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RADIATION REQUIREMENTS AND TESTING OF CRYOGENIC THERMOMETERS FOR THE ILC

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ABSTRACT

Large quantity of cryogenic temperature sensors will be used for operation of the International Linear Collider (ILC). Most of them will be subject to high radiation doses during the accelerator lifetime. Understanding of particle energy spectra, accumulated radiation dose in thermometers and its impact on performance are vital in establishing technical specification of cryogenic thermometry for the ILC. Realistic MARS15 computer simulations were performed to understand the ILC radiation environment. Simulation results were used to establish radiation dose requirements for commercially available cryogenic thermometers. Two types of thermometers, Cernox® and TVO, were calibrated prior to irradiation using different technique. The sensors were subjected then to up to 200 kGy electron beam irradiation with kinetic energy of 5 MeV, a representative of the situation at the ILC operation. A post-irradiation behavior of the sensors was studied. The paper describes the MARS15 model, simulation results, cryogenic test set-up, irradiation tests, and cryogenic test results.

KEYWORDS: Thermometry, radiation, simulation, testing

INTRODUCTION

Large quantity of cryogenic temperature sensors will be used for operation of the International Linear Collider (ILC). Most of them will be subject to high radiation doses during the expected twenty year accelerator lifetime. Understanding of particle energy spectra, accumulated radiation dose in thermometers and its impact on performance are vital in establishing technical specification of cryogenic thermometry for the ILC.

Radiation simulation through the ILC cryomodule due to one milli radian beam loss from stray beam loss was conducted. The affect of dark current generated due to an electron field in the wave guide, cavities, RF gun cathode, etc. was not part of these simulations.

RADIATION REQUIREMENTS

For the International Linear Collider project (ILC), a superconducting Radio Frequency (RF) cryomodule is the major accelerator component. Estimation of energy deposition due to electro-magnetic and photo-neutron showers induced by electron beam loss is essential to evaluate the radiation hardness of the electronics devices associated with the cryomodules. Particularly important is to understand long term radiation impact on sensitivity, repeatability and accuracy of cryogenic thermometry associated with the ILC cryomodules.

Irradiation behaviors of a cryogenic thermometers have been studied for neutrons and photons in Dubna [1,2]. Potential thermometers for the ILC cryomodule should also be tested by experiment and simulation to clarify its characteristics. To define radiation requirements, simulations of radiation and energy deposition by the MARS15 Monte Carlo code [5] were performed with a 250-GeV electron beam for the ILC project [3] and 750 MeV for ILCTA NML [**Error! Reference source not found.**].

The simulation was used to generate electron, neutron, photon, and proton particle spectra at the proposed location of cryogenic thermometers for the ILC cryomodule. From the simulation it was determined that the photon spectrum dominates radiation requirements. The maximum absorbed dose was obtained for cross sections at the expected thermometry location is about 0.85 mGy/sec, which translates in an integrated dose of 310 kGy over twenty year accelerator lifetime at assumed 5000 hours per year operation.

A cryomodule geometry for simulation is based on the TESLA type 3 plus cryomodule designed by INFN, Italy and DESY, Germany [5]. The geometry was simplified without compromise of the major geometrical and material constraints of the cryomodule. Rectangular shaped silicon pieces inside appropriate cryomodule pipes were used to model cryogenic thermometers. [3]

From the calculated energy deposition distributions, absorbed dose rates for the cryogenic thermometers at various locations were obtained. Energy spectra of electrons, photons, neutrons and protons were also obtained and particle-dependent absorbed doses were clarified. A sample energy spectra for a thermometer located in the cryomodule cooldown line is presented on FIGURE 1.

