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Babcock & Wilcox

SAFETY HAZARDS EVALUATION REPORTS

UPDATE FOR LICENSE No. R-47

RESEARCH AND DEVELOPMENT DIVISION

LYNCHBURG RESEARCH CENTER

Lynchburg, Virginia

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BAW-74

Supplement 12

SAFETY HAZARDS EVALUATION
REPORTS UPDATE FOR LICENSE No. R-47

November 1978

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Babcock & Wilcox

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1. INTRODUCTION

Since September 19, 1958, The Babcock & Wilcox Company (B&W) has operated in Lynchburg, Virginia a research reactor known as the Lynchburg Pool Reactor (LPR). Under License R-47 and amendments, the LPR can be operated up to 1 MW in the forced convection mode and up to 200 kW in the natural convection mode.

B&W on March 3, 1978 requested renewal of the LPR license for an additional 20 years. This update of Safety Hazards Evaluation Reports[1-12] has been prepared at the Commission's request to reflect current conditions at the facility.

2. SITE LOCATION AND DESCRIPTION

2.1. Site Location

The Lynchburg Research Center (LRC) is located in Campbell County, Virginia approximately 3 air miles from Lynchburg, the nearest principal city. Site location, population density and meteorological data are detailed in reference 13.

2.2. Administration

The LPR Operations Supervisor is a licensed senior operator and is responsible for the safe operation of the LPR. He is responsible for assuring that all operations are conducted in a safe manner and within the limits prescribed by the facility license. The Operations Supervisor is appointed by the Manager, Advanced Controls and Experimental Physics Laboratory, and reports to the Manager of the Nuclear Physics Section.

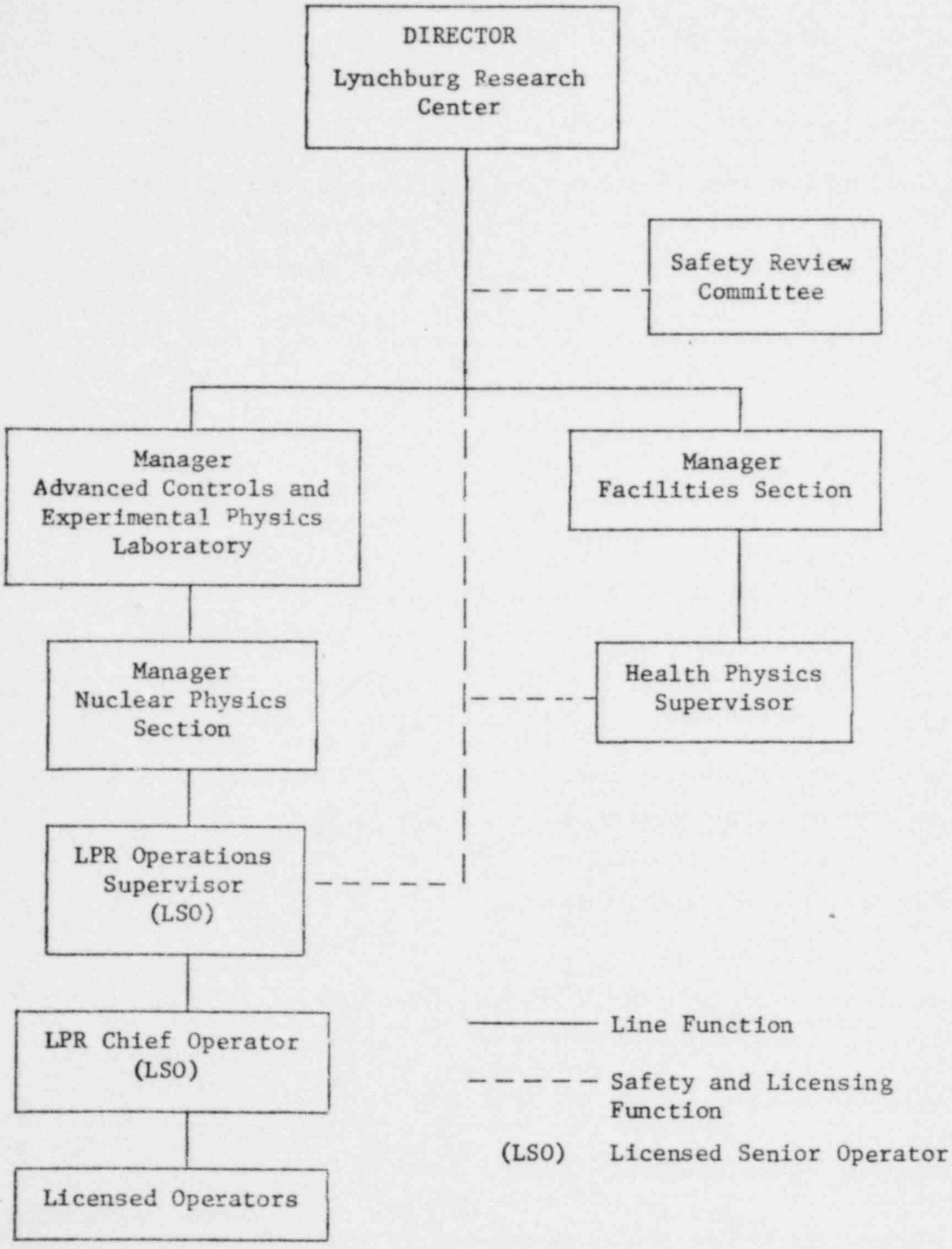
The LPR Chief Operator is responsible for operation of the reactor in accordance with established procedures and regulations; scheduling and coordinating reactor operations and maintenance; maintaining required records; assisting the Operation Supervisor in the review and approval of reactor operations and experiments, writing reports, and reviewing operations with the Safety Review Committee and USNRC representatives. The Chief Operator reports to the LPR Operations Supervisor.

