum
Fuel Length	2743 mm (9.0 ft.)
Flux	
Peak Thermal in J-16 with CR16 up	4×10^{14} $n.cm^{-2}.s^{-1}$
Average Thermal in Moderator	1×10^{14} $n.cm^{-2}.s^{-1}$
Maximum Fast	1.3×10^{14} $n.cm^{-2}.s^{-1}$
Average Fast	4.5×10^{13} $n.cm^{-2}.s^{-1}$
Cosine Flux Length	3640 mm (143.3 in.)
Control	by raising and lowering control rods
Number of Control Rods	18
Number of Adjuster Rods	4
Operating Cycle	2-4 weeks operation, 4 day shutdown

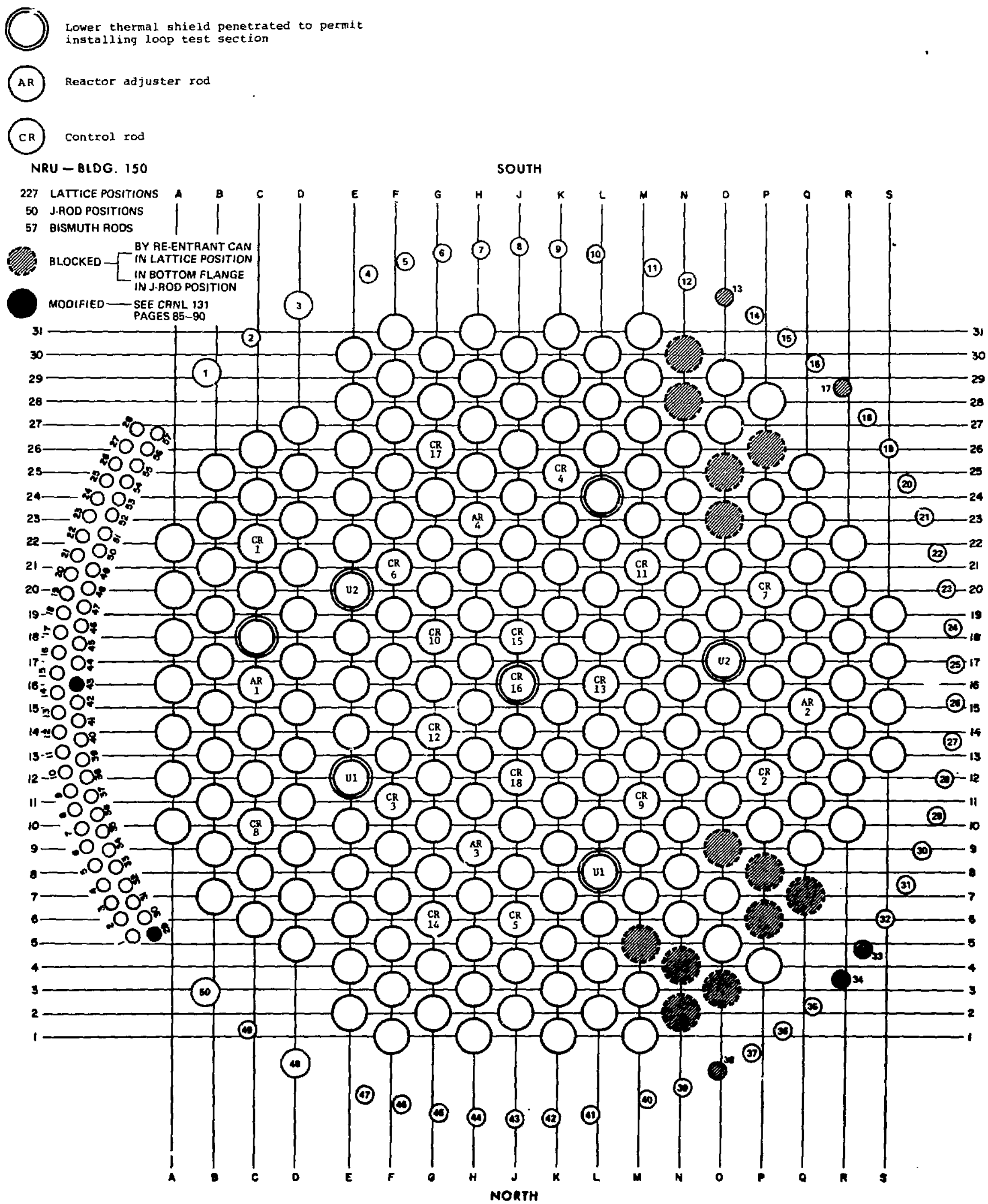


FIGURE 3.1.1

NRU LATTICE DIAGRAM

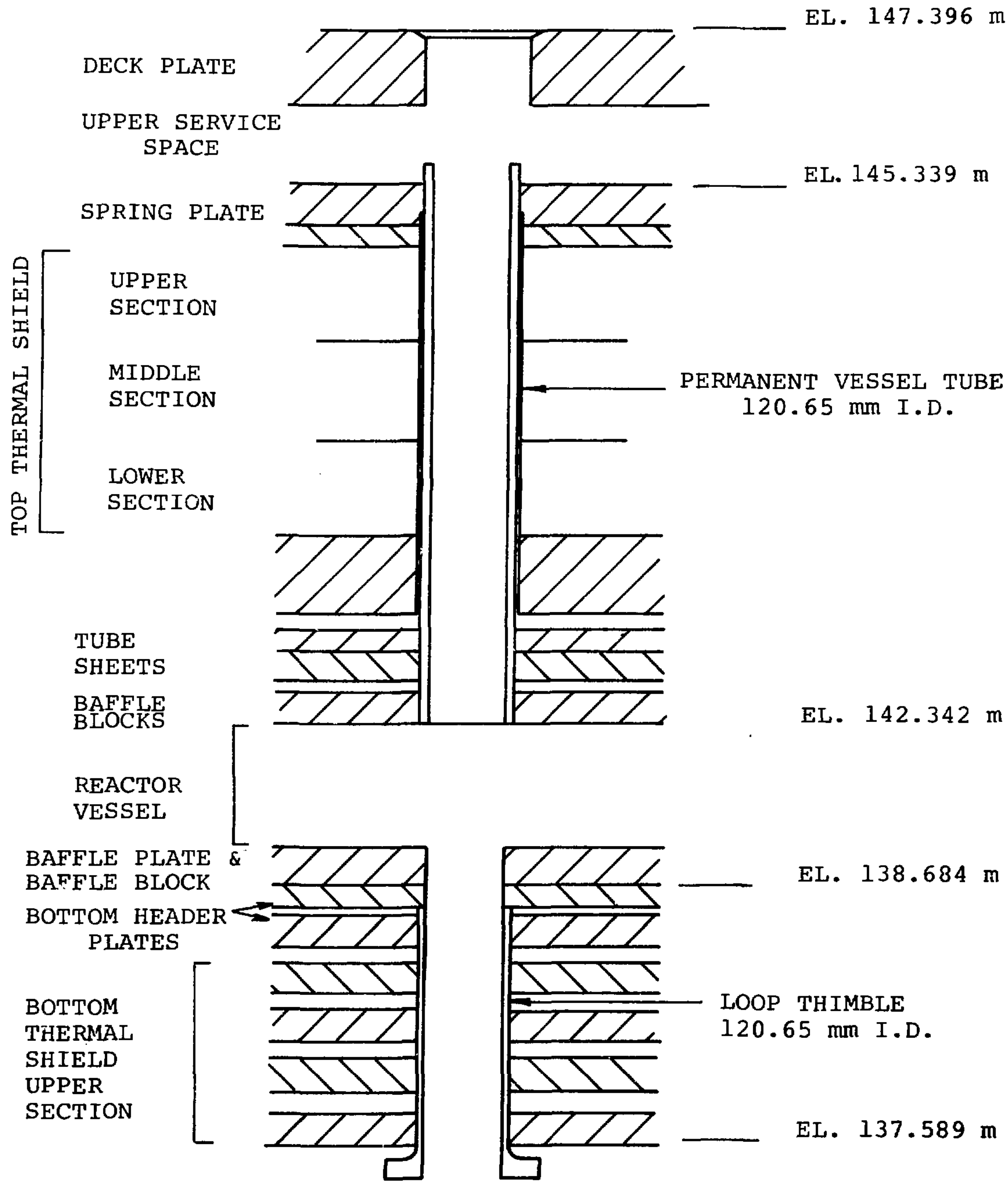


FIGURE 3.1.2

NRU LOOP SITE

3.2 LOOPS

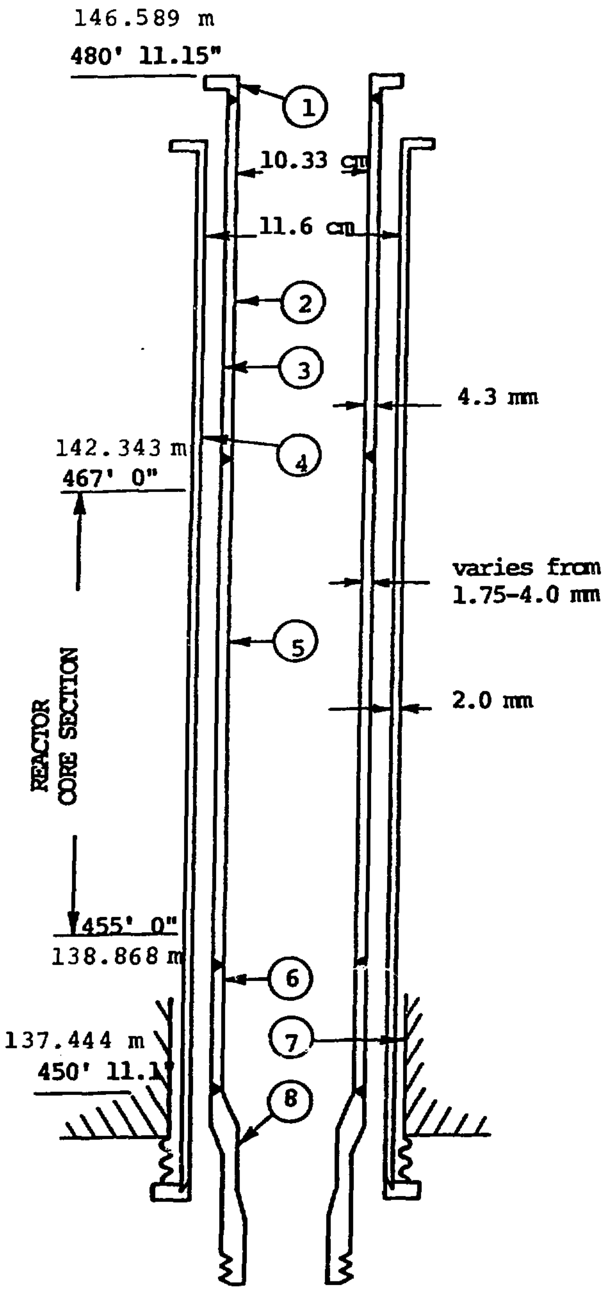
Of the three loops operating in the NRU reactor, two loops, U-1 and U-2, are designed for fuel irradiation while the third, U-5, is suitable for material testing only. The pressure tubes in the two fuelled loops are completely interchangeable and of the design shown on Fig. 3.2.1. The U-5 loop test sections are often designed to suit the particular experiment, therefore, they may be similar but not necessarily the same. (See Section 3.2.3).

