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RADIATION PROTECTION STUDIES FOR LCLS TUNE UP DUMP

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The Linac Coherent Light Source (LCLS) at the Stanford Linear Accelerator Center is a pioneer fourth generation hard x-ray free electron laser that shall start to deliver laser pulses in 2009. Among other components of LCLS that present radiation protection concerns, the tune up dump (tdund) is of special interest because it also constitutes an issue for machine protection, as it is placed close to radiation sensitive components, like electronic devices and permanent magnets in the undulators.

This paper first introduces the stopper of tdund looking at the heat load, and then it describes the shielding around the dump necessary to maintain the prompt and residual dose within design values. Next, preliminary comparisons of the magnetization loss in a dedicated on-site magnet irradiation experiment with FLUKA simulations serve to characterize the magnetic response to radiation of magnets like those of LCLS. The previous knowledge, together with the limit for the allowed demagnetization, are used to estimate the lifetime of the undulator. Further simulations provide guidelines on which lifetime can be expected for an electronic device placed at a given distance of tdund

I. INTRODUCTION

The LCLS accelerator is currently under construction at SLAC. In the coming year commissioning will take place, and it is very likely that during the optic tuning phase the beam will be frequently parked onto an in-beam dump (*tdund*) in order to preserve the integrity of the downstream elements. Tdund has a steel container inside of which a water-cooled stopper (ST1) is vertically motioned by a pneumatic actuator into or out of the beam trajectory. The ensemble is enclosed in a small bunker, with inner layers of borated polyethylene and outer plates of marble. ST1 shall accept 170 W of 17 GeV electrons pulsed at 10 Hz. Section II validates its thermal endurance. Sections III, test the shielding configuration in terms of prompt dose and residual dose, while section III defines the maximum allowable use of *tdund* in terms of magnet lifetime. Finally, section VII establishes a zoning around *tdund* as a function of the expected lifetime of the electronic devices.

I.A. THERMAL ENDURANCE

The ST family of stoppers is rated to 5 kW. In order to validate this point, instantaneous temperature rise (fig. 1) and energy deposition maps were generated [1] by running the FLUKA Monte Carlo code [2,3] over an accurate description of the stopper. In order to catch possible unacceptably high temperature spikes, a fine scoring mesh was defined and radial biasing was applied to increase the statistics in the periphery of the stopper. Beam was taken cylindrical with 30 micron RMS.

The results from FLUKA were used as input for ANSYS to evaluate the stresses, which were found to be acceptable [4].

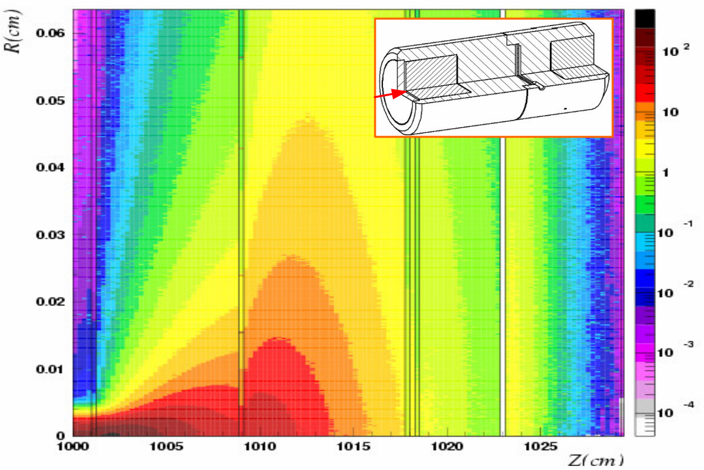

Fig. 1. R-Z mesh of the instantaneous temperature rise [K] in ST1 (shown in the right hand side upper corner) for a 30 micron RMS, 17 GeV, 5kW electron beam.

In the particular case of the ST1, this stopper will be less solicited, since only a small fraction (3 %) of the rated power will be taken. Thus, even in the unlikely event of an eventual failure of the rep-rate interlock (10Hz→120Hz), the stopper would still withstand the heat load.

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II. SHIELDING OF TDUND

FLUKA simulations were run for several shielding configurations and materials to minimize the prompt and residual dose around *tdund*. The resulting shielding (fig 2) has an inner sheath of about 20-25 cm of 5 %-borated polyethylene (to moderate and absorb neutrons) and 10-15 cm of marble to shield the aisle from the gammas emitted by the activated dump and shielding (the marble hardly gets activated). Moreover, a steel collimator is placed downstream of the dump to attenuate the forward showers.