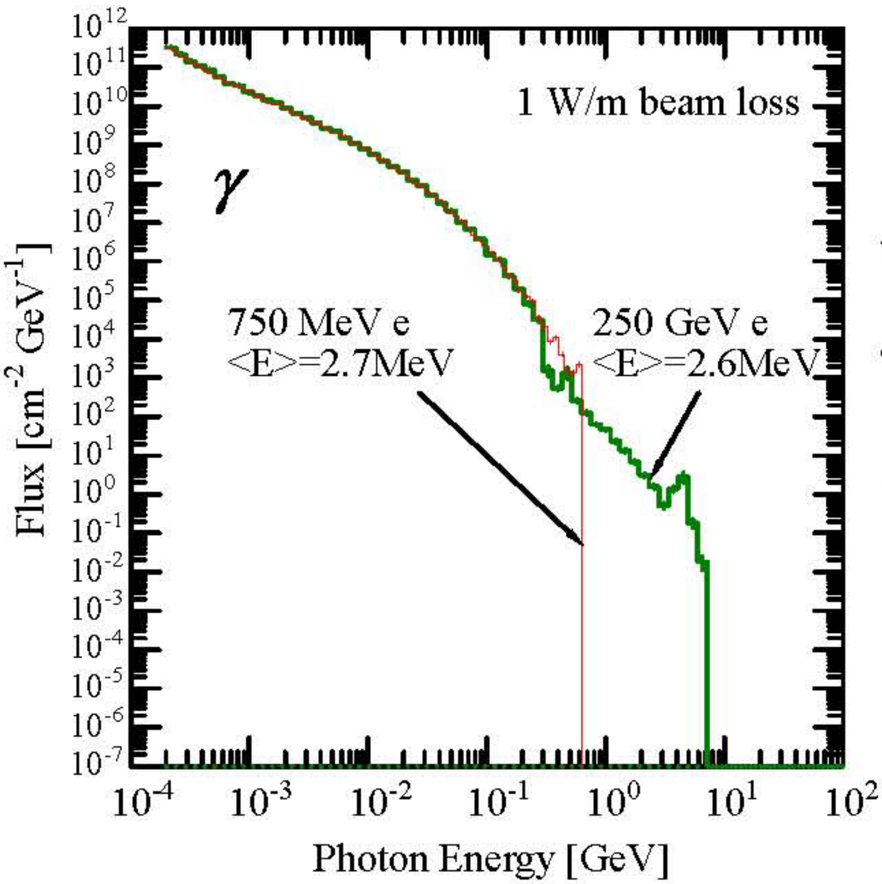

Figure 1 A sample energy spectra of photons due to primary beam loss as seen at cryogenic thermometer located in a cryomodule cooldown line

IRRADIATION

Five G-10 boards each containing a single TVO and a single Cernox ® 1010 thermometers were subjected to electron beam irradiation at average energy of 5MeV. Each board has received a different dose of radiation. The irradiation was conducted on the industrial DC accelerator "DYNAMITRON" capable of producing an electron beam of up to 10 mA current. The accelerator also was equipped with a conveyor. Applied radiation doses were varied by changing the accelerator beam current and the conveyor speed. Actual received doses were measured by utilizing Alanine and CTA film dosimeters [6]. The following doses were registered: Board 1 - 22.7 kGy, Board 2 - 45.9 kGy, Board 3 - 94.5 kGy, Board 4 - 146.7 kGy, and Board 5 - 203.8 kGy.

CALIBRATION SETUP

The five boards, shown in FIGURE 2, were mounted on the end of a probe with a cap suitable to be fixed to a top of a helium dewar, FIGURE 3. This cap included five 12 pin connectors which were wired to the sensors through the probe. The sensors were subjected to calibration readings at Room Temperature, in liquid nitrogen, and in liquid helium.

