Upgrade Challenges at a 2nd Generation Ring

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Abstract

Recently, the CAMD facility, a 1.3 GeV, 2nd generation synchrotron source, has been planning some major upgrades. Though funding has not been completely secured, several steps have already been initiated.
It is clear that each CAMD machine upgrade carries with it the potential for increased radiation as a consequence of enhanced energy or flux. Amongst the completed or proposed upgrades are the installation of a 2nd RF cavity in preparation for some new insertion devices. In tandem with this upgrade, the Linac energy will be increased from 200 to 300 MeV and the timing structure increased from 1 to 5 Hz.
Due to space limitations, the addition of a 3rd, 100MeV accelerating section to achieve the desired energy will require the movement of the Linac tunnel chicane, and its associated Radiation Interlock System (RIS), as well as necessitate the removal of the Klystron gallery from the Linac tunnel to the experimental hall floor. This task will require new wave guide structures, another potential radiation source. Knowledge of how and where losses occur remains an important feedback parameter for machine optimization in addition to radiation safety.
This paper will also discuss a novel method for evaluating beam losses in a synchrotron ring.

1. Introduction

The Center for Advanced Microstructures and Devices at Louisiana State University is a 2nd generation synchrotron source optimized for soft X-ray production (Fig.1). The first upgrade, the attachment of a He cryostat to a 7T wiggler, began in January, 2009. Removal of the wiggler (Fig.2) created new radiation patterns and elevated radiation readings during injection but not during the ramp file. The injection process in the CAMD facility takes only about 1 minute. Thus, it is difficult to attempt to pin-point a radiation source that dramatically disappears during the ramp file.
A novel method for the isolation and the characterization of this source point was developed. Knowledge of how and where losses occur remains an important feedback parameter for machine optimization in addition to radiation safety.

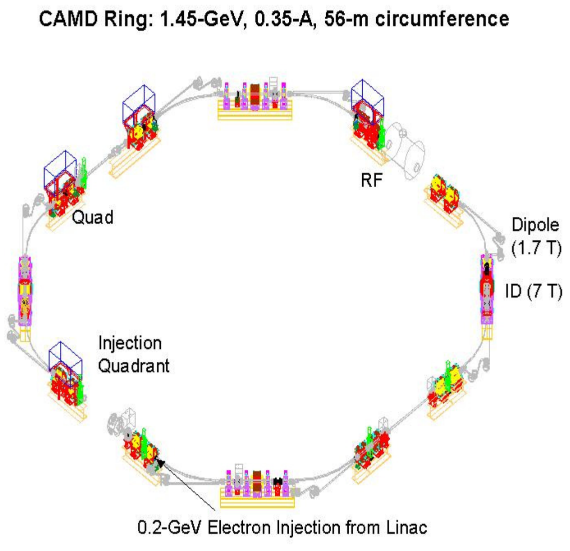

Fig.1 - Layout of the CAMD Storage ring.

Additional shielding had to be implemented. There is a proposal to replace the 7T wave-length shifter with a new super-conducting wiggler of 7.5 T. Two additional undulators are also proposed. Since the operating energy of the ring is severely constrained by the low energy injection, the Linac will be upgraded from 200 to 300 MeV.
Further, the injection rate is scheduled to increase from 1 Hz to 5 Hz. Each of these changes brings to light a myriad of Health Physics problems, each of which must be addressed [1,3]. These include the increased energy of these radiation sources that requires upgraded shielding, as well as a change in the timing structure. These changes can be calculated directly from the power equation (*Eq.1*). There is also a requirement for a new radiation interlock system for the Linac, as well as the movement of the chicane in the tunnel, wave-guide penetrations from the Linac tunnel to the experimental hall floor and relocation of the Klystron gallery to the experimental hall floor which must be assessed and considered for final approval of the new operational parameters. The change in power density is calculated using *Equation 1*.

$$\textbf{Watts [Power] = [eV] x [Hz] x [sec] x [Amperes]} \qquad (1)$$

2. Materials and Methods

The first phase of the upgrade involved the installation of a 2nd RF cavity, as a precursor to all other upgrades. Following the completion of this task, preparations were made to receive the components for the Linac upgrade as well as for the removal of the 7T super-conducting wiggler.
The wiggler was to be re-furnished with a He cryostat to reuse and to conserve Helium losses. Shielding (20cm) was placed upstream of the wiggler in preparation for this task. Since vacuum had been broken, a period of time was set aside for ring-re-conditioning. However, new radiation patterns emerged and persisted during the injection cycle but not during the ramp file.