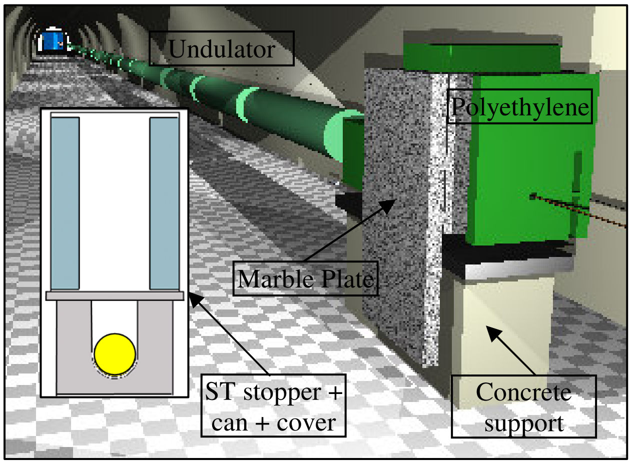


Fig. 2. Povray [5] view of FLUKA geometry.

II.A. PROMPT DOSE

FLUKA Simulations of the (prompt) effective dose [6,7] were computed with all the shielding in place. The dose next to *tdund* reaches 1 Sv/h, but then it drops rapidly downstream (20 mSv/h at the 1st undulator segment, 3 mSv/h at the 2nd , 200 µSv/h at the 3rd,… and less than 0.1 µSv/h in the FEE, well below the design limit (5 µSv/h).

In the upstream direction, however, it was observed that due to a reduction of the concrete wall thickness close to the mouth of the undulator tunnel, the dose leaking to the roof of the (outer) BTH building was somewhat high (~5 µSv/h). Soil was added around the building-tunnel interface to reduce the radiation below the 3 µSv/h limit.

II.B. RESIDUAL DOSE

As seen above, the prompt radiation produced during the interception of LCLS beam by *tdund* is kept away from the occupied areas. However, in the vicinity of *tdund*, where the radiation fields are high, there are radiation-sensitive components like permanent magnets or electronic devices (sections III, IV) which may need to be changed or serviced after a given exposure.

This not only entails replacement and operation costs, but it also augments the number of interventions around *tdund*, thus increasing the personal exposure to residual radiation. This aspect was taken into account during the design of the shielding of *tdund*, for which many simulations were performed. As an example, figure 3 displays the (gamma) dose equivalent [µSv/h] around the final shielding configuration 10 minutes after having irradiated *tdund* for 200 hours with 17 GeV electrons at 170 W. Similar plots have been produced for several cooling times and cross-sectional views, allowing to predict the roping perimeter around *tdund* under several circumstances. Further studies will need to address the dose received during interventions on *tdund*, and specially while disassembling it.

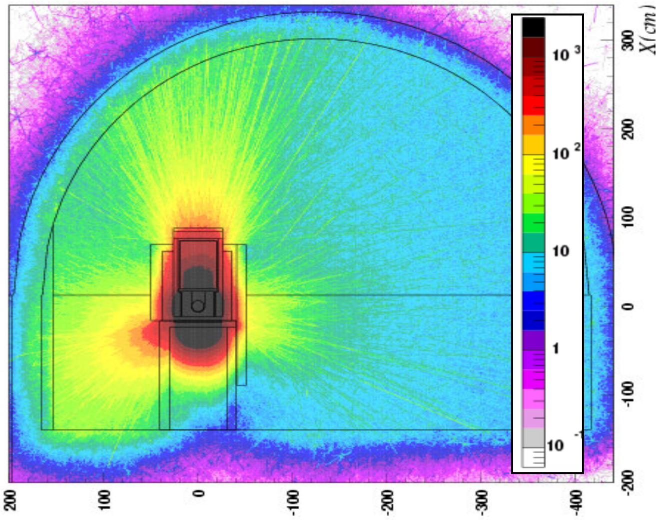


Fig. 3. Residual dose rate [µSv/h] around *tdund* (onto the reader) after 200 h beam interception (170 W, 17 GeV) and 10 min of cooling time.