A flux detector rod is installed in a site adjacent to each U-1 and U-2 loop site. The existing flux detector rods are designed with eight vanadium flux sensors distributed along the cosine flux length but future design will have 16 or more sensors, some being fast response flux sensors.

Fuel power ramping tests are usually done during reactor startup by ramping the reactor power up to or near its nominal power. Also available for use in any 103.3 mm pressure tube is a fuel moving device for fuel cycling experiments.

A U-3 organic loop operated until decommissioned in 1972. It has been retained as intact as possible to facilitate recommissioning when required.

A common data logger records the data from the loops including the pertinent NRU and NRX reactor data on magnetic tape for future retrieval. The data logger also assists in setting up and monitoring the various experiments.



1. Flange to top closure
2. Upper extension
3. Insulating air space
4. Containment tube
5. In-flux tube usually experimental with various stress zones
6. Lower extension
7. D_2O outside containment tube
8. Fitting to bottom closure

FIGURE 3.2.1

U-LOOP PRESSURE AND CONTAINMENT TUBE

3.2.1 U-1 Loop

The U-1 loop as originally installed in 1964 operated in four coolant modes, viz., pressurized water, boiling, steam-water inlet, and steam inlet. In 1974 the loop was uprated to operate with two in-reactor test sections in series. This modification limited the operation of the loop to the pressurized and boiling water modes. The flow diagram and a tabulation of the pertinent data for the present loop are shown on Fig. 3.2.1.1 and Table 3.2.1.1, respectively.

Regardless of the operating mode, the boilers are always an integal part of the operating circuit; therefore, only ammonium hydroxide is used for pH control to prevent caustic corrosion in the boilers.

Some of the past programs in this loop included: fuel development in the various coolant modes, fuel power ramping, fuel power cycling, coolant chemistry, pressure tube development, in- and out-reactor corrosion, activity transport, and out-reactor critical heat flux.

