Design of Pool Water Management System for Storage of Radioactive Materials

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***Abstract*—Water is the most common fluid used to remove the heat produced in a research reactor (RR). Maintaining high quality water is the most important factor in preventing degradation of fuel elements, and other structural components in the water-cooled pool. Excellent water quality in fuel wet storage facilities is essential to achieve optimum storage performance.**

Keywords—Waterpool, Cooling system, Cleaning system, Makeup system.

I. INTRODUCTION

For over 60 years, research and test reactors (hereinafter referred to as „fuel water pool reactors") have made valuable contributions to the development of nuclear power, basic science, materials development, education, training, and radioisotope production for medicine and industry [1]. Considering that the majority of shutdown reactors still have nuclear fuel elements within the facility, they require, for safety reasons, a continuous maintenance programme, especially to avoid corrosion of fuel elements to maintain fuel integrity, prevent release of radioactivity, and ensure safe handling throughout the storage period.

Regardless of the reactor type, its application, composition or power level, in the majority of them, water is used as the core cooling fluid, moderator and biological shielding. As the cooling fluid, water removes the heat produced by the stored radioactive fuel and transports it to the heat exchanger system; as moderator, the water also acts as radiological shielding, it attenuates the radiation emitted in the reactor core in order to assure a safe environment for the reactor operators. Being an efficient agent for all these purposes, it can produce undesirable conditions if its quality is poor and it can result in unwanted high radiation levels.

In order to maintain the quality of the water for proper working of the reactor and for the storage of fuel, the water pool has different systems installed in it, some of these are: Water cooling system, Cleanup system and Makeup system. The pool Water Cooling, Treatment and Cleaning System is located near the hot cell or near the Reactor Well and is comprised of various processes subsystems designed to support waste handling operations. This system maintains the pool water temperature within an acceptable range, maintains water quality standards that support remote underwater operations and prevents corrosions, provides the capability to remove the debris from the pool, control the pool water level, and helps limit radiological exposure to personnel. The pool structure and liner, pool lightning, and the fuel staging racks in the pool are not within the scope of this report.

Pool water temperature control is accomplished by circulating the pool water through heat exchangers. Adequate circulation and mixing of the pool water is provided to prevent localized thermal hotspots in the pool. Treatment of the pool water is accomplished by a water treatment system that circulates the pool water through filters, and ion exchange resins. These water treatment units remove radioactive and non-radioactive particulate and dissolved solids from the water, thereby providing the water clarity needed to conduct operations.

A. System Functions

- The system controls pool water temperature to support safe radioactive handling operations.
- The system suppresses the growth of micro-organisms in the pool.
- The system maintains water clarity in the pool. The system treats the pool water to control radiological exposure to personnel and equipment.
- The system controls pool water chemistry.
- The system provides the means for cleaning and removing debris from the pool surface.
- The system monitors and controls the pool water level.
- The system helps control the spread of radioactive particles in the pool during waste handling operations.
- The system provides the required equipment to support pool liner cleaning. The system provides indications and alarms of system parameters.
- To remove decay heat released from fuel bundles.
- To maintain water quality for refueling activities and storage of fuel bundles.
- To provide shielding to reduce radiation levels on the refueling floor.
- To maintain fuel bundles in a subcritical configuration."

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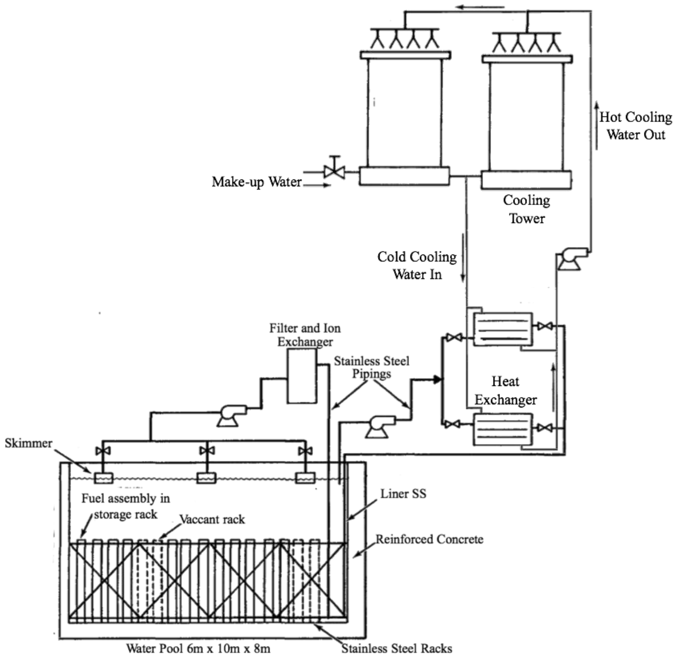

1. Schematic view of water pool and components.

In this project, we have designed a complete system for the maintenance and cooling of a radioactive fuel storage tank.