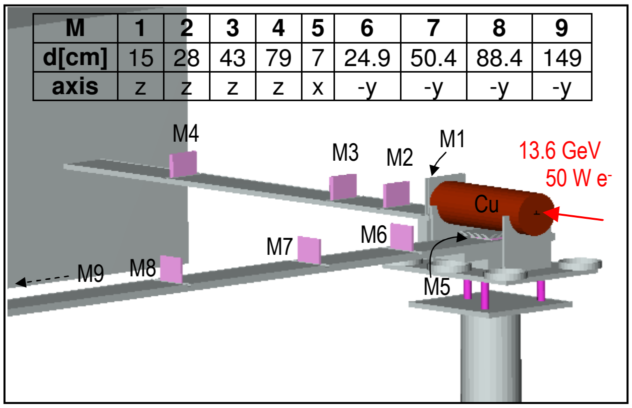
IV. RADIATION DAMAGE TO LCLS PERMANENT MAGNETS

LCLS accelerator core goal is to produce an intense, high quality FEL light. The laser is generated by having the electron beam wiggle along the undulator, at the action of the alternating field created by its permanent magnets. These fields must stay within 99.99 % of their nominal value to meet the FEL specifications. Since the undulator starts just 2 m downstream of *tdund* in a zone subjected to outstanding doses (20 mSv/h), it seems clear that, eventually, some segments will exceed the 0.01% allowed demagnetization, and consequently, they will have to be serviced or replaced.

So far there is no unanimous agreement on the exact damaging mechanism (total dose, neutron fluence…) of permanent magnets. The experimental data seem to depend strongly on the magnet alloy and on the irradiation pattern. Thus, as a first step to forecast (and eventually reduce) the intervention cycle of the LCLS segments, identical magnets were irradiated in an on-site test facility. The demagnetization was measured and compared to several dose quantities simulated with FLUKA, so that a radiation damage response function could be inferred.

IV.A. T-493 IRRADIATON EXPERIMENT

In the T493 experiment nine Nd-Fe-B magnets like the ones designed for LCLS undulators were irradiated in the End Station A at SLAC. The samples were exposed to the radiation field induced by dumping a 50W, 13.7 GeV electron beam onto a 25 cm long, 10 cm diameter copper cylinder. As shown in fig 4, four magnets (M1-M4) were placed in the beam axis (0°), downstream of the dump, and another five magnets were located at 90°, one below (M5) and four to the left side (M6-M9).



M	1	2	3	4	5	6	7	8	9
d[cm]	15	28	43	79	7	24.9	50.4	88.4	149
axis	z	z	z	z	x	-y	-y	-y	-y

Fig. 4. FLUKA geometry of T-493 experiment visualized with SimpleGeo [8].

The magnetic induction of the samples was measured prior to the irradiation and at the end of the experiment, which was simulated with Fluka. A preliminary analysis of the correlations between the measured demagnetization and the simulated quantities appear in figures 5 and 6. In figure 5 it is seen that the demagnetization grows significantly with the total dose, but it increases even faster with the non-electromagnetic dose, which would be in accordance with those publications [9] where neutrons are mostly are identified as the cause of magnetization loss. From the two sets of data, the maximum (0.01% demagnetization) allowed total dose and non-EM dose would be 2500 and 20 rad/h, respectively.

In figure 6, the demagnetization is plotted against the neutron fluence. Two separate neat correlations are found, one for magnets M1-M4 and another for M5-M9. The underlying cause for the higher damage response in the axial magnets could again be the presumed more noxious impact of higher energy neutrons, which are more numerous at smaller angles. The maximum neutron fluxes (for 0.01 % demagnetization) are ~1E11 (0°) and 5E12 (90°) n/cm^2.

Ongoing studies review the irradiation conditions (particles and spectra) the temperature of the samples as well as other effects. Moreover, further experiments are scheduled.

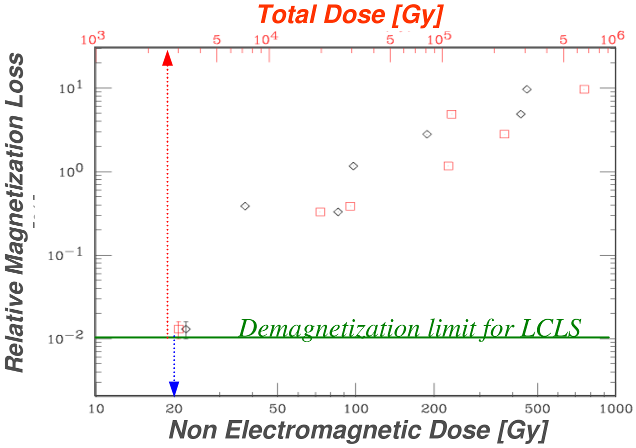


Fig. 5. T-493 measured demagnetizations and simulated doses (total and non-electromgnetic).