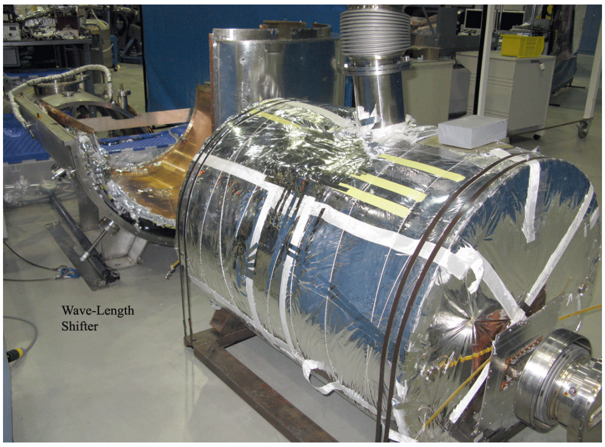

Fig.2 - 7T Wiggler removed from the CAMD storage ring.

To assess this new problem, normal ASA 400 exposed film was calibrated at 1 cm intervals. This film "ruler" was then placed over the suspected area of loss with the leading edge of the film marked on the beam pipe being assessed. This was so that the film could be placed back in the precise position after being surveyed for activation of the AgCl in the exposed film gel. Injection was turned on for 5 minutes without ramping. The film was retrieved from the beampipe and laid on a flat table.
Then, a survey meter (*Ludlum Model 12 equipped with a pancake probe*) was passed over the exposed film. When a section of film was found to be radioactive, it indicated that the Silver Halide had been activated from ^{107}Ag to ^{108}Ag [T $^{1/2}$ = 2.39 minutes]. A pin hole was cut into a 1.58mm plate of lead. This lead shield was placed between the pancake probe and the exposed film, making it possible to isolate the highest radiation reading on the film.
The area with the highest activation was marked on the film and the film placed back in its original exposure position on the beampipe. The hot spot was transferred to the precise location on the accelerator, indicating the source point [3]. The complete assembly is shown below (Fig.3). Due to the extremely short half-life of ^{108}Ag, the film could be re-used within 20 minutes.

Fig.3 - Exposed film with sheet of lead containing a pin-hole (not visible) and the Ludlum Model 12 survey meter equipped with a pancake probe to ascertain the area on the film with the maximum activation. Once maximum activation had been located, the film was transferred back to its original exposure placement and the loss point transferred from the film to the beam pipe to determine where beam was being lost.

3. Results

3.1. Planning and Evaluation of Health Physics Challenges

Several iterations of the Linac upgrade were considered. Due to lack of space to accommodate both the 3rd 100 MeV accelerating section and its associated klystron assembly, it was decided that the optimal solution required the movement of the klystron gallery with its associated modulators up to the experimental hall floor. Both the klystrons and their associated modulators will be moved up to the experimental hall floor (Fig.4).

Some of the other considerations include the movement of the shielding chicane to accommodate the third 100 MeV accelerating section, new wave guides from the Linac tunnel to the klystron-modulator assemblies, a new radiation monitoring system as well as additional shielding to account for the higher energy and timing structure. The output from the power density alone could conceivably increase radiation 6.9 times from current operational modes (Table 1).

P (W) = [eV] x [Hz] x [sec] x [Amperes]	**Watts**
Current	0.4
Approved	1.1
Upgrade	6.9

Table 1 - Increase in power density from current and approved operational modes to "Upgrade" mode as a consequence of proposed energy and frequency changes.

A summary of the various contributions to overall predicted radiation from each proposed change is given in Table 2. Although the maximum current achieved is slightly lower and the damping time (Tau) is decreased, significant radiation increases have been calculated with this upgrade.

Upgrade Component	Predicted Radiation over Current Ops
Energy Increase [from 200 to 300 MeV]	5 to 7.78 times
Frequency Increase [from 1Hz to 5Hz]	5
Pulse length [from 150 to 184nsec]	1.23
Tau	-3.38
Current Decrease [from 30mA to 25mA]	-0.2

Table 2 - Calculations of predicted radiation doses as a consequence of proposed Linac upgrade parameters at the CAMD facility. Not shown are the contributions from the klystrons and their associated modulators which will be moved from the Linac tunnel to the experimental hall floor.