Firstly, the calculations for the amount of heat generated by the radioactive fuel was calculated. In case of Cobalt-60, the heat generated is 160 KJ/s. Thus, the total temperature rise is about 8 degrees per day for the total amount of water in the tank. According to these calculations the cooling system required for cooling the water in the tank is designed.

The evaporation rate is calculated by the formula given below.

Evaporation inch/day:

$E = 0.497 \times (1-1.32 \times 10-2 \times Pa) \times (1+0.262w) \times (V-v)$

Here,

Pa = Barometric pressure in inches of Hg = 29.9

W = Wind Velocity in mph.

V = Vapor Pressure in inches of Hg at water temperature.

v = Vapor Pressure in inches of Hg at dew point temperature of the atmosphere.

According to this evaporation rate, the amount of water to be made up by the makeup system can be calculated.

Finally, by referring to different underwater cleaning systems available and the new types of research being done, a simple cleaning system that can be used to clean the impurities that get accumulated on the internal side of the walls of the water tank is suggested.

II. DEGRADATION OF MATERIALS IN WATER

Water is a strong polar solvent; metallic materials tend to dissolve (corrode) in water and water solutions through mechanisms involving electrochemical reactions. Due to the various working and environmental conditions that they are subjected to, different degradation mechanisms can occur, some of an electrochemical nature and some not (e.g. leaching), which have to be individually considered in water systems.

A. *Effect on metals*

1) *Stainless Steel*
   - *a) Pitting corrosion.*
   - *b) Crevice corrosion.*
   - *c) Transgranular stress corrosion cracking.*
   - *d) Intergranular stress corrosion cracking.*
   - *e) Discoloration of stainless steel..*
2) *Concrete*
   - *a) Pitting corrosion.*
   - *b) Thermal degradation.*
   - *c) Carbonation and reinforcement steel bar corrosion.*
   - *d) Leaching.*
   - *e) Radiation effects.*

III. SYSTEM SPECIFICATION

Company : Board of Radiation and Isotope Technology, Vashi, Navi Mumbai.

Pool Dimensions : 6 m x 10 m x 8 m (deep).

Radioactive Element	: Cobalt-60
Heat Released	: 160 KJ/s
Volume	: 480 m3.
Recommended Water level in Pool	: 7 m to 7.5 m
Recommended Temperature range	: Below 60 °C
Change in Temperature	: 8°C/day

IV. WORKING OF THE SYSTEM

The function of this system is to remove heat from the pool water. This heat is the result of radioactive decay heat continuously being transferred to the pool water. The removal of decay heat allows the pools to operate at a reduced temperature, (e.g., 35°C). This low temperature minimizes the amount of water being continuously evaporated from the pools, minimizes corrosion to pool components and fuel assemblies, and minimizes the occurrence of algal bloom within the pool, thereby facilitating the maintenance of water clarity.

When the water temperature rises to a set point, due to excess heat input, water is pumped through a heat exchanger to cool the water and return that cooled water to the source. The heat rejected by the pool water is transferred to an independent chilled water (CHW) loop. The CHW loop, in turn, rejects the heat to the environment by means of air-cooled heat exchangers. The working fluid used in the refrigeration is water. The pressure on the chilled water side of the heat exchangers is maintained above the pressure of the pool water being cooled. This reduces the possibility of the closed-loop-CHW being contaminated in the event of a heat exchanger failure.

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The water is initially passed through a filtration step to remove particulate materials. After filtration, the water passes through cation and anion ion exchange system, a mixed (cation and anion) bed ion exchange system to remove dissolved constituents. Finally, after ion exchange, the water is passed through a polishing filter to remove any ion exchange resin carried with the water. The water is then returned to the pool system.