The organizational structure of the Lynchburg Research Center relating to the LPR is shown in Figure 1.

2.3. Laboratory Operations

The Lynchburg Research Center began operation in 1956 as the Critical Experiment Laboratory. Since that time it has grown and diversified. Of the 238 members currently on the LRC Staff, 38 have doctorate degrees and 37 have masters degrees. Disciplines include nuclear physics, radiochemistry, ceramics, metallurgy, radiation control, process control, electrical engineering, heat transfer and criticality safety.

Figure 1. Line Organization Chart for the LPR



In addition to the LPR, one other reactor facility is in operation at the laboratory. This is the water moderated critical facility CX-10 which has been utilized since 1957.

Available to support LPR operations are several counting rooms including a variety of NaI and Ge(Li) detectors with large capacity multichannel analyzers, a large hot cell complex, radiochemistry labs, machine shops, electronic maintenance labs, and a health physics organization complete with personnel dosimeter calibration facilities. LRC maintains National Bureau of Standards traceable standards for neutron flux, gamma dose, weights and measure, time and frequency, and most of the available radioisotopes. The LRC also has its own licensing, nuclear materials control, purchasing, shipping and receiving departments. The large well-equipped technical library of the Nuclear Power Generation Division supports the entire Lynchburg operations.

3. LPR DESCRIPTION

3.1. Pool

Figures 2 and 3 are plan and vertical views of the pool. The pool is 13 feet long, 7 feet wide, and 18 feet deep. The poured concrete walls range from 6 to 8 feet thick at the basement (core) level and are 6 feet thick at the first floor level. The water level is about 13 feet above the top of the core. A storage pit at one end of the pool is 2.5 feet wide and extends 5.5 feet below the bottom level of the pool. The pit contains racks for fuel element storage. Concrete shield covers are available to permit pool drainage during maintenance and repair operations.

There are four beam ports: three 3-inch ports, and one 8-inch port which can be fitted with either a tube extending to the edge of the LPR grid plate or with a 2-foot cube of graphite in an aluminum box. The beam ports may be plugged with concrete blocks to provide biological shielding.

There is a thermal column penetration in the shield wall adjacent to Grid #1. A steel shell with a 5-foot square cross section penetrates the concrete pool wall north of grid 1. A 1-inch-thick aluminum pressure or closure plate secured to the pool end of the shell prevents the loss of pool water. The closure plate is reinforced by horizontal and vertical metal ribs.

At the present time, an autoclave occupies the space inside the steel sheel and a 4-inch-thick layer of lead bricks is stacked against the closure plate with a 2-foot square opening in the center of the stack. Sand fills the space between the shell and the autoclave. A description of this autoclave is given in reference 7.

The LPR core may be positioned on either of two grids within the pool. The bridge is attached so that it can be moved to a position directly over either grid. Grid 2 which is near the pool center has the option of either forced or natural convection cooling. A core on grid 1 can be cooled by natural convection only.

3.2. Fuel

Twenty-five MTR-type fuel elements are available. Seventeen are full elements with 10 fuel plates each. The sandwich-type plates contain a 0.020-inch-thick core of U-Al alloy with 30 wt % highly enriched uranium (greater than 90% U^{235}). The sides of the plates are clad with 0.015-inch aluminum. Each plate contains about 19 grams of U^{235} — a total of 190 grams of U^{235} per full element. The curved-plate fuel elements, which fit in a 2.996 by 3.222-inch rectangle, have an active length of 23.5 inches. The water gaps between plates are 0.276 inches. In addition to the 17 full elements, two partial fuel elements with five fuel plates and five aluminum plates may be used for mass shimming. Six other fuel elements have six outer fuel plates each; the inner region is used for the control rods. Three of these elements normally contain safety rods and the fourth contains the regulating rod. Each of the four control rod elements contains 114 grams of U^{235}.