The Linac upgrade will also require additional shielding [5.1cm] in the vertical transport line. The two 45 degree bending magnets in both the upper and lower portions of the vertical transport line may require the gap between the magnets to be narrowed to reach the proposed energy of the upgrade.
In their current configuration, some 5 cm of lead is placed in the band gap of these magnets to limit radiation.

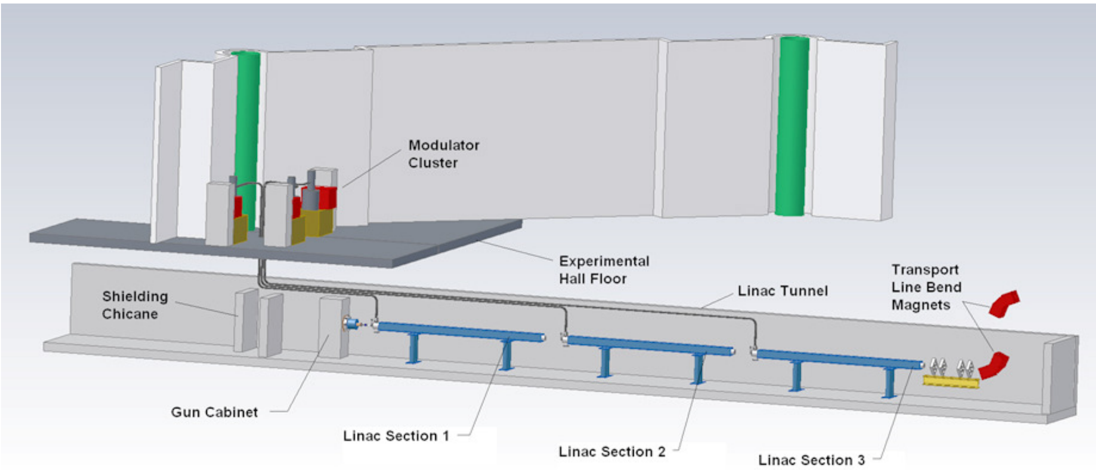

Fig.4 - Proposed new layout of the CAMD Linac upgrade, showing the Klystron galleries moved to the 2nd floor [indicated as modulator cluster], the new waveguide arrangement [shown in black]and the movement of the gun cabinet and the chicane wall [both shown in light grey]to accommodate the 3rd accelerating section (100 MeV) [shown in blue]. One of the Radiation Interlock interfaces occurs at the chicane, necessitating a complete electrical re-run of the Linac portion of the interlock system.

This shielding would have to be reconfigured to fit within the narrower gap and the shielding increased by 2 cm in thickness. Made-to-order shielding will have to be applied to the new klystron unit. Each of the klystron modulators operates at 280 KV, an electrical hazard. Klystrons, as well as, the Linac may be significant sources of dark current, a quantity not easily modeled.
Since the 3rd accelerating section must be tested in the experimental hall, test protocols must be developed for the safe commissioning of this unit within the constraints of a user-occupied facility. It is proposed to conduct these tests with remote radiation monitoring and a locked experimental hall during non-user beam dedicated machine studies time. Nevertheless, care must be taken to limit any activation potential of such activities so as not to create any restricted access places once user-beam is again available.

3.2. Measurements

Radiation monitoring was conducted during the installation and commissioning of the 2nd RF cavity. No radiation excursions were observed. An interesting radiation profile however, developed when the 7T Wiggler was removed. In preparation for this task, 20cm of shielding had been placed upstream of the wiggler.
During re-commissioning of the ring, a unique radiation pattern was found associated only with the injection and not the ramp portion of the ring fill. This persisted even after good operating vacuum had once again

been achieved. Since the injection portion of the fill only takes about one minute, it was difficult to track. However OSL [optically-stimulated luminescent dosimeters] monitoring throughout the facility, showed a higher than anticipated dose in direct line of sight from the former Wiggler position.

