Temporary Cooling System for Critical Loads During Recirculation Cooling Water (RCW) System Outage

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Abstract

As part of the Point Lepreau Refurbishment Project, Recirculation Cooling Water (RCW) system will be shutdown for maintenance activity. During the RCW outage, alternate cooling flow for critical heat loads such as Spent Fuel Bay (SFB), D2O vapour dryers and Instrument Air Compressor Coolers will be provided through a temporary cooling system to remove approximately 3MW of heat. This paper describes a practical strategy to build in the temporary cooling system for this project. Major equipment involved, piping modifications required and system reliability analysis are also addressed.

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1. Introduction

The Recirculation Cooling Water (RCW) system is a closed loop demineralized water cooling system which supplies cooling water to various coolers located at Reactor Building (R/B), Service Building (S/B) and Turbine Building (T/B). The system is designed to provide demineralised cooling water of adequate quantity to meet heat removal requirements of all plant RCW loads during normal and abnormal operating conditions. The heat absorbed in cooling the station equipment is transferred to the Raw Service Water (RSW) via the RCW heat exchangers.

In order to ensure extended design life of the RCW system, refurbishment of the RCW system valves and replacement of expansion joints are required to address age related degradation. RCW system shutdown is scheduled during Point Lepreau Generation Station (PLGS) 2008 refurbishment outage. During that time, the temporary cooling system is to take over the duties of the RCW system to accommodate the heat loads of essential systems.

