Main Control Room Hvac Inlet Location Optimization To Improve Control Room Habitability Under Postulated Accident Conditions

Stéphane Boucher, Mech EIT
Field Engineer, Atomic Energy of Canada Limited, Saint John, New Brunswick, Canada

Abstract

As part of the Point Lepreau Refurbishment Project, an emergency filtering unit will be installed on the Main Control Room make-up air system to ensure habitability of the Main Control Room is maintained following an accidental atmospheric release.

This enhancement has provided an opportunity to relocate the existing make-up air inlet in an effort to minimize intake of radioactive by-products and loading of the filter bank. Atmospheric dispersion calculations were performed at radioactivity release points based on local historical weather data to estimate plume dispersion.

This paper presents the results of this study and summarizes the improvement of operator dose uptake during the specified occupancy period.

Acknowledgement

The author would like to recognize and acknowledge the efforts of Philip G Smith and Kam Aydogdu – Reactor Core Physics who performed all analyses presented in this paper, as well as Bill Cooper – Field Engineering Manager who provided his experience and guidance throughout the collective effort.

1. Introduction

1.1 Background

The Point Lepreau Generating Station (PLGS) is a one-unit CANDU® 6 nuclear facility that supplies approximately 30% of the electricity consumed in New Brunswick [1]. As part of the Refurbishment Project, whose aim is to extend the life of the plant another 30 years at 80% capacity factor, the Main Control Room (MCR) Heating, Ventilation and Air Conditioning (HVAC) system will be upgraded to include a radioactive element filtration system. This upgrade is a standard feature on the enhanced CANDU 6 design and has been implemented on newer stations.

The function of this additional filtration system is to reduce the level of airborne activity to provide safe conditions under a controlled environment for the personnel inside the control room under limiting design-basis accident scenarios such as Loss of Coolant Accident (LOCA) with Loss of Emergency Core Cooling (LOECC) and Feeder Stagnation Break (FSB) with Loss of Containment Isolation (LOCI). To achieve this objective, the main control room area must remain habitable even

---

CANDU is a registered trademark of Atomic Energy of Canada, Limited (AECL).

in the event of accidental radioactive material release to the outside atmosphere. This requires a new emergency filter unit in the HVAC system serving the MCR to ensure the radiation dose the MCR personnel might receive, if such accidents were to occur, will not exceed allowable limits set by the Canadian Nuclear Safety Commission (CNSC).

This paper illustrates the practical application of As Low As Reasonably Achievable (ALARA) principles in an effort to minimize MCR personnel dose uptake during a design-basis accident over the past implemented design. A summary of the analysis and dispersion calculations made to quantify the MCR operator dose reduction is also presented.

1.2 System Description

The existing MCR HVAC make-up air system is comprised of an air intake louver on the Service Building roof and a duct that ties into the MCR HVAC system near the MCR. Approximately 2800 cfm of air is drawn into the system via this duct.

1.2.1 Filter Unit

The filter unit will be installed and tied to the existing make-up air duct on the Service Building roof. The filter unit consists of two 100% centrifugal fans, a filter train including a pre-heat coil, two HEPA filters, a charcoal adsorber filter and a number of isolation dampers. See Figure 1 below. One fan is operated in AUTO mode while the second is on STANDBY mode. A filter bypass duct, equipped with redundant motorized dampers, will provide an unfiltered flow path during normal operation. The customary air inlet location has been at the filter. An opportunity exists to locate the inlet elsewhere to reduce the concentration of contaminated make-up air introduced in the MCR during an accident.

Figure 1 – Cernavoda 2 filter unit at manufacturer facility.

1.2.2 HEPA Filters

The HEPA filters are nuclear-grade, fire resistant and have a minimum efficiency of 0.3 μm monodispersed aerosol at over 99.97%.

1.2.3 Charcoal Adsorber

The charcoal adsorber is designed to remove radioactive iodine from the air in the form of elemental iodine (I_2) and organic iodine, namely methyl iodide (CH_3I) by adsorption. The removal efficiency of iodine is approx. 99%.

1.2.4 Filter Unit Operation

During normal operation, the filter train is bypassed and air is routed directly to the existing plant HVAC system.

During accident conditions, the two redundant bypass dampers automatically close while the fan on AUTO starts and its isolation dampers open. Air is drawn through the pre-heat coil to elevate its temperature and maintain a low relative humidity in order to prevent moisture from condensing in the filter adsorbent and charcoal media. The air then travels through a pre-filter, HEPA filter, charcoal adsorber and a final HEPA filter prior to being introduced to the plant HVAC system. See Figure 2. Manual activation of the system can also be initiated by the operator.

2. Design Considerations

2.1 Accident Scenarios

For the purpose of establishing bounding conditions, two design-basis accident scenarios were considered:

1. Loss Of Coolant Accident (LOCA) with Loss Of Emergency Core Cooling (LOECC)

   In this scenario, the radioactivity releases into containment are the highest among all other design-basis accidents; the leakage from containment and the releases from the stack prior to containment button-up are of primary interest. Release durations are in the order of several days.

2. Feeder Stagnation Break (FSB) with total Loss Of Containment Isolation (LOCI)

   Since containment isolation is impaired, the releases from the Reactor Building Ventilation System (RBVS) inlet and stack are of primary interest. Release durations are in the order of several hours, though most of the release occurs well within the first hour.