TABLE 3.2.1.1

U-1 LOOP

Loop Type	pressurized water, boiling			
Reactor	NRU			
Reactor Lattice Site(s)	E12 downflow, L8 upflow			
Nominal Thermal Flux(1)	3×10^{14} n.cm^{-2}.s^{-1}			
Cosine Flux Length	364	cm	(143.3 in.)	
Design:				
Pressure	13.9	MPa	(2,000 lb/in^2 gauge)	
Flow	17	kg/s	(135,000 lb/h)	
Temperature	354	^oC	(670 ^oF)	
Heater (loop)(2)	N/A	kW		
Boiler	3,888	kW		
Heat Removal	12,000	kW		
Surge Tank Volume	0.949	m^3	(33.5 ft^3)	
Pump Head(3)	251.4	m	(825 ft)	
Construction Material	stainless steel			
Coolant				
Operating Volume	2.9	m^3	(102.4 ft^3)	
Circulating Volume	2.9	m^3	(102.4 ft^3)	
Total Volume	3.4	m^3	(120.0 ft^3)	
Chemistry (normal)	pH 10(NH_4OH), 5-10 cm^3/kg H_2			
Purification:				
Flow	0.06	kg/s	(475 lb/h)	
Ion-Exchange I.D.	7.8	cm	(3.07 in.)	
Resin Volume	4,200	cm^3	(0.148 ft^3)	
Monitors:				
Gamma	water monitor and steam monitor			
Delayed Neutron	usually water			
γ - Spectrometer	able to monitor several samples, instrument installed as required			
Test Section:				
Pressure Tube				
Material	cold-worked Zr-2½ wt.% Nb, other Zr alloys			
Length	9.48	m	(31.1 ft.)	
Internal Diameter	103.3	mm	(4.07 in.)	
Flow Tube	no design provisions for its installation			

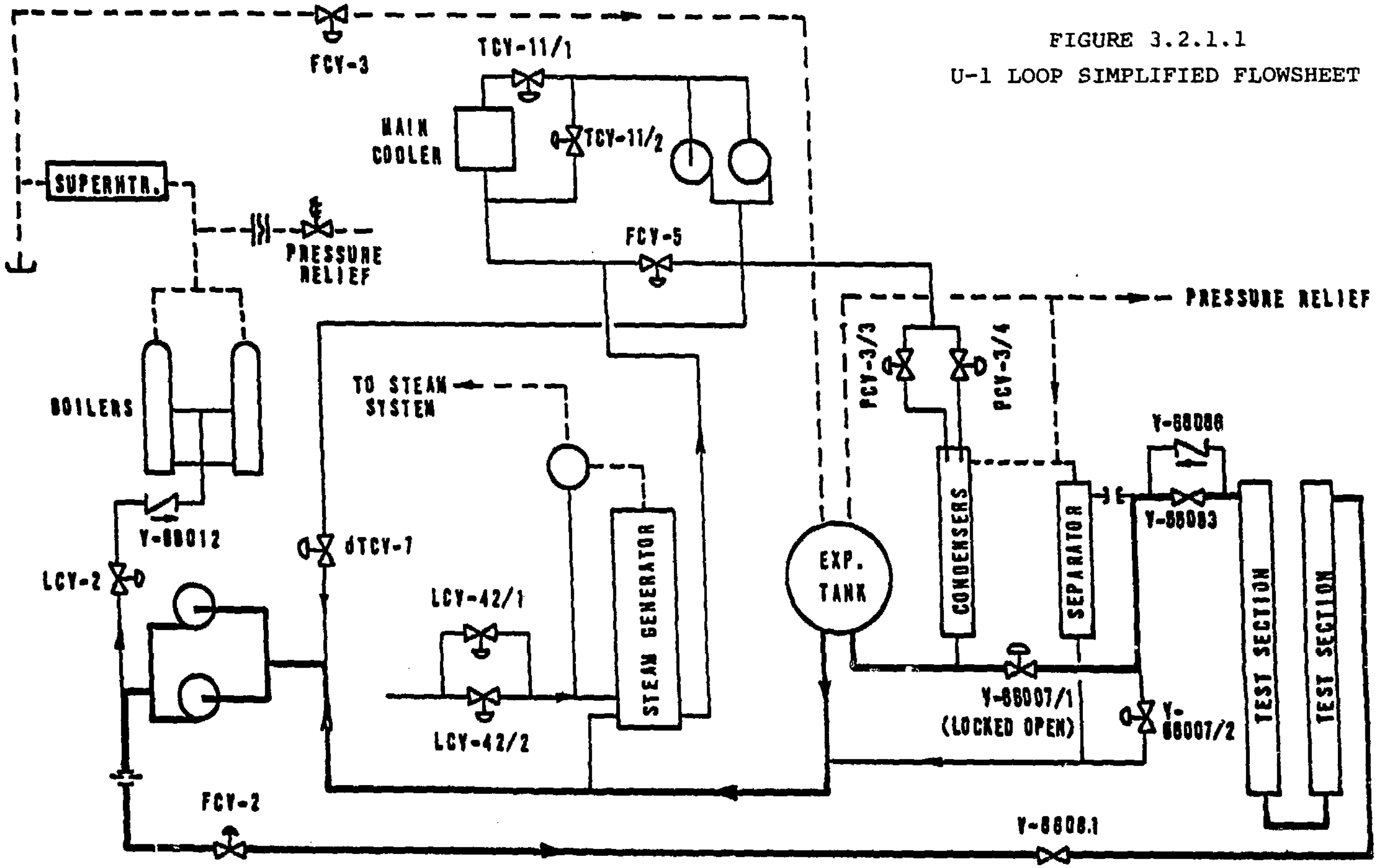
Out-Reactor Test Section

Location	Length cm	Length in.	Internal Diameter cm	Internal Diameter in.
Test section outlet	~600	~235	8.98	3.535

(1) Axial peak flux at the cell boundary.
(2) Heaters for heating the coolant in the pressurized water mode - excludes heaters in the surge tank, boilers, etc.
(3) Head in metre (feet) of flowing fluid.