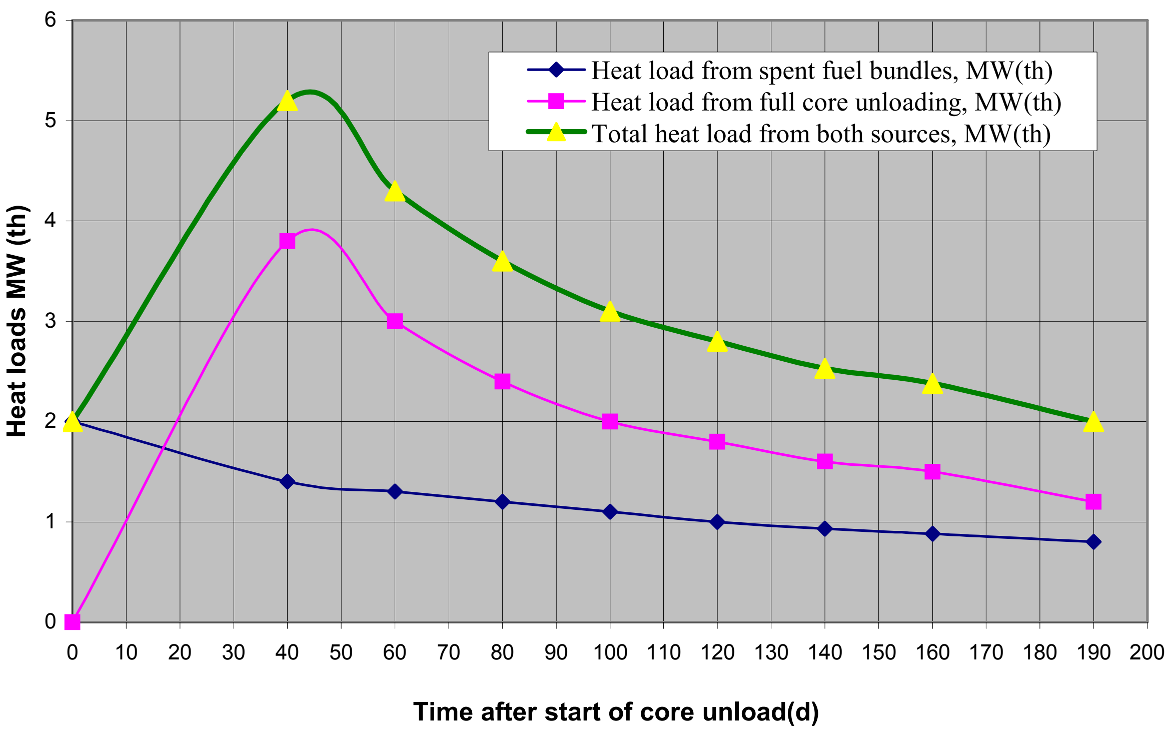
2. Temporary Cooling System

2.1 **Built-in Strategy**

One of the major requirements of the temporary cooling system is to remove decay heat after a full reactor core fuel dump to the Spent Fuel Bay (SFB). The fresh full core fuel transferred to the bay will impose a significant heat load in excess of normal condition. During the early stage of the full core of fuel being discharged into the storage bay, the RCW system will be required to run at full capacity to dissipate enough decay heat from SFB. The temporary cooling system is designed to handle the residual heat of decay which is 2 MW of the normal heat load.

To calculate the appropriate time to start the RCW outage and to put the alternative cooling in service, AECL reactor core physics department at Sheridan Park performed reactivity level analysis for a full-core fuel dump after reactor shutdown. Heat load after one full core of fuel transferred to the SFB during refurbishment together with normal heat input from spent fuels accumulated over ten years is presented in Figure 1.

Figure 1: Spent Fuel Bay heat load from spent fuel accumulated over the last 10 years prior to shutdown for refurbishment plus the heat load from full-core unload over 40 days as a function of shutdown time.



The total heat load when the full-core unload operation has been completed will be equal to approximately 5.2 MW. It will take about 190 days after shutdown before the total heat loads drop below 2 MW, which falls in the normal SFB heat load condition. The refurbishment activities will occur after 190 days of shutdown to take advantage of lower decay heat after core fuel unloading.

Besides the SFB, other essential systems like D2O vapour dryers (to recover D2O leakage and reduce tritium contamination), Instrument Air Compressor Coolers (for station instrument air supply), chillers (for plant air conditioning), etc. which are required to operate during plant outage, represent an additive of approximately 1 MW of heat load. The combined total heat load during PLGS outage is approximately 3 MW (approximate 853 refrigeration tons).

Temporary cooling system failure will impair the operation of safety related function of keeping the spent fuel cool in the SFB, so the possibility of occurrence of accident and time at risk is addressed.

Time at risk is considered to make sure the system failure risk has been reduced as low as reasonably practicable.

The solution involved weighing the risk against the mission time. To reduce the risk, the decision is weighted in favour of minimizing the system mission time to the shortest possible duration. A 21-day mission time, which can accomplish field refurbishment work and achieve risk reduction as low as practicable, was evaluated for system reliability.

2.2 System Description

2.2.1 Design Aspects

The concept of the temporary cooling system design is to replicate the original RCW system. It transfers heat from the current station equipment heat exchangers to the temporary loop. The heat picked up by the temporary loop is then transferred to the rental chiller units. To be compatible with current station heat exchangers, the cooling water is to be provided within original RCW design condition.

Based on RCW system original design, the temporary cooling system supply temperature must be maintained at between 13°C and 22°C under all conditions. To achieve these temperature, the rental chiller units must supply chilled water at 13~22°C. When the cooling water supply temperature is low or the heat load is low, the chillers shall maintain a minimum water supply temperature 13°C. Water temperature controller from cooling skids to the loads is to be provided as one of the basic features of chiller units.

The cooling flow requirements for individual heat load are selected based on station RCW system Design Manual (DM) under the condition of Reactor Trip, Turbine Down and Class IV power available.