Both scenarios present source terms in the form of activated particulate, to be entrapped by the HEPA filters and shielded from the MCR, iodines to be adsorbed in the charcoal filters, also to be shielded from the MCR, and noble gases, which are not affected by the filter unit. The main method of mitigating operator dose uptake from noble gases is to increase the filter inlet distance from the source terms (i.e. RBVS inlet, stack and reactor building wall) such that dilution will reduce entrainment of the activated gases. It should also be noted that increasing the filter inlet distance will also reduce particulate and iodine loading on the filters and thus its shielding requirement for the same reason.

2.2 Filter Unit Configuration and Inlet Location Selection

Location of the filter unit was established considering the proximity to the existing make-up air duct, weight and space constraints, and accessibility. The Service Building roof presented favourable conditions for this installation. This is consistent with the past filter unit design layout.

Fan configuration on the PLGS filter unit was changed from the past filter unit design at the newer CANDU stations: Previously, the fans were located downstream of the filters. As a result, any potential air leakage between the filters and fans would allow unfiltered air into the airstream, thus bypassing the filters.

For PLGS, the fans were relocated upstream of the filter bank such that the entire air path through the filters is now under positive pressure. This has two effects: Any leakage into the inlet duct (upstream of the fans) would still be filtered and any leakage downstream of the filters would flow out to the outside air and therefore not potentially compromise the system. Refer to Figure 2 below.

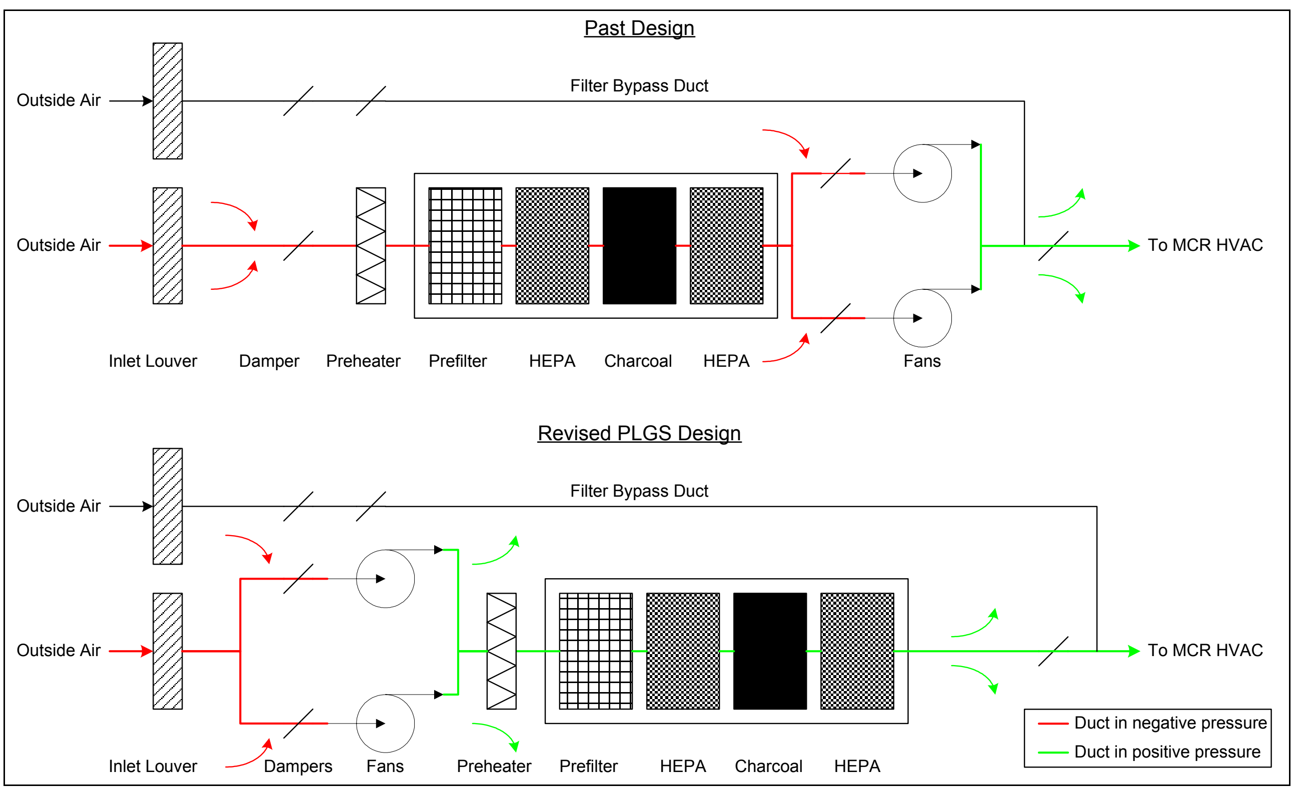

Figure 2 – PLGS Filter unit design configuration comparison with past design.

Three filter inlet locations (i.e. inlet louver in Figure 2) were proposed for the purpose of calculating atmospheric dispersion factors and are numbered Locations 1, 2 and 3. The filter unit itself is situated at Location 3. Historically, Location 3 has also been the chosen location for the filter inlet. Two additional locations were considered for the PLGS project as shown in Figure 3 below.