FIGURE 3.2.1.1

U-1 LOOP SIMPLIFIED FLOWSHEET



3.2.2 U-2 Loop

The U-2 loop was installed in 1959 as a pressurized water loop but subsequent tests showed limited boiling to about 10% outlet steam quality was possible. In 1974 the loop was uprated to operate with two in-reactor test sections in series. The present loop flow diagram and a tabulation of its pertinent data are shown on Fig. 3.2.2.1 and Table 3.2.2.1, respectively.

Some of the past programs in this loop included: fuel development, fuel power ramping, fuel power cycling, in- and out-reactor corrosion, pressure tube development, water chemistry, and critical heat flux.

TABLE 3.2.2.1

U-2 LOOP

Loop Type	pressurized water	
Reactor	NRU	
Reactor Lattice Site(s)	E20 downflow, O17 upflow	
Nominal Thermal Flux(1)	3×10^{14} $n.cm^{-2}.s^{-1}$	
Cosine Flux Length	364 cm	(143.3in.)
Design:		
Pressure	13.9 MPa	(2,000 lb/in^2 gauge)
Flow	20 kg/s	(158,000 lb/h)
Temperature	354 °C	(670°F)
Heater (loop)(2)	235 kW	
Boiler	N/A kW	
Heat Removal	8,000 kW	
Surge Tank Volume	0.715 m^3	(25.2 ft^3)
Pump Head(3)	210 m	(690 ft)
Construction Material	stainless steel	
Coolant		
Operating Volume	1.20 m^3	(42.4 ft^3)
Circulating Volume	0.70 m^3	(24.7 ft^3)
Total Volume	1.45 m^3	(51.2 ft^3)
Chemistry (normal)	pH 10 (LiOH), 5-15 cm^3/kg H_2	
Purification:		
Flow	0.035 kg/s	(277 lb/h)
Ion-Exchange I.D.	7.8 cm	(3.08 in.)
Resin Volume	4,200 cm^3	(0.148 ft^3)
Monitors:		
Gamma	inlet to purification circuit	
Delayed Neutron	will be installed in 1980	
γ - Spectrometer	monitoring line installed, instrument installed when required	
Test Section:		
Pressure Tube		
Material	old-worked Zr-2½wt.% Nb, other Zr alloys	
Length	9.48 m	(31.1 ft.)
Internal Diameter	103.3 mm	(4.07 in.)
Flow Tube	no design provisions for its installation	

Out-Reactor Test Section

Location	Length		Internal Diameter	
	cm	in.	cm	in.
Test Section Outlet	190	75	8.98	3.535

(1) Axial peak flux at the cell boundary.
(2) Heaters for heating the coolant in the pressurized water mode - excludes heaters in the surge tank, boilers, etc.
(3) Head in metre (feet) of flowing fluid.