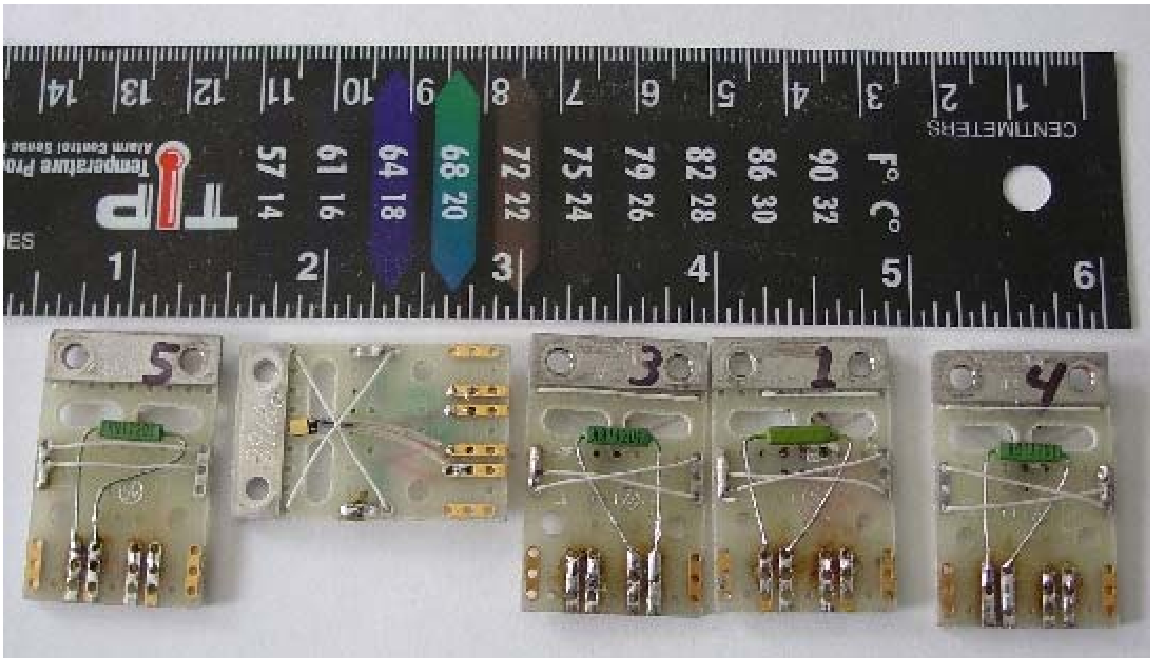

Figure 2 Five resistor boards each containing a TVO and a Cernox® thermometer. Higher numbered boards received higher dose rates. Board pictures were taken prior to irradiation.

At liquid helium, the pressure was measured using a pressure transducer during the tests. A schematic of the helium experimental test setup is shown in FIGURE 4. The data was retrieved through a 15 channel Temperature monitor which was connected to the 12 pin connectors and extracted the data into a computer. These tests were performed before irradiation and compared to calibration curves were tested again after receiving radiation doses.

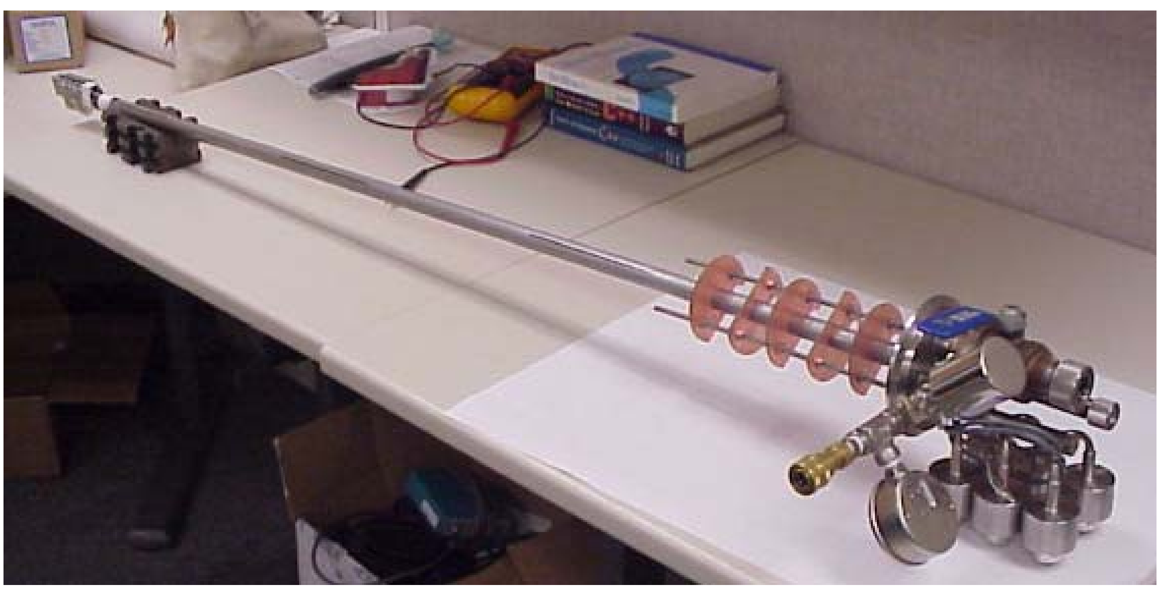

Figure 3 Test probe with resistor boards and associated instrumentation.