Debris floating on the surface of the pool water is removed by skimmers. A manually operated pool vacuum system is provided for the purpose of removal of accumulated debris on pool wall and floor surfaces. Water collected in these cleaning operations is passed through roughing filters for large particle removal before passing through the continuous water treatment system.

A. Cooling System Details

The radioactive elements placed in the water pool emits radiation generating heat, because of this heat, the temperature of the water rises by 0.3186°C/hr. which is approximately 8°C/day. This rise in temperature reduces the radiation shield effect and also increases the evaporation rate. As a result, maintaining the temperature of the water is necessary. To overcome this heat, cooling system of the following specification is designed.

1) Heat Exchanger

Quantity : 3 nos. (1 for emergency).

Dimensions : 200NB x 3000 mm Length.

Area : 6.3 m^2.

Flow Rate : 60 m^3/hr.

Number of Tubes : 36.

OD of Tubes :19.05 mm x 1.6 mm thick.

Number of Baffles : 4.

Liquid in Tube Side : Pool Water.

Liquid in Shell Type : Cooling water.

Design Pressure : 8 kg/cm²

MOC : SS 304.

V. *Cooling Tower*

Quantity : 2 nos.

Dimensions : 6.05 m x 2.44 m x 2.89 m.
Min / Max. Flow : 30 / 80 l/s

:108 / 288 m^3/hr.

A. Demineralize PLANT DETAILS

Plant Consists of :

1) One FRP Column containing Cation Exchanger Resin.
Resin Quantity : 300 Ltrs, generates 80000 Ltrs of DM water in one cycle.

Regenerant : HCl 30%, 24 Ltrs.

2) One FRP Column containing Anion Exchanger Resin.
Resin Quantity : 150 Ltrs, generates 80000 Ltrs of DM water in one cycle.

Regenerant : NaOH 100%, 8 Kg.

3) One PP/FRP Mixed Bed Column containing Cation & Anion Exchanger Resin.
Resin Quantity : 25 Ltrs Agrion C100H+ and Agrion 600MP 40 Ltrs, generate 80000 Ltrs.

Regenerant : HCl 30%, 4.8 Ltrs. & NaOH 100%, 3Kgs.

4) Inter connecting pipe-line of P.P / PVC with PP Ball valves complete from inlet of the D.M. Plant to outlet of the D.M. Plant.

5) One double range conductivity meter with cell Pressure Gauges at inlet / outlet of each columns Sampling cock at the outlet of each column 2 nos. Plastic Regeneration Tanks 2 nos. Ejector will be provided.

6) Plant is mounted on Channel / Base Plate for easy erection and commissioning.

7) Pressure.

Maximum Operating Pressure : 3.5 kg/cm^2.

Minimum Operating Pressure : 2 kg/cm^2.
Maximum Operating Temperature : 65°C.

8) Maximum Flow Rate : 5 m^3/hr..

B. Makeup Plant Details

Demineralized Water Plant also has the function of making up of the water loss from the water pool due to evaporation.

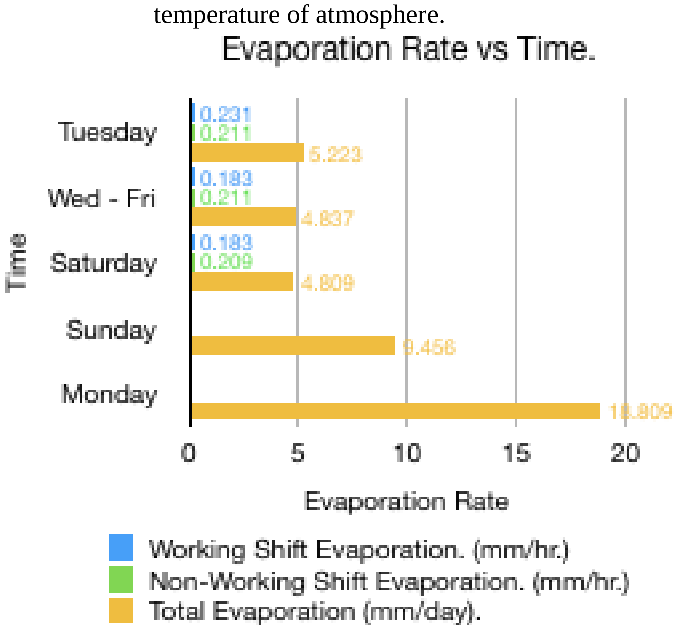
The Evaporation from the pool is given by [13]:

Evaporation inch/day;

E= 0.497 x (1-1.32 x 10-2 x Pa) x (1+0.262w) x (V-v).