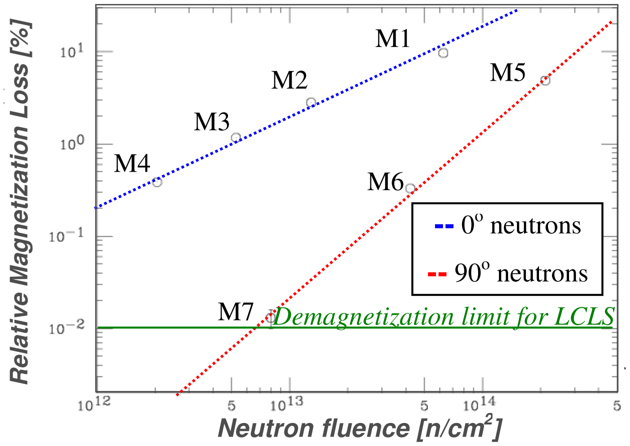


Fig. 5. T-493 measured demagnetizations and simulated neutron fluences.

IV. B DAMAGE TO LCLS UNDULATOR

The quantities used in the previous section (total and non-EM dose, neutron flux) were scored in the magnets of a FLUKA simulation for LCLS. The results for the first magnets in the first segment were 0.1 Gy/h, 1.8E-3 Gy/h and 2.63E7 n/cm^2/h. When these values are divided by the limits obtained in IV.A, the following lifetimes are obtained: 25000, 11000 and ~4000 h. The last value results from considering the threshold for 0° neutrons, which matches the irradiation pattern from *tdund*. The second segment should last about 10 times longer.

Tdund is expected to be used less than 10 % of the time. This means that, for the current numbers, in the worst case, only the first segment would need to be replaced, and that would happen after about 7-9 years of operation.

Future simulations will provide estimations of the magnet lifetimes for several misesteeming conditions and for other radiation cases, like those occurring during the insertion of thin diagnostic devices.

V. PERMANENT DAMAGE TO ELECTRONICS

In order to evaluate the life time of electronic devices close to *tdund*, a silicon square bar (5x5 cm) was added in the FLUKA geometry 40 cm below the beam line. This generic approach allows scoring two quantities: 1) The dose imparted to silicon (typically through ionizations), which is responsible of surface or interface defects and 2) The *1 MeV neutron equivalent fluence,* which reflects the non-ionizing energy losses in the bulk of electronic components. It is obtained by convolving the fluence energy spectra of the participating particles with silicon displacement-damage functions, normalized to the value of the damage function of 1 MeV neutrons. This approach is very useful to compare limits obtained for different radiation fields.

Table 1 lists the estimated lifetime of electronic equipments as a function of their distance to *tdund*, based on the two scored magnitudes. The thresholds for damage used in the table are 10 krad and 1E12 cm^{-2}, respectively.

TABLE I. Expected lifetime of the electronics as a function of their distance to *tdund*

Distance form *tdund* [m]	Lifetime based on dose damage	Lifetime based on 1 MeV neutron fluence damage
1.2-1.3	100 h	100 h
2.8-2.9	41 d	42 d
6.2-9.2	420 d	420 d
16-25	4200 d	3650 d

VI. CONCLUSIONS & OUTLOOK

Calculations show that the tune up dump stopper will withstand the energy deposited by the electron beam even at full pulsed rate. As for the shielding, it manages to contain the prompt dose and the residual dose with an inner layer of borated polyethylene and outer marble plates. An on-site irradiation experiment and dedicated FLUKA simulations provide correlations between the dose and the demagnetization. The results seem to indicate that high energy neutrons play a major role in the alteration of the magnetic inductance. When these conclusions are extrapolated to LCLS, only the first segment is likely to require a replacement, and that would not happen until the 7th-10th year of operation. Further studies and experiments are projected to confirm these preliminary findings. Simulations using two different criteria provide comparable lifetime expectations for electronics, showing that local shielding is needed near the dump. Additional studies have been performed to determine the environmental impact of tdund, including groundwater activation, air activation and cooling water nuclei production.

ACKNOWLEDGMENTS

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