The present operational program does not anticipate reactor operation at integrated powers or burnup requiring fuel element replacement. Therefore, if fuel elements need to be replaced, the NRC will be informed.

3.3. Reflector Elements

Thirty-one canned graphite reflector elements are available. The reflector elements are 33-3/4 inches in overall length (25-11/16 inches of graphite) by 3 inches square and are fabricated with end fittings for positioning in the LPR grid plates. The solid block graphite is sealed in 0.045 inch thick aluminum cans.

3.4. Control and Safety Rods

The LPR normally uses three aluminum-clad boron stainless-steel rods as shim-safety rods, and one hollow aluminum-clad stainless steel regulating rod. However two shim-safety rods are acceptable as long as all reactivity limits specified in the technical specifications are met. The shim-safety rods are fabricated from solid boron stainless-steel stock, which has a natural boron content of 1.5 to 1.7 wt %. Each rod is grooved and finished.

The rod drives have operated since September, 1958 without failing to fall when a scram is initiated. The safety rods are coupled through an electromagnet to a threaded nut and a shaft driven by an electric motor. The regulating rod-drive is the same except the rod is attached directly to the shaft. During a scram signal or a power failure, current to the electromagnets is interrupted and the rods fall by gravity.

The maximum time from the initiation of a scram condition in the logic scram circuit until the shim-safety rods are inserted is 650 msec. The maximum delay time from the initiation of the scram condition in the logic scram circuit to the release of the shim-safety rods is 100 msec. The maximum rod-drive speed is 3.75 inches per minute for the shim-safety rods, and 40 inches per minute for the regulating rod.

The rod withdrawal movements are not ganged. Each rod is raised separately as selected by a switch at the console. The rod control switches are spring loaded to return to the off position from the withdraw position. Rod positions are displayed at the console. The rod drives are built so they provide positive mechanical means to prevent the inadvertent lifting of fuel elements through control or safety rod movements. The regulating rod may be controlled automatically by either an analog or digital servo system.

3.5. Grids

The LPR core may be positioned on either of two grids within the pool.

3.5.1. Grid 1

Grid 1 is an 8x10 lattice with a pitch of 3.035 inches by 3.189 inches located in the north end of the LPR pool and used in conjunction with the thermal column and the stationary beam ports. Cores operated on grid 1 are cooled by natural convection.

3.5.2. Grid 2

Grid 2 is a 7x7 lattice with a pitch of 3.035 inches by 3.189 inches. It is located approximately 6 inches south of grid 1 with its west edge aligned with the west edge of grid 1. Grid 2 may be operated in "forced" or "natural" convection cooling.

The outlet header is constructed with one side hinged. This side is a gravity-operated flapper valve which permits natural convection cooling in case of a loss of forced flow. The flapper valve is held closed manually while the primary system pump is activated. The valve is held closed by the pressure differential during normal pump operation. Figure 3 shows grid 2 and header.

3.6. Cooling System

Figures 3 and 4 show the cooling system. The water is drawn down through the core and header at 890 gpm, and flows through a pipe in the pool wall, a pump, and into the shell side of the heat exchanger. The cooled water returns through a pipe in the pool wall to a distribution header at the bottom of the pool. This header returns the water to the pool with a minimum of turbulence. The bulk pool temperature rises to about 105F during a sustained operation under unfavorable summer conditions.

The secondary water flows through the tube side of the heat exchanger, the cooling tower, and the pump. The secondary pumping rate is 445 gpm.

Measurements of the primary and secondary coolant pressures at the heat exchanger are given in Table 1. These measurements show that in the static condition, the primary system pressure is higher by about 2 psi. With the primary pump on and the secondary pump off, the primary system pressure is higher by about 13 psi. With the secondary pump on, the secondary system pressure is higher by 21 to 63 psi.

Overflow from the primary coolant system is collected in a liquid waste retention tank of approximately 5500 gallon capacity. An alarm which indicates the liquid waste tank is in need of emptying is tied to the LPR upper annunciator panel as a serious alarm condition. The alarm point can be set at either the 4500 gallon or the 5000 gallon level and is controlled by a switch inside the console. The switch setting is normally at the 4500 gallon level; and in the event of an alarm, it is raised to the 5000 gallon level. This allows time to notify health physics and arrange for disposal.

Overflow from the secondary coolant system normally discharges into the storm drain which ultimately empties onto a hillside on the site. Piping and valves are installed to divert this overflow into the 5500 gallon liquid waste retention tank if it becomes necessary.

Table 1. Pressures in Heat Exchanger (psig)

Condition	Primary System	Secondary System
Static	6.7	4.8
Pump On	17.5	27.8 (spray valve open) 69.3 (spray valve closed)

3.6.1. Primary System

Heat Exchanger

The heat exchanger is an aluminum, single-pass shell, two-pass tube unit designed to dissipate 1000 kW (3.413×10^6 BTU/hr) at a flow rate of 700 gpm. The primary inlet temperature is about 110 F and the outlet temperature is about 100 F.