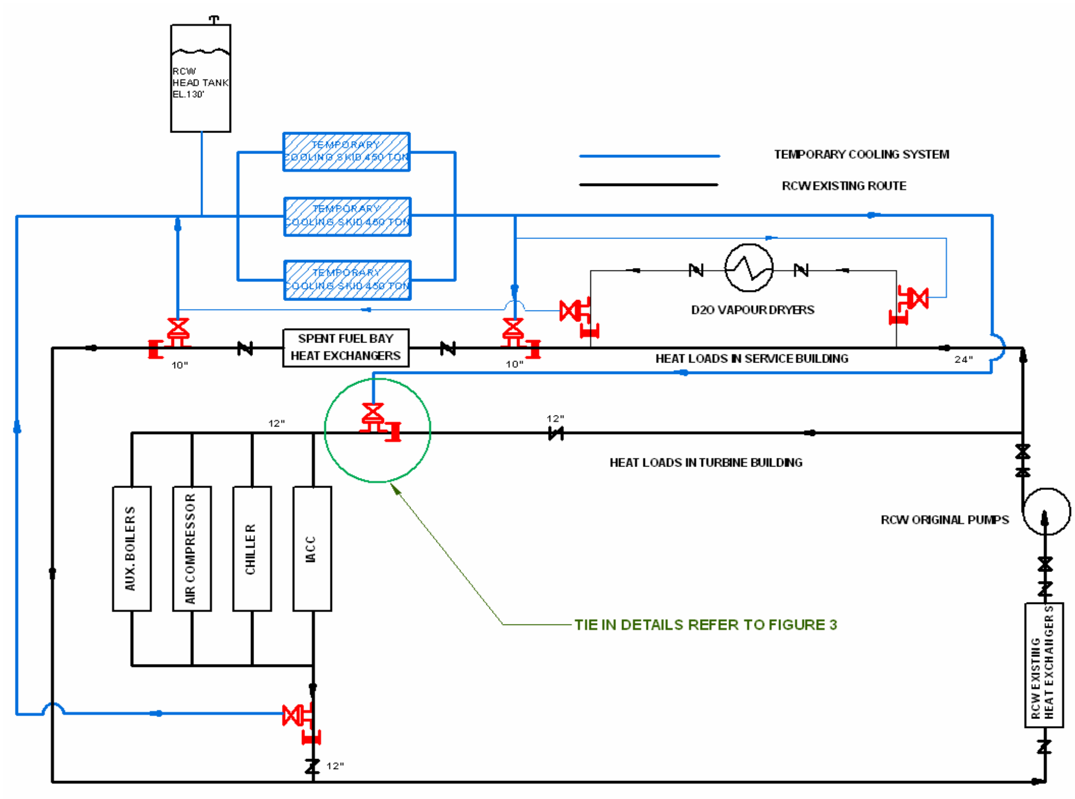
The major function of temporary cooling system is to maintain the temperature of the SFB water below 49ºC. The bay water temperature may follow variations in the cooling water temperature provided, but the bulk bay water temperature is never reduced by more than 1.7 ºC/day. This avoids any damage in the reinforced epoxy resin lining of the bay. The temperature of the process stream, through SFB heat exchangers is controlled by varying the flow of RCW temporary cooling by means of existing temperature control valves.

Other loads do not require continuous temperature control. They have manually operating throttling valves or orifice plate in existing RCW cooling circuit to limit the flow through the equipment.

2.2.2 System Layout

The temporary cooling system consists of two parallel circuits, one for SFB with a sub-loop for D2O vapour dryers, which are both located in S/B, and the other for cooling loads located in T/B. The tie-in locations for temporary cooling system are chosen at the closest possible locations to heat loads on the RCW original piping route, in order to limit the interference with other systems. The sketch of the system diagram is shown in Figure 2.

Figure 2: Temporary Cooling System Diagram



To accommodate a total of approximately 3 MW (866 tons) of heat, three 450-ton portable chiller skids, each including pumps and a heat exchanger, are piped in parallel. Two of the three chillers have sufficient cooling capacity to provide chilled water to the heat loads, while the third chiller remains in standby. This configuration permits safe and reliable operation with 50% capacity redundancy. The chilled water is brought to a common header. The header branches into two lines that supply the S/B and the T/B respectively. After extracting heat from the heat exchangers and coolers, the water is returned to chiller suction common header. Throttled manual butterfly valves will be provided at the system tie-in points to regulate the flows to the S/B and the T/B. The process stream flows from the chiller skids to the heat loads via the system tie-in tee connections. The tee connections comprise a tee, a manual butterfly valve, and a knife gate valve which shifts the heat loads to the temporary cooling system or to the RCW normal route.