Here,

Pa = Barometric pressure in inches of Hg = 29.9.
w = Wind Velocity in mph.
V = Vapour Pressure in inches of Hg at water temperature.
v = Vapour Pressure in inches of Hg at dew point temperature of atmosphere.



2. Evaporation Rate VS Time.

According to the Evaporation, the Makeup water required is, Makeup Water = 11.407 m3/month.

= 380 L/day.

C. Cleaning System Details

During operations in water pools or reactor vessels, a quantity of sludge and other radioactive debris tends to collect on the pool floor.

1) UNDERWATER VACUUM CLEANER

The Under Water Vacuum Cleaner (UVC) for cleaning tasks is a logical development of a unit specifically designed and constructed for the cleaning of BWR and PWR reactor cavities. It is anticipated that in the majority of applications, the most radioactive parts of the vacuum cleaner, the collection pot and bag or element filters are installed below the pool water surface, thus providing the operators with radiological protection. Alternatively, the vacuum cleaner could be mounted behind a shielding wall although the unit would still operate on water.

UVC Components

a) Hydrocyclone

The Hydrocyclone, which is the heart of the underwater vacuum cleaner and which has been specifically designed to suit the prevailing conditions, that is: constructed in austenitic stainless steel material with a minimum envelope size and with a performance based on the flow provided by the encapsulated, submersible pump. The hydrocyclone is provided with an inlet, overflow and underflow connections. Impurities carried by the fluid are separated in the cyclone by a combination of centrifugal and gravitational forces. Heavy particles (density > 1) are automatically directed to the underflow connection while light particulate (density <1) are routed out through the overflow connection. The overall performance characteristics of this special hydrocyclone are:

Flow	: 400 L/min.
Under pressure	: 0.5 kg/cm^2.
Particle size distribution	: 40 - 5000μm
Particle density range	: 15 – 200 kg/m^2.
Efficiency of cyclone	: 95 – 98%.
Materials of construction	: Stainless steel 304L.

b) Submersible Pump

The Submersible Pump is specifically designed to operate in a flooded condition and is manufactured from stainless steel, compatible with demineralised water. It utilises a unique two-stage impeller with advanced design vanes for high efficiency.

Flow	: 400 L/min.
Pressure head	: 20 metres.
Motor size	: 1.5 kW(2 HP) thermally protected
Dimensions	: 139 mm- dia x 796 mm long.
Weight	: 25 kg.
MOC	: Stainless steel.
Power	: 380 volts 3 phase.

c) Collection Systems

The Collection Systems amounts to 3 i.e. a collection pot at the underflow from the hydrocyclone where the heaviest particles accumulate by gravity. The outlet of the pump, has two choices of collection system. This amounted to either a sack cloth bag capable of capturing particles greater than 40μm. For particles of greater size than 2μm, a multi - element filter is employed. To complete the UVC, a series of debris collection nozzles is designed supported on the end of an extendable tubular tool.

2) POOL SKIMMER, Filter and Pump

The Pool Skimmer is a portable surface water skimmer for the Water Pool and/or the Reactor Cavity. It is designed to operate in conjunction with a Underwater Filter/Vacuum system.

The Underwater Filter/Vacuum Systems takes suction on the skimmer’s bottom outlet camlock fitting. This draws water across the Skimmer Skirt and through the overflow trough.

As the filter cartridges start to load up from dirt buildup with extended operations, the flow can decrease through the skimmer. This will not significantly affect the skimming efficiency of the unit, since it is designed for a flow rate of between 200 and 600 L/min. The floating skirt weir will automatically adjust its level to the flow rate and maintain an efficient thin overflow stream.

It permits a thin overflow depth, which is necessary to effectively use water tension to skim pool surface water and not dilute the overflow stream with sub-surface water. The system operates under negative pressure. This design feature eliminates the need for special bolted pressure closures on the pump housing requiring tooling for operation. The pump housing seals with a simple flat cover plate held in place by negative pressure during operation.

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