Primary Pump

The primary pump is a motor driven centrifugal-type with a rating of 700 gpm. (Actual flow rate is about 890 gpm.) The housing is constructed of aluminum with a stainless-steel impeller.

Piping and Valves

The piping is 6-inch diameter, schedule 40 aluminum. The valves are either aluminum or stainless steel.

3.6.2. Secondary System

Heat Exchanger

The secondary side of the heat exchanger has a flow rate of 445 gpm with an inlet temperature of 82 F and an outlet temperature of 97 F.

Secondary Pump

The secondary pump is a motor driven centrifugal-type with a rating of 475 gpm. (Actual flow rate is about 445 gpm.) The housing is constructed of carbon steel.

Cooling Tower

The cooling tower is a forced draft design rated for the removal of 1000 kW (3.413×10^6 BTU/hr) of heat at a wet bulb temperature of 77 F.

Piping and Valves

The piping is of 4-inch carbon steel. The valves are carbon steel.

3.7. Demineralizer System

Pool water makeup is handled by a 10-gpm mixed bed demineralizer. This bed also supplies water to CX-10 facility. A 25-gpm mixed bed demineralizer in the heat exchanger building is restricted to pool recirculation. This bed is shielded and is regenerated with the effluent going to a 5500 gallon storage tank.

3.8. Nuclear Instrumentation

3.8.1. Measuring and Safety Channels

A source range channel is employed for startup and for inverse multiplication measurements in core loading operations. The range of this channel is extended into the power range by the expediency of allowing the fission chamber to be moved away from the core as the power increases. Its components will include a fission chamber, a pre-amplifier, a linear amplifier, a scaler, a logarithmic count-rate amplifier, and a logarithmic count-rate recorder.

A linear level channel is used to indicate the flux level in the power range. It will also supply the feed back signal to an automatic controller on the regulating rod. The channel is fed by a compensated ion chamber.

An intermediate range channel is employed to provide neutron flux and period indication over the range of criticality through full power. It is fed by a compensated ion chamber.

Two safety channels employing uncompensated ion chambers are used for over-power protection.