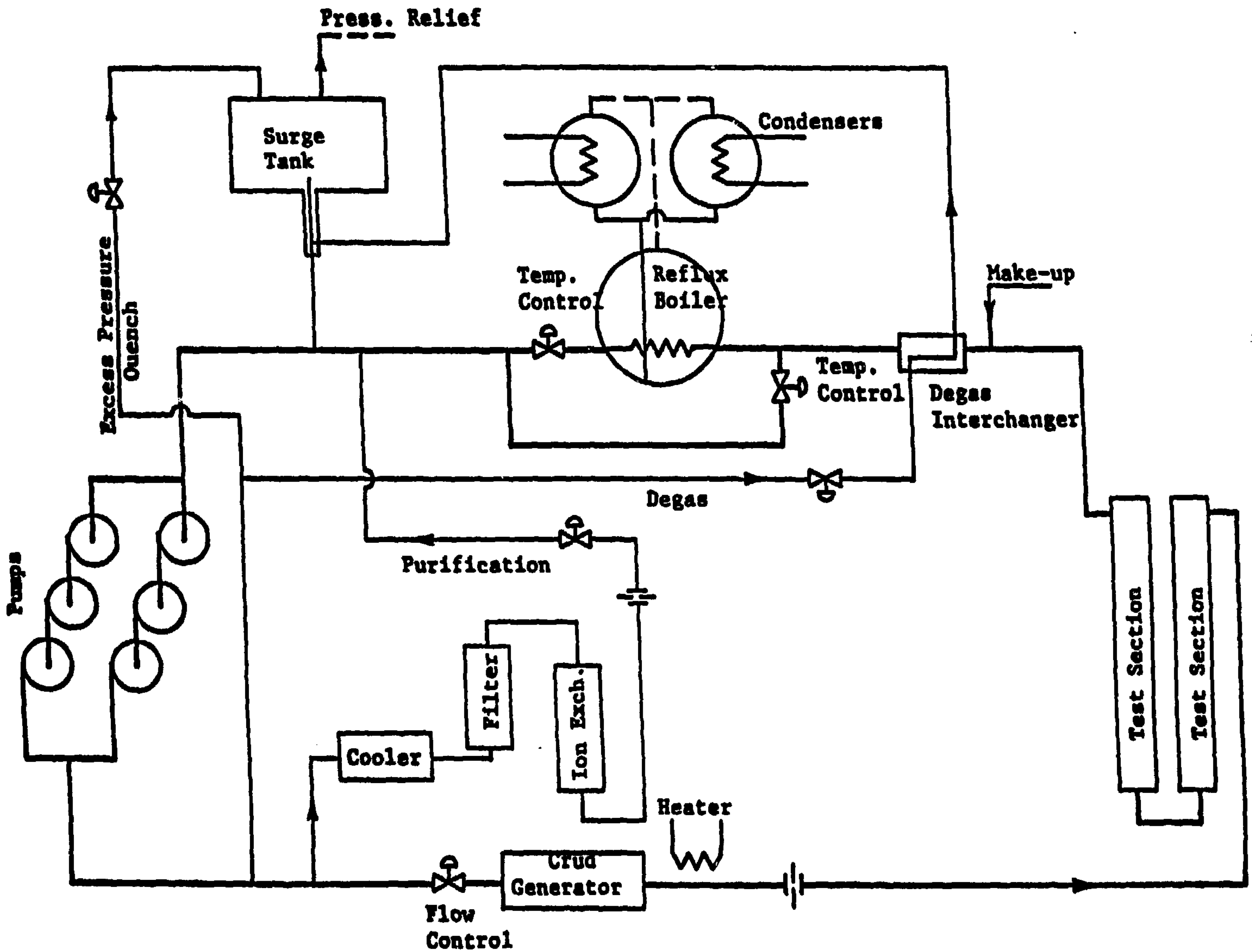


FIGURE 3.2.2.1

U-2 LOOP SIMPLIFIED FLOWSHEET

3.2.3 U-5 Loop

The U-5 loop is a pressurized water loop designed for materials testing and not for fuel testing. Light water at the required chemistry, pressure, and temperature is supplied to as many as six in-reactor test sections operating in parallel. The test sections, designed to suit the individual experiments, are normally installed inside a hollow fast neutron rod as shown on Figure 3.2.3.1. These test sections can be located in any driver fuel site not restricted to this use by reactor physics requirements, pipe routing, etc.

The pertinent design and operating parameters for the U-5 loop are tabulated on Table 3.2.3.1 and the flowsheet is shown on Figure 3.2.3.2.

The fast neutron rods used have fuel length of about 142 cm (56 in.) with a cavity 7.37 cm (2.9 in.) in diameter. The fast flux in the cavity varies between 1.5 and 4.6×10^{13} $n.cm^{-2}.s^{-1}$.

Some of the past programs included: low cycle fatique, torsion creep, and fast neutron effects on metal properties such as nil duality transition temperature, yield stress, and fracture toughness.

TABLE 3.2.3.1

U-5 LOOP

Loop Type	materials test (pressurized water)	
Reactor	NRU	
Reactor Lattice Site(s)	into driver fuel sites	
Nominal Thermal Flux(1)	N/A	
Cosine Flux Length	cm	(in.)
Design:		
Pressure	17.3 MPa	(2500 lb/in^2 gauge)
Flow	1.2 kg/s	(9500 lb/h)
Temperature	354 ^{o}C	($670^{o}F$)
Heater (loop)(2)	134 kW	
Boiler	N/A	
Heat Removal	140 kW	
Surge Tank Volume	0.102 m^2	(3.6 $ft.^3$)
Pump Head (3)	30.5 m	(100 ft)
Construction Material	carbon steel	
Coolant:		
Operating Volume	0.27 m^3	(9.5 ft^3)
Circulating Volume	0.22 m^3	(7.8 ft^3)
Total Volume	0.32 m^3	(11.3 ft^3)
Chemistry (normal)	pH 10 (LiOH), 10-20 cm^3/kg H_2	
Purification:		
Flow	0.15 kg/s	(119 lb/h)
Ion-Exchange I.D.	5.62 cm	(2.25 in)
Resin Volume	.0018 m^3	(0.06 ft^3)
Monitors:		
Gamma	N/A	
Delayed Neutron	N/A	
γ - Spectrometer	N/A	
Test Section:		
Pressure Tube		
Material	Zr alloy	
Length	~7.3 m	(24 ft)
Internal Diameter	63.25 cm	(24.9 in.)
Flow Tube	re-entrant flow ,therefore ,required	
Out-Reactor Test Section	none	