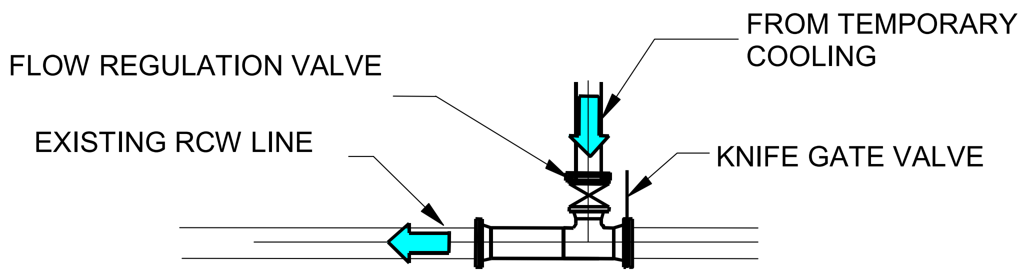
The temporary cooling system is filled with demineralised water directly from the RCW head tank at elevation 130’ via a temporary hose connected to the pump suction at elevation –5’. A static pressure of 135 feet can be maintained during operation to maintain system make-up water, if required as a result of pump gland leaks, valve leaks or piping leaks.

2.3 Equipment Involved

2.3.1 Tie-in Tee with knife gate valve

The purpose of tie-in tee is to alter the water flow route from the normal RCW loop to the temporary cooling loop. A knife gate valve is used at one end to obtain an absolute shutoff of flow. This isolation mechanism provides a positive external lock of the blade and visual check of its open or closed position, which will not affect system reliability model. Sketch of the tie-in tee is shown in Figure 3.

Figure 3: Details of tie-in tee connection



In the event that the RCW piping will be out of service at some time in station's life, for inspection or repair, this configuration can be left in the system as a permanent modification to allow for future system isolation.

2.3.2 Ice plugs

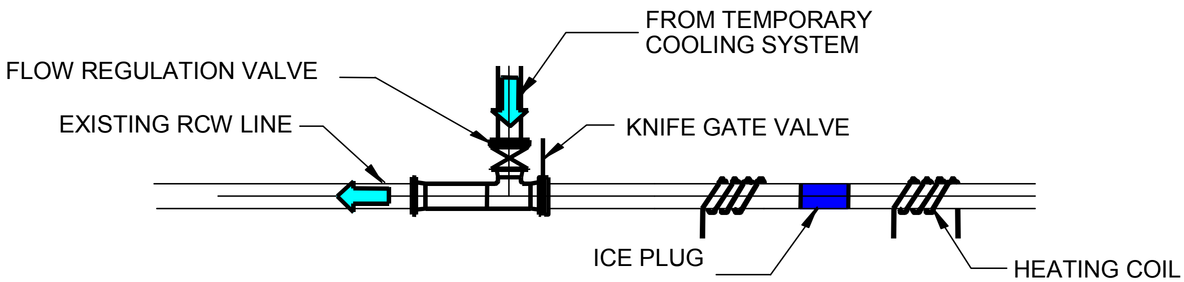
To set up the whole piping system, especially to perform the tie-ins, it is necessary to streamline the activities to minimize the RCW downtime without temporary cooling. Ice plugs, also known as pipe freezing, are to be used initially to isolate critical heat loads from the RCW normal route.

This pipe freezing technology utilizes liquid nitrogen to create cryogenic temperatures necessary to form ice plugs. Freezing is performed by isolating the pipeline with a pipe freeze jacket that is bolted onto the line. Liquid nitrogen is then released into the pipe freeze jacket, allowing a solid ice plug to form inside the pipe.