Figure 2. Plan View of LPR

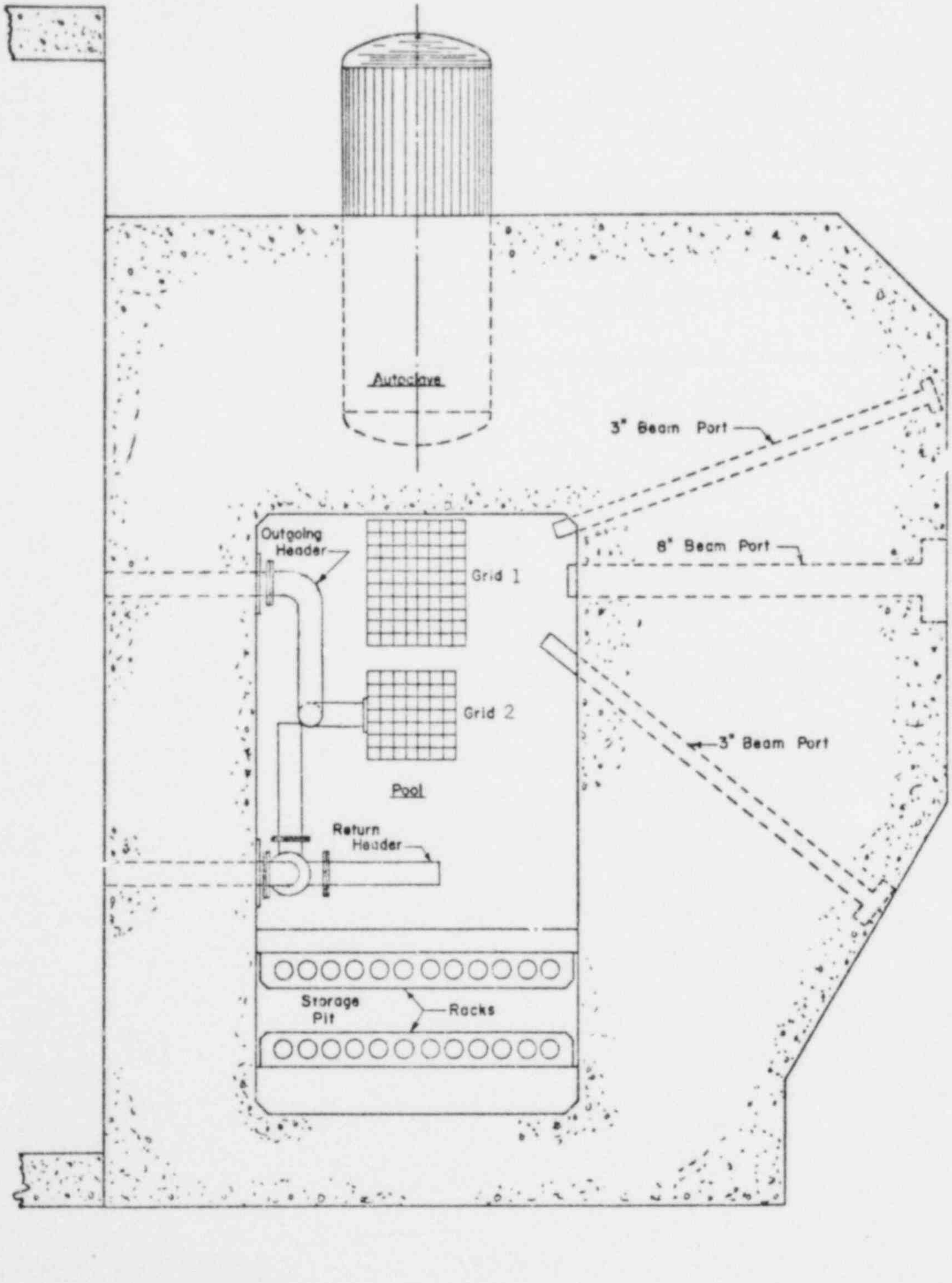


Figure 3. Vertical View of LPR

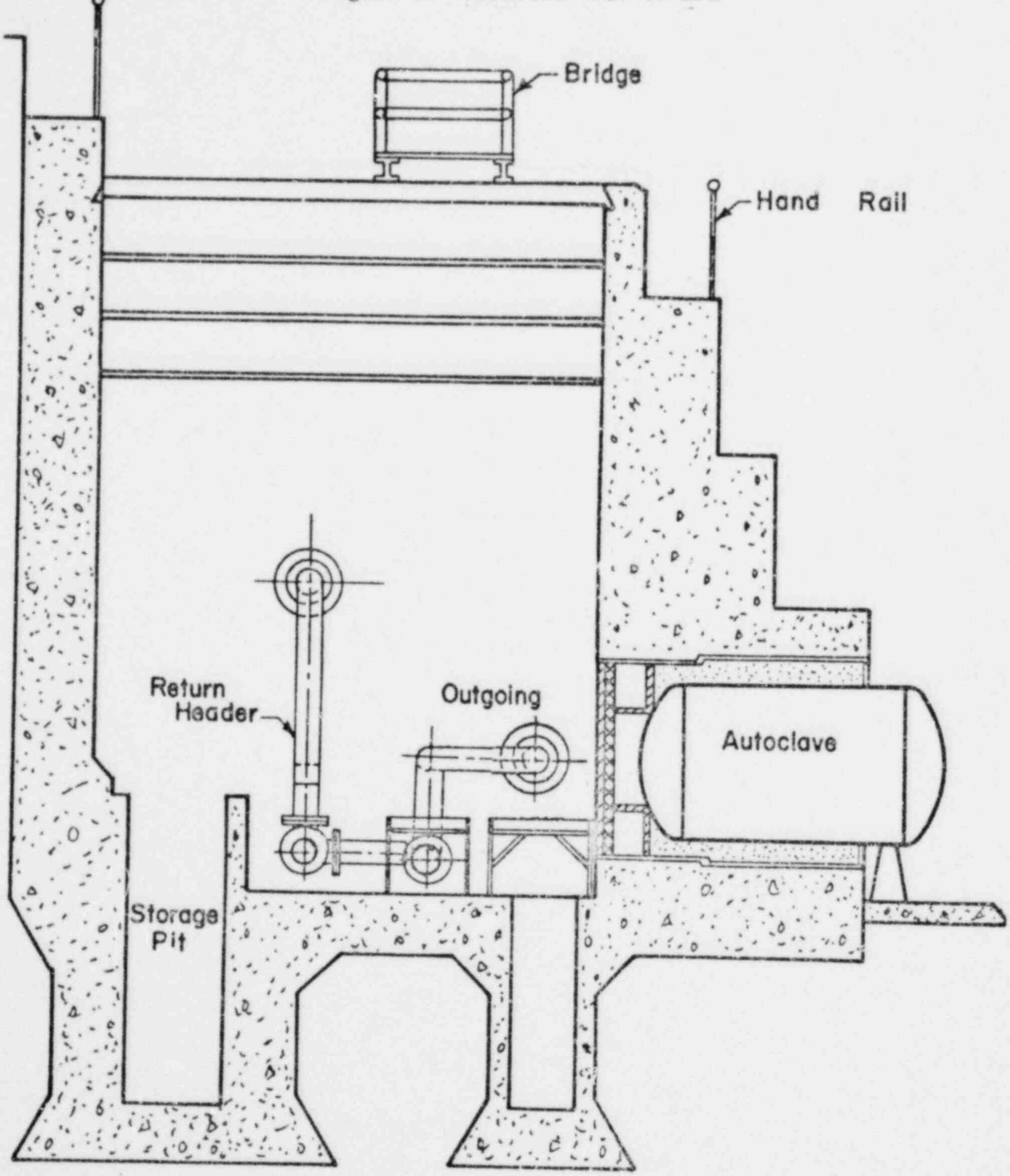
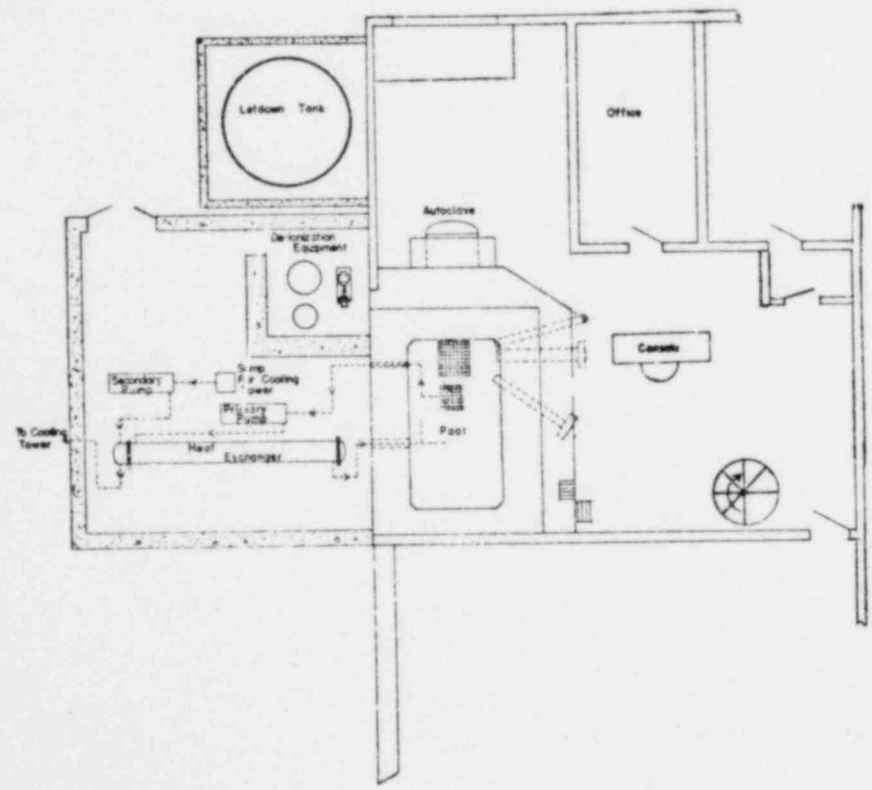