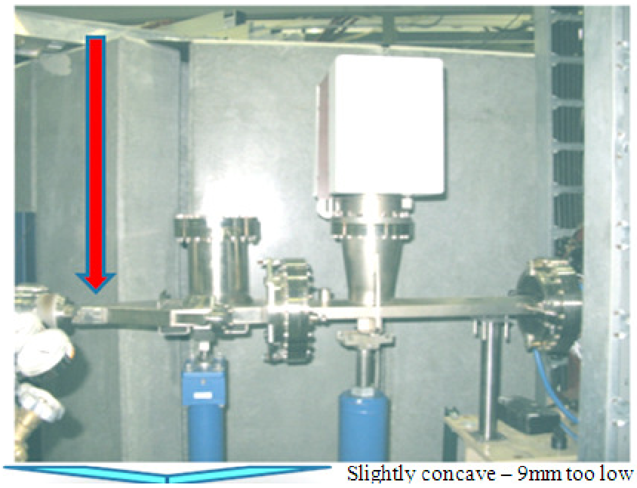

Fig.5 - Location of radiation source as a conse-quence of the beam-pipe being 9 mm too low. Point was identified by unique method of using exposed photographic film and looking for activation of ^{107}Ag to ^{108}Ag in the film emulsion. This isotope has aTt½ of 2.39 minutes. BMP's had been unable to detect this anomaly. With the beam pipe in the correct position, radiation dose was reduced from 72mSv to 32μSv.

This forward directed peak was assumed to be Gas Bremsstrahlung [2], so the shielding in place was increased in both size and breath. This failed to mitigate the injection associated dose pattern.
Radiation Safety suspected that a pair of knife edges where responsible such that the beam was hitting the knife edges. Of course, a 200 MeV beam is larger than the beam during ramp at 1.3GeV. However, beam position monitors [BMP's] indicated the beam was in the correct position. It was possible to verify the loss point through the use of exposed film with a built-in ruler[see under Materials and Methods], then to focus the maximum activation point of the AgCl in the film a pinhole was cut through a 1.6mm sheet of lead.to isolate the maximum activation point. When the maximum loss point was identified the film was placed back in the original exposure position and the source point identified by transferring the maximum loss point on the film to the pipe beam section directly below the film. Even though the BMP's showed the beam to be in the correct position, the beam pipe was 9 mm too low (Fig.5). The realignment of the beam-pipe reduced the overall radiation levels inside the ring from 72 mSv to 32 μSv.

Shortly after the re-positioning of the beam pipe, a bad coil was discovered in dipole magnet 5. This coiled displayed an intermittent short. The fault required beam position optimization two to three times per day.
No "*Golden Orbit*" could be maintained and continual adjustments were required. Since much of this optimization passed through the area that had been mis-aligned (Fig. 5), 20 cm of shielding was added to the area to protect from beam losses during the search for an optimal "Golden Orbit" during each injection cycle. No further radiation excursions were observed following this implementation of this safety precaution as evidenced by radiation surveys and from readings from optically stimulated luminescent dosimeters [OSL] routinely used as passive radiation integrating devices.
Thus, the new placement of Pb shielding continues to offer adequate shielding despite multiple orbits. Recently CAMD achieved a new injection maximum of 412MeV. However, for the moment, shielding appears to be adequate.

Several new insertions devices are also planned for the CAMD facility. This includes a 7.5T multipole wiggler with 18kW beam power, a 3.5T Multipole undulator (2kW) and a 35 period undulator. To accommodate this 3rd insertion device some sextupoles will be removed and the RF cavities split into these shorter straight sections.

4. Conclusions

It is clear that every upgrade requires careful and thorough planning. Despite the best planning scenarios, there are always unanticipated problems. Often, it is necessary to think "out of the box" to achieve the desired results. Health Physicists must rely on intuition in addition to technology. This was exemplified in the problem with the beam pipe in the synchrotron ring. The accelerator group maintained that the beam was in the correct position given the readouts of their BPM's. Through the application of a novel method to ascertain beam losses in the synchrotron ring, it was possible to reduce or eliminate both the parallel and forward directed radiation peaks on the experimental hall floor that were apparent during injection following the removal of the 7T Wiggler to attach a He cryostat. Dose rate measurements inside the ring fell from 72mSv to 32μSv when the beam-pipe was re-positioned. Planning, measurements and simulations [4] will continue through each phase of the proposed upgrades.

5. References

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