Weather data at the Point Lepreau site was obtained to indicate the direction and frequency of prevailing winds. The wind rose in Figure 3 summarises the occurrence of winds in a particular direction. Each branch of the rose represents wind coming from that direction. The length of each branch is proportional to the frequency of winds blowing from that direction.

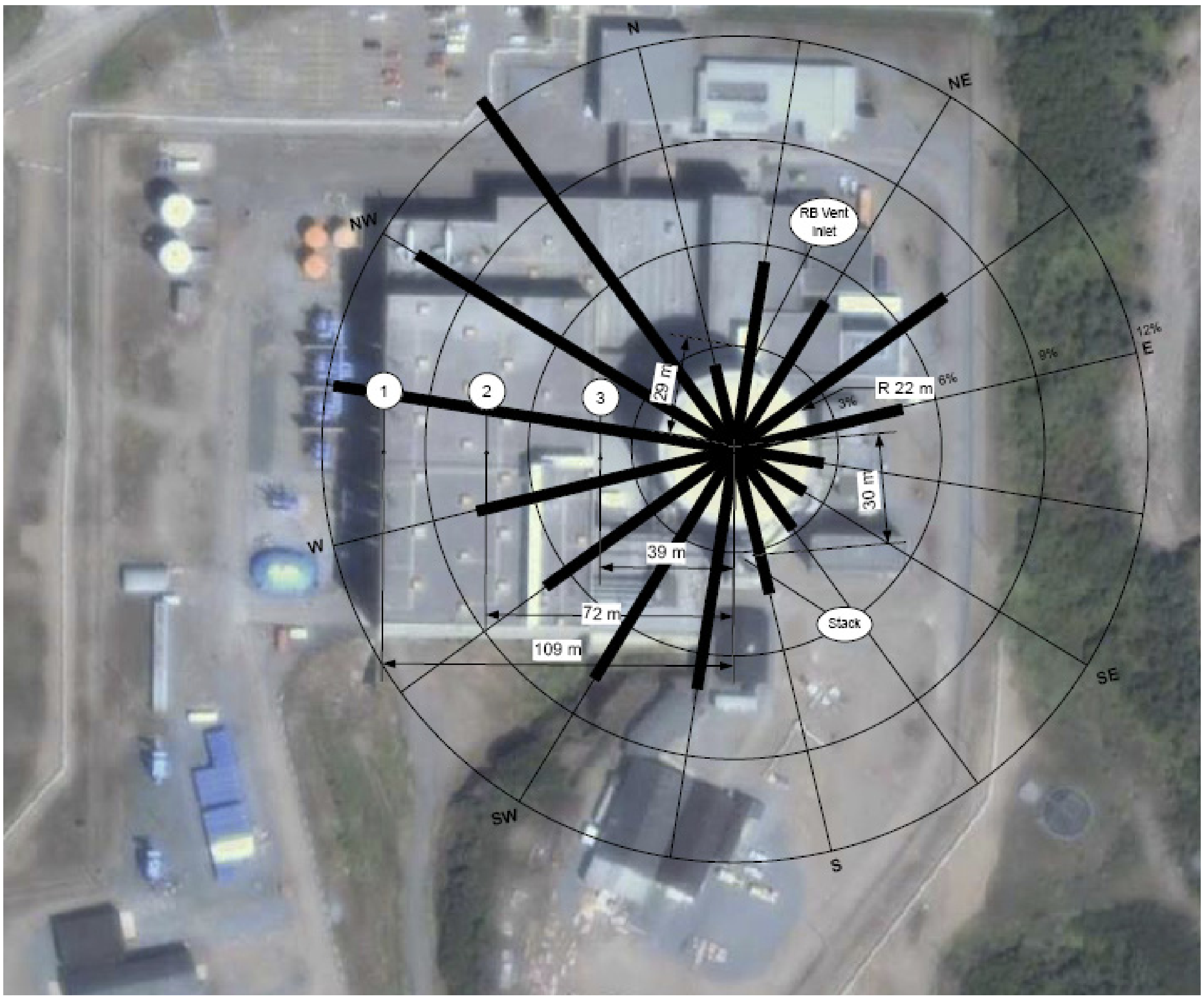

Figure 3 – Proposed filter inlet locations with superimposed wind rose. Arial photo courtesy of Google Earth™.

Figure 3 shows that all three proposed filter inlet locations are located in a favourable sector where they are upwind of prevailing winds. Moreover, Location 1 benefits most from dilution effects given its superior distance from the release points. As a result of this preliminary qualitative assessment, Location 1 was the favoured location for the filter inlet.

3. Operator Dose Estimation

3.1 Operator Dose Acceptance Criteria

Historically, in the design of the MCR HVAC filter unit at the newer stations, the whole body dose acceptance criteria for control room personnel was taken to be 100 mSv, twice the annual dose limit for Nuclear Energy Workers (NEW). This has been consistent with CNSC regulations that in exceptional circumstances, twice the yearly allowable dose can be tolerated.

As part of the design implementation process for PLGS utilizing ALARA principles, the maximum allowable operator dose target was challenged: A 50% reduction to 50 mSv was considered. The main goal of this ALARA exercise was to build on the existing design to further improve dose savings well beyond regulatory requirements. The mission time for the filter system is 30 days, during which the filter unit must be capable of performing its function without operator intervention. For individual operators, continuous occupancy of the MCR is assumed to be 24 hours immediately after the accident and 8 hours per day thereafter.