The pipe freezing will take place on 6" lines (D_2O Vapour dryer coolers), 10" lines (SFB heat exchangers) and 12" lines (TB cooling loop). It is estimated that it will take approximately 0.8 hour, 2 hours and 3 hours to establish an ice plug on 6", 10" and 12" lines respectively.

This technology allows for very little drain-down or refill of the process lines, and in certain conditions, no system downtime. Once the work is complete the plugs are thawed and the line is placed back in operation. The process sketch and a typical ice plug service picture are shown in Figure 4.

Figure 4: Tie-in tee with ice plug installed



Ice plugging service
(Pictures were reprinted with the permission of TDW services Inc, USA [1])

Under normal conditions, in the case of the loss of coolant for SFB, it takes approximately 20 hours to reach the bay water high temperature alarm point (~49 $^{\circ}$C). So the ice plugs can only remain in place for a very limited time to perform the tie-ins.

2.3.3 Chiller skids with associated pumps

The chiller skids are trailer mounted water cooled chillers with on-board chilled and condenser water pumps. Figure 5 shows a standard module of water cooled tractor trailer chiller units with a packaged portable cooling tower.

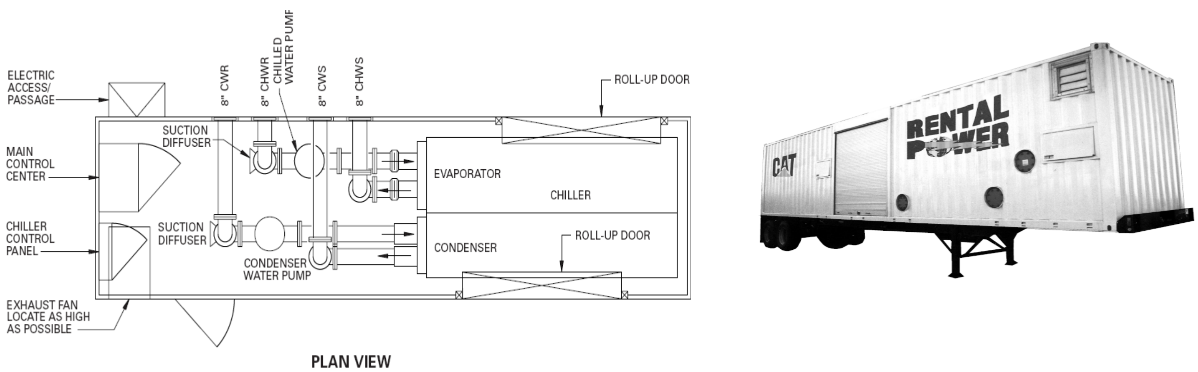
The major components of the chiller unit are:

- Water-cooled screw chiller (assembly) with a microcomputer control center for operating and safety controls;
- Condensate pump;
- Chilled water pump;
- Triple duty valves to dial in proper flow to evaporator and condenser;
- Check valve on condenser water line to ensure proper suction requirements to condenser water pump;
- In-line water strainers to protect system from foreign objects;

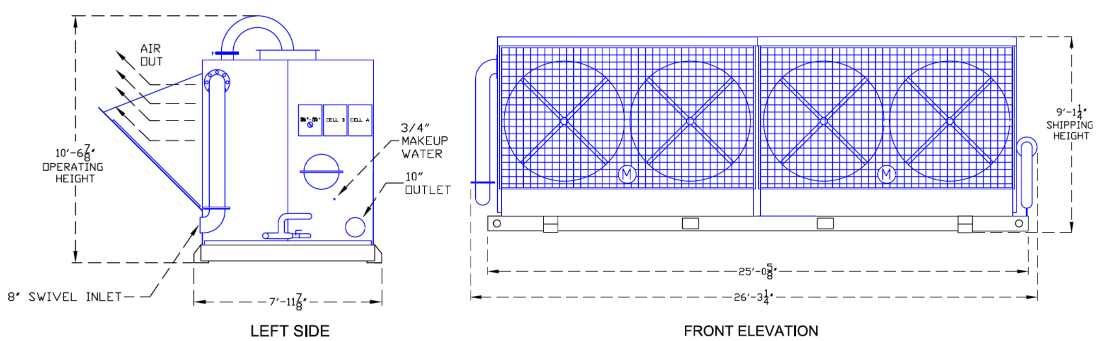
- Main adjustable circuit breaker;

Figure 5: General layout for the Tractor Trailer Cooling Skid.