(1) Axial peak flux at the cell boundary.
(2) Heaters for heating the coolant in the pressurized water mode - excludes heaters in the surge tank, boilers, etc.
(3) Head in metre (feet) of flowing fluid.

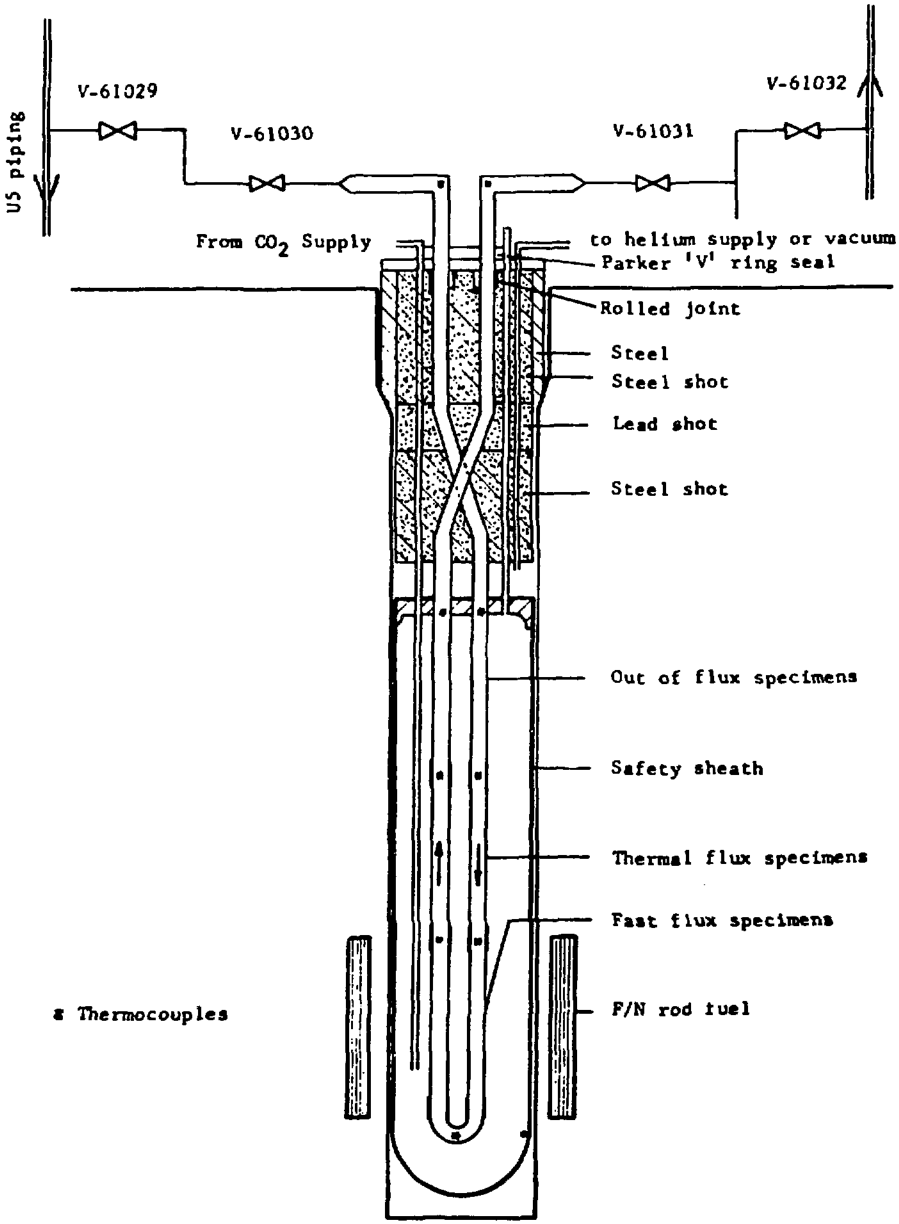


FIGURE 3.2.3.1

Typical hairpin Type Test Section Insert

U-5 LOOP

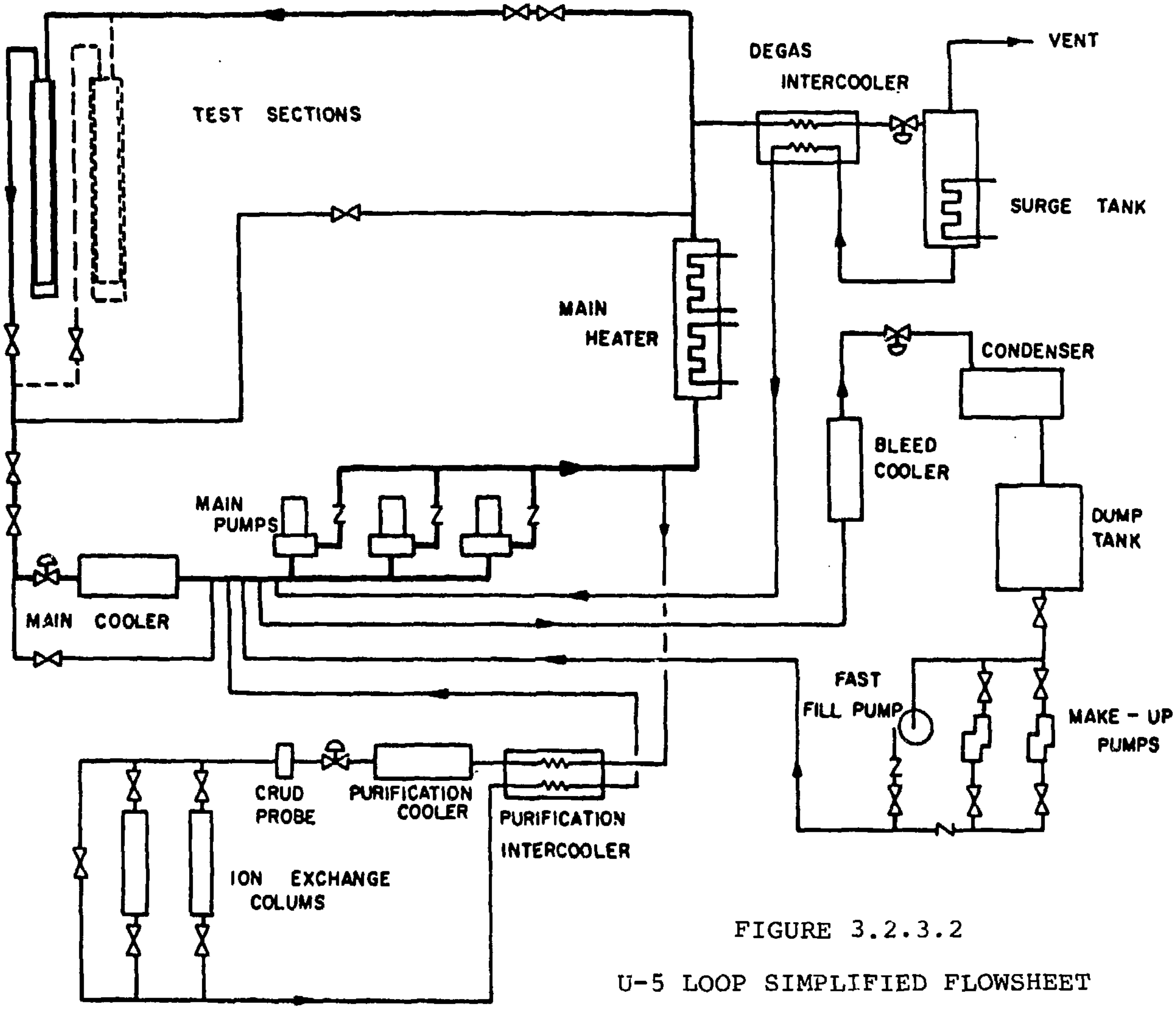


FIGURE 3.2.3.2

U-5 LOOP SIMPLIFIED FLOWSHEET

4. ACKNOWLEDGEMENT

The author wishes to express his appreciation to R.D. Delaney, C.E. Ferris and W.L. McCrea for providing much of the detailed information, and to S.P. Gibson for the helpful comments during the preparation of this report.

ISSN 0067 - 0367

To identify individual documents in the series we have assigned an AECL- number to each.

Please refer to the AECL- number when requesting additional copies of this document

from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada
KOJ 1JO

Price $4.00 per copy

ISSN 0067 - 0367

Pour identifier les rapports individuels faisant partie de cette série nous avons assigné un numéro AECL- à chacun.

Veuillez faire mention du numéro AECL- si vous demandez d'autres exemplaires de ce rapport

au

Service de Distribution des Documents Officiels
L'Energie Atomique du Canada Limitée
Chalk River, Ontario, Canada
KOJ 1JO

Prix $4.00 par exemplaire

243-81