Figure 4. Plan View of LPR Area



Area radiation monitors are located at (1) the top of the pool under the bridge, (2) at the reactor console, (3) in line with the 8-inch beam port, (4) the thermal column area, and (5) the heat exchanger room.

An air monitor which samples air at the top of the pool, alarms and shutsdown the ventilation system if its setpoint is reached.

3.8.2. Composite Safety Amplifier

The LPR composite safety amplifier contains all components necessary to provide current to the safety rod magnets. It also contains all logic necessary to rapidly shut off the magnet current when it receives scram demand from other instruments in the safety circuit.

Two types of scram capability are resident in the safety amplifier; relay scrams and logic scrams. The relay scram is relatively slow and is activated when a scram input is grounded. Logic scrams are fast electronic scrams and are activated when the scram input deviates from 24V. (When the eletronic logic switching shuts off the magnet current, a relay in the circuit is tripped to prevent the magnet current from turning back on when the scram demand goes away.)

The following conditions cause a logic scram:

1. High power trip from either safety channel.
2. Period trip from the intermediate range.

In addition to the above, the following conditions cause either a logic scram or a relay scram:

1. Low primary coolant flow rate (forced cooling mode only)
2. Natural convection header open (forced cooling mode only)
3. Loss of Primary Coolant Pump Power (forced cooling mode only)
4. Coolant Mode Switch in Intermediate Position

5. High reactor coolant inlet temperature
6. Low pool water level
7. Manual scram
8. Magnet power keyswitch off
9. High radiation level in reactor console area
10. High radiation level in other selected areas where experiments are being performed
11. Loss of water from autoclave (during autoclave operation only)
12. High pressure or temperature in autoclave (during autoclave operation only)

3.9. Cooling System Instrumentation

Indication and control instrumentation for the cooling system is located on the LPR console. It consists of (1) on-off and pilot lights for all pumps, (2) indicators for inlet and outlet temperatures of the heat exchanger, (3) primary system flow rate indication, (4) secondary system flow rate, and control. Interlocks, warnings and scrams ensure that:

1. The primary system pump may be turned on only if the shim-safety rods are in the core and the header-flapper valve is closed.
2. A scram will occur if the primary system pump is deenergized.
3. A scram will occur and primary system pump will stop if the header valve should open.
4. A scram will occur if the reactor coolant inlet temperature reaches the Limiting Safety System Setting.
5. A scram will occur if the primary system flow rate falls to its Limiting Safety System Setting.