3.2 Atmospheric Dispersion and MCR Operator Dose Calculations

In order to estimate the MCR operator dose for each proposed filter inlet locations, an atmospheric dispersion model was created for the two postulated design-basis accidents using weather data obtained from PLGS. Dispersion factors obtained were scaled against previously calculated operator doses from previous work to obtain a reasonable estimate of PLGS's operator dose uptake. Figure 4 illustrates the dispersion factors relating to stack emissions at each of the three proposed filter inlet locations. Similar factors were obtained for the RBVS inlet and RB wall leakage source terms.

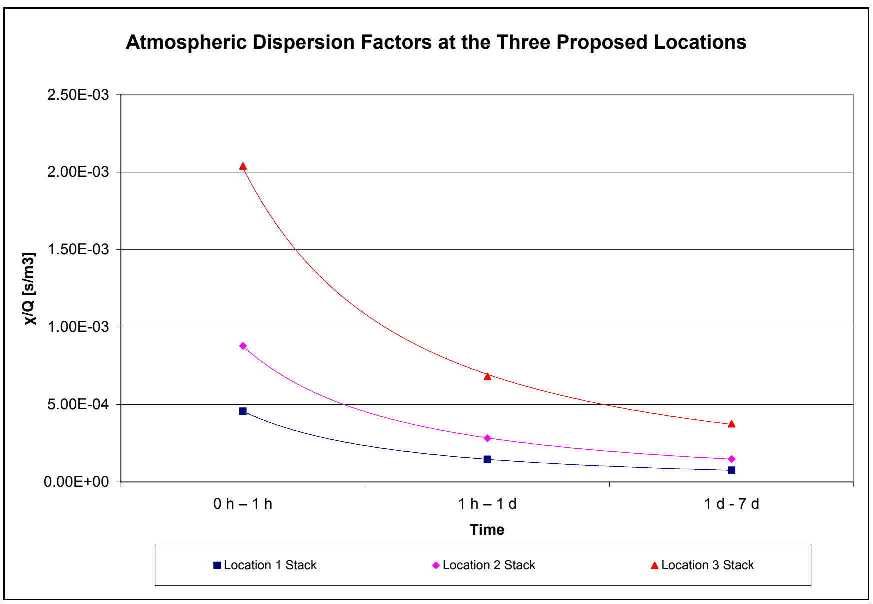

Figure 4 – Atmospheric dispersion factors from stack emissions at the three proposed locations.

The above figure demonstrates that Location 1 exhibits the greatest dispersion from stack emissions compared with Locations 2 and 3. This is also representative of RBVS inlet and containment leakage source terms. Location 3 illustrates poor dilution due to its close proximity to the emission points, particularly during short-term stack emissions, although no credit was taken for plume rise or buoyancy effects in any releases.

It can be observed from the full dataset that Location 2 factors are nearly half in magnitude of those at Location 3 and that Location 1 factors are half those of Location 2. It was therefore reasonable to conclude that the dose rate in the MCR should drop by a similar factor.

By observation of the PLGS dispersion factors for the three locations, the operator dose obtained from Location 3 was prorated accordingly. The FSB with LOCI scenario was determined to be the bounding condition relating to MCR personnel dose uptake. The results of this analysis are summarized in Figures 5 and 6 below:

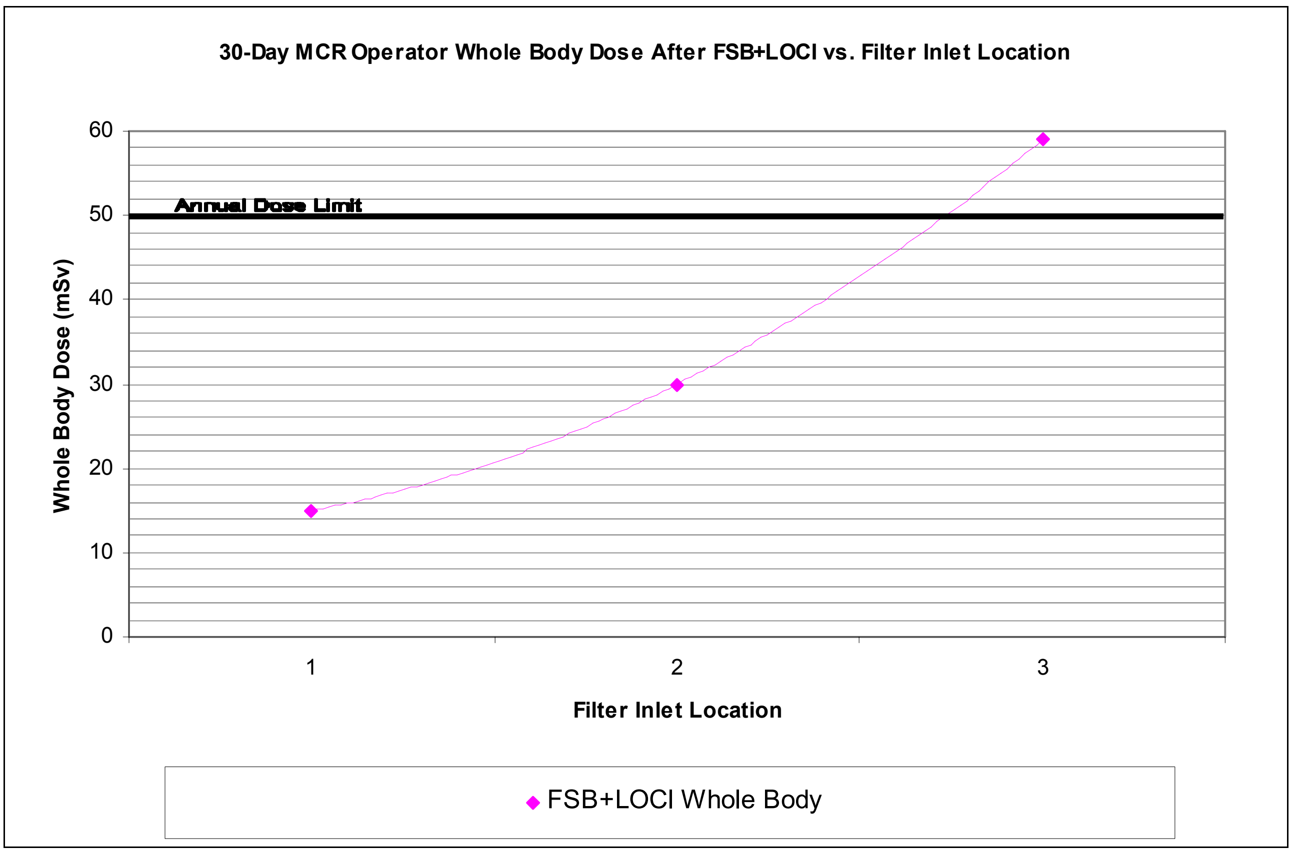

Figure 5 – Total MCR operator whole body dose estimate 30 days after a FSB+LOCI accident. This scenario proved to be the bounding condition for total whole body operator dose.

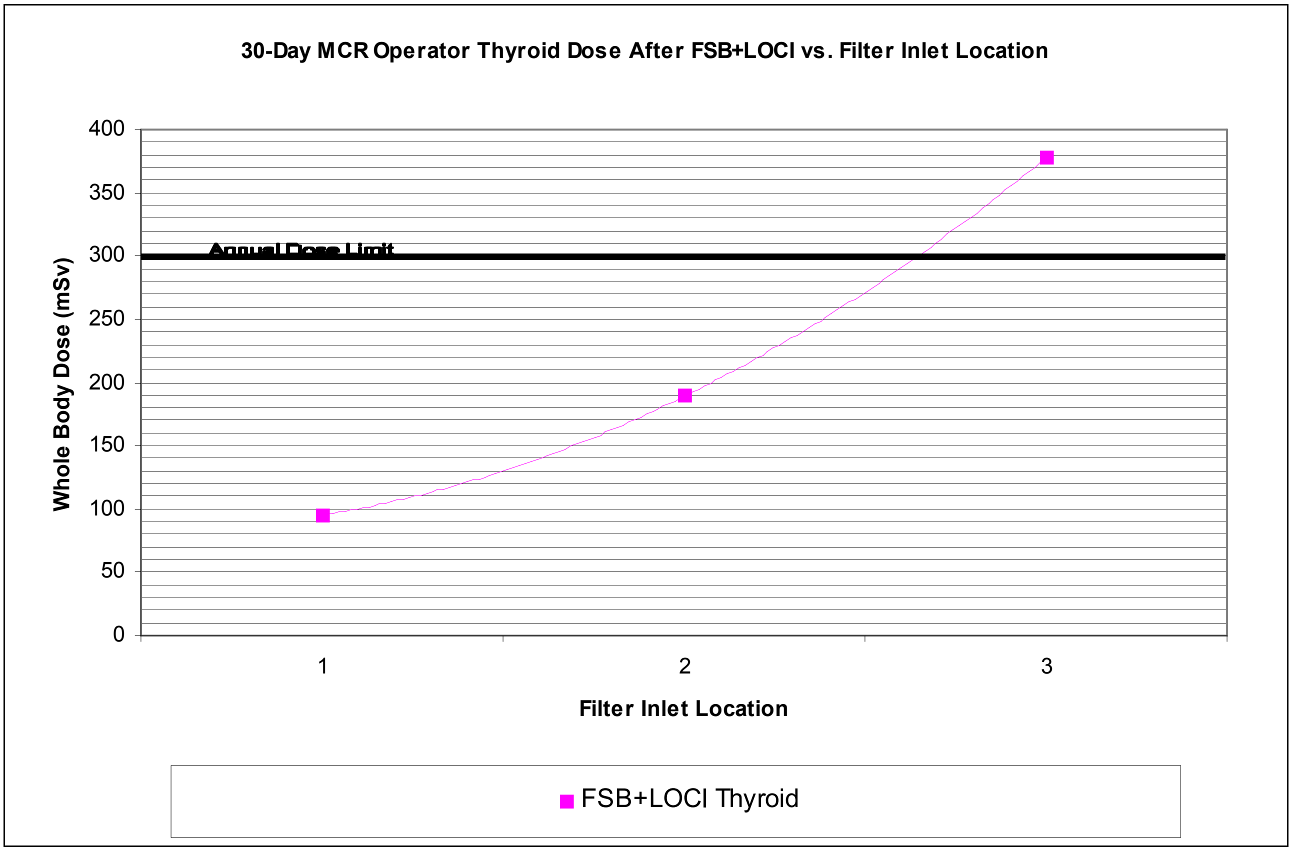

Figure 6 – Total MCR operator thyroid dose estimate 30 days after a FSB+LOCI accident. This scenario proved to be the bounding condition for total thyroid operator dose.