(Pictures were reprinted with the permission of Caterpillar®, American Chiller Service, and USA, [2])



Water cooled chiller module



Portable cooling tower module

The major components of the cooling tower are:

- Baltimore Aircoil (BAC) Cooling Tower;
- Flow control valves are pre-mounted;
- Single point overflow, bleed and drain connection;
- Electronic water level control with ¾" fill connection;
- Dual main power inputs with lockable breakers
- Victaulic piping connections (inlet and outlet).

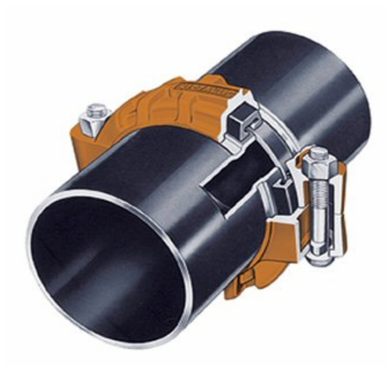
2.4 Pipe Work

The discharged cooling water from the cooling units are collected in a 10" Carbon Steel (CS) header and are branched into 6" and 8" CS pipe to TB and SB respectively. After passing through the coolers, the water returns to a 10" suction header. Most of the piping is conveniently located at ground level.

The pipe used for temporary cooling system is CS with Victaulic piping joints. Victaulic pipe joining provides a grooved end mechanical pipe joining system, a mechanical bolted coupling that would engage into grooves and a gasket seal. Figure 6 represents a typical Victaulic piping joints assembly. This pipe joining method dramatically reduces the amount of installation time and reduces total installed costs as compared to welding, threading or flanging. They have also been shown to reduce man-hours over welding and to accelerate construction to meet compressed schedules.

Figure 6: Victaulic piping joint assembly

(Picture was reprinted with the permission of Victaulic Company, USA [3])



The Victaulic joint involves three basic concepts:

- A pressure-responsive gasket that creates a leak-tight seal;
- Couplings that hold the pipe together and;
- Bolts and nuts that secure the couplings.

A groove is rolled or cut into the end of the pipe to engage the couplings, whereupon the gaskets seal on the outside diameter of the pipe. The sealing action is enhanced as the couplings are tightened by line-operating pressure or vacuum.

The whole piping system for the temporary cooling system, including piping installation and chiller units hook up, will adopt this Victaulic piping method to achieve fast and easy piping installation and removal.

3. System Reliability Analysis

In order to replicate a similar reliability target of the temporary cooling system to that of the RCW system configuration, a comparison of temporary cooling system reliability with the RCW heat exchanger reliability was performed by the AECL Probabilistic Safety Assessment (PSA) group.