3.10. Autoclave Instrumentation

A pressure safety trip in the loop is set at approximately 775 psig. If the loop pressure reaches this value, the reactor will scram. This limit of 775 psig is below the setting of the loop pressure relief so that the reactor will be scrammed before there is any letdown in the loop due to an overpressure. Another safety installed in the loop depends upon the water level. This is set after the water has been introduced into the loop system and will scram the reactor if there is a loss of water due to any cause. There is not an automatic water makeup for the system so this is a positive safety. In addition to these two safeties there is an overtemperature safety in the loop. The reactor will be scrammed if a temperature of approximately 515 F is reached in the loop system. These scrams are in addition to the normal control system of the loop The normal control of the loop is accomplished by separate instrumentation. This instrumentation will control the heaters and pressurizer to reach and maintain the temperature and pressure as selected by the operator. The maximum settings for the normal control of the loop water are 720 psig and 505 F.

4. OPERATION

4.1. Power Level

The LPR is licensed to operate at power levels not exceeding 1 MW in the forced convection mode and at power levels up to 200 kW in the natural convection mode.

4.2. Reactivity Requirements

Table 2 gives typical requirements for excess reactivity. The excess reactivity will always be kept at a minimum necessary for proper operation.

Table 2. Reactivity Requirements-Sustained 1000 kW

	$\Delta k/k$
Negative temp coeff.	0.003
Equilibrium poisons	.023
Restart at peak xenon	.006
Adequate control	.003
Movable & unsecured experiments	.015
	0.050

The shutdown margin relative to the cold xenon free critical condition will be at least 0.01 $\Delta K/K$ with the most reactive shim-safety rod and the regulating rod fully withdrawn. During loading changes, the reactor will be subcritical by more than 0.0275 $\Delta K/K$.

4.3. Emergency Plan

Reference 14 describes the emergency plan. In the event of an evacuation alarm, the LPR operator scrams the reactor, leaves the pumps and instrumentation on and evacuates.

5. REACTOR ACCIDENTS

5.1. Flooding and Other Failures

The maximum reactivity that could be inserted if all movable and unsecured experiments failed simultaneously while the reactor is critical is 0.015 $\delta k/k$. The rate of insertion would depend on the rate of failure.

5.2. Rod Withdrawal

The failure of the analog or digital Servo Systems causing continuous withdrawal of the regulating rod would never add more than 0.006 $\delta k/k$.

The worst rod accident would involve the simultaneous and continuous withdrawal of the three shim-safety rods. In the worst case, more than 28 seconds would be required to add 0.015 $\delta k/k$. This would require the simultaneous failures of the interlock which prevents the withdrawal of more than one rod at a time, the variable and 3-second period scrams, and the operator. More than 0.015 $\delta k/k$ is incredible.

Six minutes are required to withdraw a shim-safety rod completely. Therefore, the deliberate withdrawal of a single shim-safety rod at its maximum rate by an operator would add reactivity relatively slowly when compared with the speed of instrument response.

5.3. Fuel Addition

Measurements show that an addition of an outside fuel element to the core could be worth as much as 0.017 $\delta k/k$ of reactivity. Administrative control ensures that fuel is never handled unless the LPR is at least 0.0275 $\delta k/k$ subcritical. During fuel handling with more than six elements on the grid plate, a licensed Senior Operator is present and a licensed operator is observing the console. The core is loaded from inside out, and the rod drives are constructed to preclude the inadvertent lifting of fuel elements through movement of control rods. The addition of a central element to a near critical core is not considered credible. Therefore, 0.017 $\delta k/k$ is taken as the maximum for a fuel addition accident.

5.4. Moderator Temperature

A sudden change in moderator temperature could occur if interlocks failed and the coolant pumps were started while the reactor was critical at 200 kW with natural circulation. The pumps cannot be started without manually closing the flapper valve. If this did occur, it would bring about a moderator temperature change of less than 30 F, which is an approximate 0.003 reactivity addition.

5.5. Total Coolant Loss

A rupture in the primary piping or a failure of the beam tube or the autoclave closure plate could result in the complete loss of all the coolant from the pool. (The LPR has operated since September, 1958 without such a loss.) This loss would produce three problems. First, the direct radiation from the core would result in extremely high radiation levels at the top of the pool (15,000 r/hr assuming a 250-day operation at 1 MW). However, the water leakage rates could never be fast enough to prevent the evacuation of the area. Second, would be the dissipation of decay heat. Experiments[15] show that MTR-type fuel elements operating under the conditions in the LPR can adequately dissipate the decay heat in the air with only natural convection cooling. The third problem would be the disposal of the water released to the heat exchanger room or to the LPR basement. This would present no hazard to the general public since the water would not leave the site for a long period of time.