It should be emphasised that in actual fact, during a LOCA with LOECC, the MCR personnel will acquire the great majority of his/her entire dose within 7 days. During a FSB with LOCI, the effective time span is reduced to less than 5 hours.

Based on this analysis, Location 1 was selected as the final location for the filter inlet.

3.3 Filter Unit Shielding Analysis

Placement of the MCR HVAC Filter Unit on the Service Building roof presented the fewest constructability issues such as space constraints, discharge duct routing and weight restrictions. The close proximity to the existing HVAC system also played a significant role.

The close proximity to the Main Control Room did present a possible additional hazard where particulate loading and especially iodine adsorption to the filters could generate sufficient gamma fields as to adversely impact the accumulated total dose to operators during the mission time. Shielding is required to mitigate this consequence. Figure 7 shows the relation between the filter unit on the Service Building roof and the surrounding areas on the top floor (elevation 75’-2”) of the Service Building. The main areas of concerns were the MCR (S1-326), Control Equipment Room (CER) (S1-328), Telecommunication Room (S1-315) and corridor (S1-317).

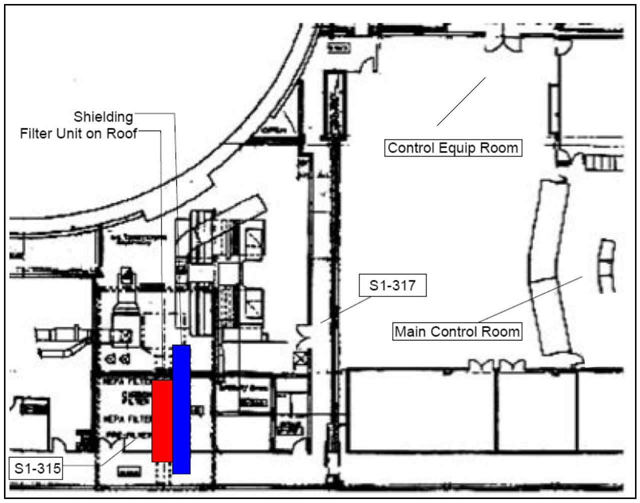

Figure 7 – Layout of MCR HVAC Filter Unit on Service Building Roof (el. 93'-3") in relation to adjacent areas at PLGS el. 75'-2".

The shielding objective was to lower the dose rates to the MCR down to negligible levels. In addition, dose rates to other adjacent areas as a result of gamma fields emitted from the filters must be reduced to acceptable levels.

For shielding calculation purposes, it was assumed that the charcoal adsorber captured 100% of all iodines and that all particulates were captured on the first HEPA filter; no credit was taken for the second HEPA filter. In addition, the Service Building roof was assumed to provide negligible shielding and was therefore not considered. The concrete walls separating the filter from the MCR were modelled as 8-in thick ordinary concrete. These walls were modelled as shown in Figure 8.

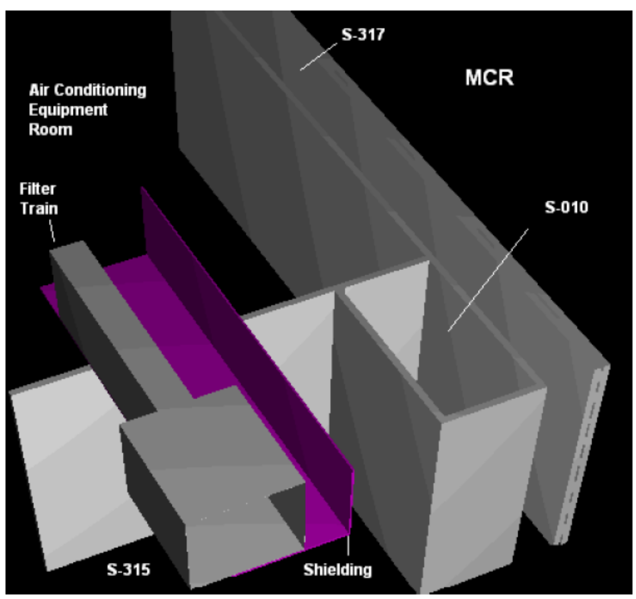

Figure 8 – Approximate Model of Emergency Filter Unit.

Two locations were chosen in the MCR and CER to evaluate operator dose rates and time-integrated doses due to fields emanating from the loaded filter unit (see Figure 7). Dose rates were also calculated in S1-315 and S1-317.

Dose rates were calculated at 1.8 m above floor elevation (el. 75’-2”) using fluence-to-dose conversion factors given in ANS-6.1.1-1991 [2]. The bounding condition for gamma fields from the filter unit was found to be in S1-315 after a FSB+LOCI. Figure 9 shows these dose rates as a function of time. Resulting gamma fields to the CER, MCR and S1-317 were similar in profile and ranged approximately 3 to 4 decades lower in magnitude.