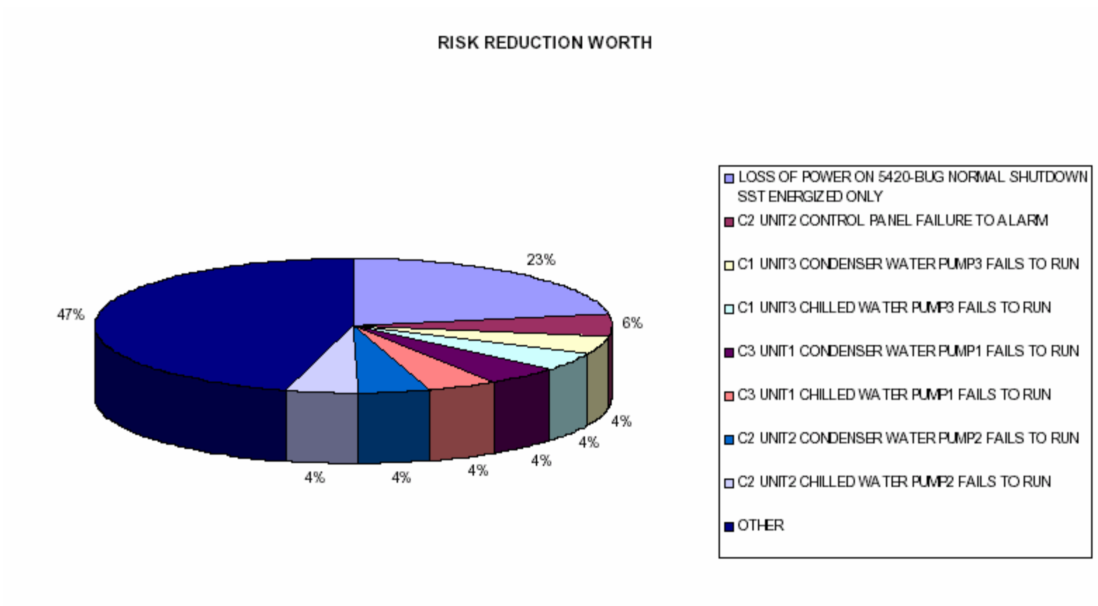
The evaluation criteria is based on a 21 day mission time, 3 x 50% Tractor Trailer Chiller Skids (TTCS) piped in parallel, and the duty cycle as follows:

	Week	Unit 1	Unit 2	Unit 3
Configuration 1(C1)	1	ON	ON	STANDBY
Configuration 2(C2)	2	ON	STANDBY	ON
Configuration 3(C3)	3	STANDBY	ON	ON

The Window-based codes package, CAFTA (Version 5.2), is used to develop, plot, evaluate, and quantify the TTCS Fault Tree (FT).

The reliability results for temporary cooling system and Risk Reduction Worth percentage have been extracted from 87RF-03611-AR-020:

Top Event	Description	Unavailability
TTCS-RCW-REPLACE	Failure of TTCS units to provide the cooling flow to loads	***4.41E-03***



Based on the Risk Reduction Worth pie chart, there is one main contributor to system failure, which is loss of power supply (23%). There are seven other components that are represented by the C2 Unit 2 control panel fails to alarm (6%), and the condenser water pumps and chilled water pumps fail to run with 4% each.

The other contributors such as piping leakage, valves failure and water strainers failure have an individual lower impact on system reliability of less than 1%, but collectively add up to ~47% of the total.

In order to compare TTCS probability of failure for 21 days with the existing RCW system probability of failure for 21 days, the RCW reliability has been calculated using the same fault tree (FT) method. The RCW reliability for 21 days mission time is ***4.0E-02.***

Therefore, there is a calculated reliability of TTCS that is ten times better than the RCW. With this comparison basis, it is concluded that the configuration of three TTCS units 3x50% with two units running and one in standby in duty cycle, represents a viable replacement of RCW cooling function for the SFB and the TB loads during the refurbishment outage.

4. Conclusion

The Point Lepreau Generating Station is the first CANDU 6 to undergo full retubing refurbishment. Placing the RCW system out of service with full core fuel unloading to SFB is unique to the retubing refurbishment process.

The RCW temporary cooling system will play a very important role to ensure plant safe conditions during PLGS 2008 outage. It is designed to keep SFB water cool and maintain an adequate water level in the storage bay to ensure proper shielding during all phases of the plant refurbishment.

The temporary cooling system outlined in this paper provides a method for isolating the RCW system for the refurbishment work while providing cooling to critical loads with reliability suitable for the design bases of the plant.

5 References:

[1]. TDW Services Inc., "Freeze plugging service", *http://www.tdwilliamson.com*

[2]. American Chiller Service, "Caterpiller Chiller units", *www.CAT-ElectricPower.com*

[3]. Victaulic, "Victaulic Couplings", *http://www.victaulic.com*