5.6. Partial Coolant Loss

A partial coolant loss to one or more fuel elements could result from foreign matter falling into the pool and being sucked into the core. This could cause local effects of voiding which would reduce reactivity. Before an element was heated to a burnout temperature, reactivity effects would be sufficient to cause the operator to shut down the reactor.

5.7. Fuel Element Cladding Failure

Periodic checks are made by the Health Physicist for low level fission products in the water. The remote area monitoring system or the air monitor will give sufficient warning of any larger release.

5.8. Maximum Credible Accident

The maximum credible accident is the rapid addition of an outside fuel element when the reactor is just below or at a delayed critical condition. This could result only through a gross set of human errors and the complete disregard of all operating procedures. A 0.017 reactivity addition would result to cause an initial power surge terminated by a reactor period scram or by a void formation in the core. If the void formation terminated the first surge, the reactor would then be shut down by period, high power, high radiation, or a manual scram. This maximum credible reactivity accident would result in no core meltdown or contained fission products release.[16] (See Appendix E of reference 9)

6. MAINTENANCF COMMITMENT

The ability of the structures, systems and components of the facility to function properly and safely for an additional 20 years is assured by the existance of a comprehensive preventive maintenance program, combined with B&W's commitment to maintain the facility in good repair. The following serve as examples of the Company's past commitment to upgrade the facility and to maintain it in proper operating condition:

1. The nuclear instrumentation and scram circuitry were upgraded to solid state in 1968.
2. A major repair was made to the pool walls in 1972.

Both of these were initiated by B&W.

To assure the continued integrity of the fuel clad, the primary coolant chemistry is maintained within much tighter limits than our license requirements. Aluminum coupons within the primary system show corrosion rates below the limit of detectability (i.e., less than 0.0001 inch per year).

7. REFERENCES

[1] BAW-74 Pool Test Reactor Hazards Evaluation, Final Report, May 1958.

[2] BAW-74-1 Pool Test Reactor Hazards Evaluation, Final Report, Supplement 1, June 1958.

[3] BAW-74-2 Supplementary Information to the Hazards Report for the Pool Test Reactor Facility, July 15, 1958.

[4] BAW-74-3 Application for Extension of AEC License No. R-47 to Permit 2-Megawatt Operation of the Lynchburg Pool Reactor, October 1959. (Note: This application was not approved.)

[5] BAW-74-4 Application for Extension of AEC License No. R-47 to Permit 450-Kilowatt Operation of the Lynchburg Pool Reactor, February 1961. (Note: This application is no longer applicable.)

[6] BAW-74-5 Application for Amendment to AEC License No. R-47 to Change the Technical Specifications for the Lynchburg Pool Reactor Control Rods, May 1961.

[7] BAW-74-6 Application for Amendment to AEC License No. R-47 to Permit Use of Moderators Consisting of Light and Heavy Water Mixtures in the Hot Exponential Experiment Facility, July 1961.

[8] BAW-74-7 Application for Exetnsion of AEC License No. R-47 to Permit the Use of Reflector Elements in the Lynchburg Pool Reactor, November 1961.

[9] BAW-74-8 Hazards Evaluation in Support of Request for Amendment 6, License No. R-47, to Operate the Lynchburg Pool Reactor at 1000 kW, April 1962.

[10] BAW-74-9 Additional Information in Support of Request for Amendment 6, License No. 4-47, to Operate the Lynchburg Pool Reactor at 1000 kW, July 1962.

[11] BAW-74-10 Application for Extension of AEC License No. R-47 to Receive, Possess, and Use Additional Uranium-235, July 1963.

[12] BAW-74-11 Application for Extension of AEC License R-47 to Permit Changes in the Natural Convection Operating Schedule of the Lynchburg Pool Reactor, August 1963.

[13] Emergency Plan, Lynchburg Research Center (SNM-778, Docket 70-824), Submitted to NRC December 1978.

[14] Environmental Report, Lynchburg Research Center (SNM-778, Docket 70-824), Submitted to NRC December 1978.

[15] Report to the Atomic Energy Commission on the Proposed Argonne Research Reactor (CP-5), ANL-WHZ-252, Argonne National Laboratory, June 15, 1950.

Lynchburg Test Reactor, Critical Experiment Hazards, BAW-109, Babcock & Wilcox , November 1959.

DISTRIBUTION

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27. CAUSE DESCRIPTION AND CORRECTIVE ACTIONS.

Low setpoint on trip device. Type of offsite personnel uncertain. Contributing cause was a loss of dash pot oil in the trip device (GE Type EC-2A). Parts were replaced in kind and setpoints adjusted.

The following actions are planned: (1) retrain appropriate personnel in setpoint adjustment, (2) check the setpoints on similar devices, (3) rebuild devices in safety related breakers and periodically replace devices in all breakers if oil leaks occur.