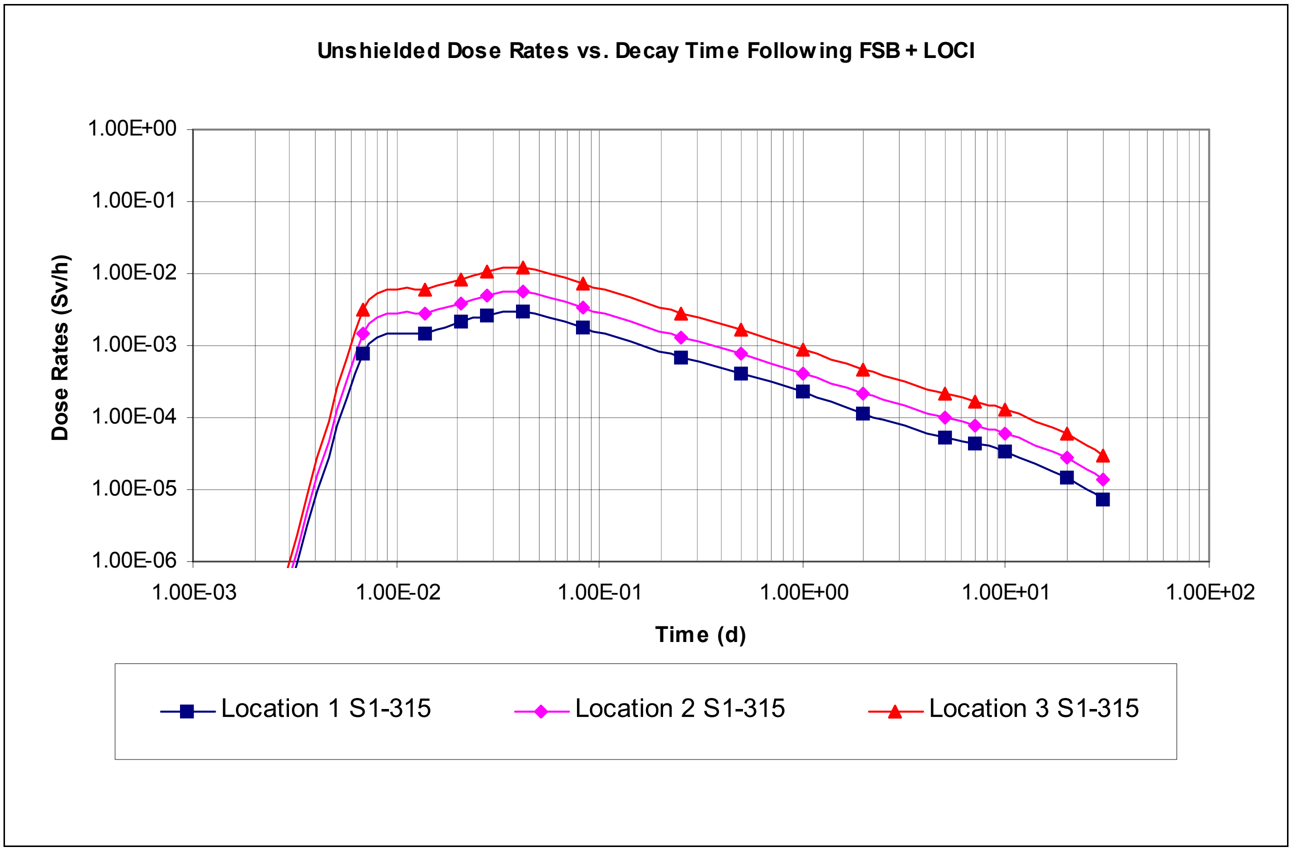

Figure 9 – Operator Dose Rates due to gamma fields from an unshielded filter unit vs. Decay Time Following FSB+LOCI. This scenario was determined to be the bounding condition for operator dose rates due to gamma fields.

Time-integrated doses in the MCR and CER were calculated from the gamma fields off an unshielded filter unit. The FSB+LOCI scenario presents the bounding condition for shielding requirement.

Selection of Location 1 for the filter unit inlet location over the original Location 3 produces at most a dose savings of only 0.11 mSv in the MCR over the 30-day occupancy period. The unshielded dose rates in the MCR and CER from the activity on the charcoal and HEPA filter as shown in Figure 10 were found to be manageable with respect to the dose rates from sources during accident conditions.

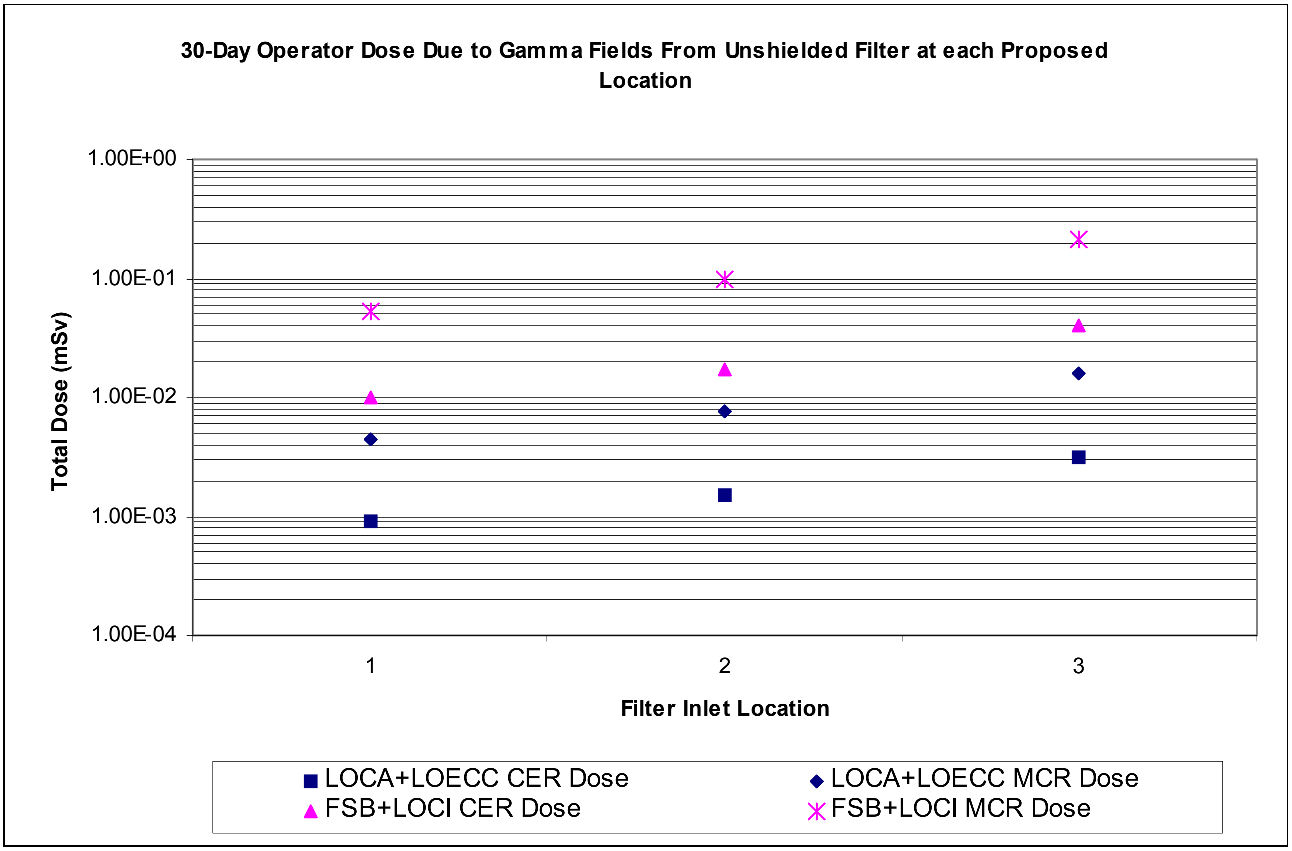

Figure 10 – 30-Day MCR operator gamma dose from Unshielded Filter at each Proposed Location.

Shielding of the filter unit, though not critical for MCR habitability, will aid in lowering fields in adjacent areas. Dose rates from an unshielded filter unit will exceed 2 mSv/h in S1-315 during the first hour from Location 1 compared to approximately 2 hours from Location 2 and 6 hours from Location 3 until by-products entrapped in the filter decay sufficiently.

It was therefore recommended that ½ in of steel shielding be installed at the filter unit with the inlet at Location 1.

4. Discussion and Conclusion

Installation of a MCR HVAC Filter Unit at PLGS provided an opportunity to refine the existing design used at other CANDU stations. These changes are summarized below:

4.1 Reconfiguration of Filter Fans

Relocation of the fans upstream of the filter bank ensures that the filters are pressurized during operation. This prevents any air in-leakage that would bypass filtration, thus potentially hindering the overall system effectiveness.

4.2 Relocation of Filter Inlet

The objective for relocating the filter inlet was to reduce MCR operator dose uptake during accident conditions. Secondly, it allows for reduction of shielding requirements and associated weight considerations.

During design implementation evaluation, it was felt that the existing dose acceptance criteria could be improved over the existing design. The MCR operator dose acceptance criteria that has historically been set at twice the annual limit for Nuclear Energy Workers was reduced by 50% to the annual limits (50 mSv whole-body, 300 mSv thyroid) as an ALARA target. The MCR operator dose was estimated for the two bounding design-basis accident scenarios, LOCA+LOECC and FSB+LOCI, at three proposed filter inlet locations.

Prevailing wind directions at PLGS presented favourable conditions for relocating the filter inlet away from major source terms during the postulated accident scenarios considered. Relocation of the filter inlet upstream of prevailing winds greatly reduces ingress of activated noble gases, aerosols and particulate into the MCR HVAC system, thus positively impacting MCR operator dose uptake.

It was found that Location 3, the standard location for both filter unit and filter inlet at other CANDU stations, does not meet the new ALARA target for PLGS.

Locations 2 and 1 both comply with the ALARA target, with Location 1 yielding the most dose savings. Location 1 reduced MCR operator whole body and thyroid dose by a factor of 4 in comparison with the original Location 3. As a result, Location 1 was chosen for the new filter inlet.

4.3 Shielding Analysis

A shielding analysis was performed on the filter unit with the goal to reduce the gamma fields to the MCR personnel down to negligible levels. With the inlet at Location 1, it was determined that no shielding is required to safeguard the MCR; however ½ in. of steel shielding is provided to reduce fields in nearby areas down to manageable levels during the initial hours after a design-basis accident.

5. References

[1] "CANDU Owners Group Inc.", http://www.candu.org/nbpower.html, (accessed March 2007).

[2] "Neutron and Gamma Ray Fluence to Dose Factors", American Nuclear Society, American National Standard ANSI/ANS-6.1.1-1991, August 1991.