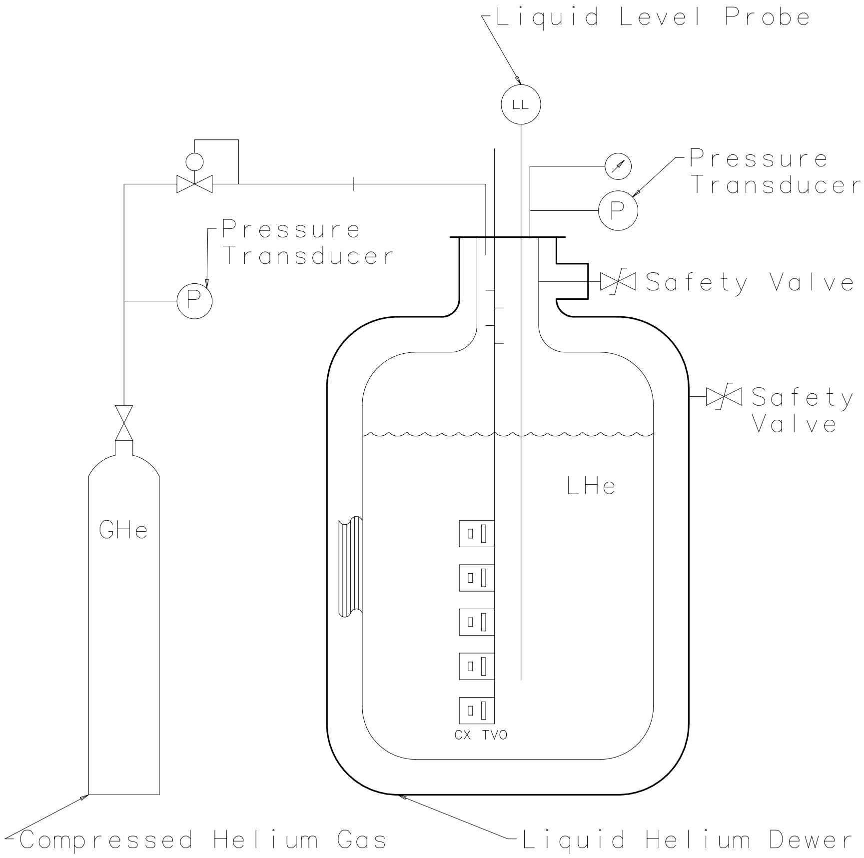

Figure 4 Test set-up flow diagram.

RESULTS

Prior to the test all thermometers were calibrated and individual curve fits were established. The resistors were tested at three different temperatures levels – ambient, liquid nitrogen and liquid helium at ambient pressure. Raw resistance was data logged on a computer using a 15 channel temperature monitor manufactured by JINR, Dubna. The raw resistance data were averaged over a time interval and ten (10) calibration curves were used to convert to temperature units. Reference temperatures were obtained by utilizing saturation pressure properties of nitrogen and helium. Comparison between the reference temperature and converted measured resistance provides a delta T for each resistor.

Calibration data for Cernox ® and TVO resistors prior to irradiation are presented in the TABLE 1. The largest difference between measured and calculated values at helium temperatures is less than 31 mK, which is within accuracy of calibration and experimental methods. Post irradiation data are presented in the TABLE 2. No significant change in difference between measured and calculated values at helium temperatures were observed as a result of radiation exposure.

TABLE 1 Calibration data for temperature sensors before irradiation.

Board Number	Resitor Type	Temperature Calculated [K]	Temperature Measured [K]	Temperature Difference [mK]
1	TVO	76.61	77.20	590
		4.327	4.333	6
	Cernox	76.73	77.20	470
		4.355	4.333	-22
2	TVO	76.68	77.20	520
		4.323	4.333	10
	Cernox	76.55	77.20	650
		4.349	4.333	-16
3	TVO	76.82	77.20	380
		4.341	4.333	-8
	Cernox	76.58	77.20	620
		4.346	4.333	-13
4	TVO	76.68	77.20	520
		4.322	4.333	11
	Cernox	76.59	77.20	610
		4.347	4.333	-14
5	TVO	76.76	77.20	440
		4.302	4.333	31
	Cernox	76.87	77.20	330
		4.358	4.333	-25

CONCLUSION

The Cx1010 Cernox® and TVO temperature sensors seemed to have a high resistance to radiation doses from the results obtained in this experiment. No significant change in calibration at the tested radiation doses was detected. Seeing that the temperature shift is at the same magnitude as before irradiation it can be concluded that this shift is just due to inaccuracy of the experimental setup and curve fitting. Although the data seems to follow other experiments that conclude no significant temperature shift with this radiation dose, additional tests to gain statistical information will be required. This work exposed the resistors to two-thirds the expected twenty year dosage. High exposure rates limited to the total dose in order to avoid overheating. Further work achieving the full twenty year dosage and beyond should be performed using a lower dose rate.

TABLE 2 Calibration data for temperature sensors after irradiation.

Board Number	Resitor Type	Radiation dose	Temperature		
			Calculated	Measured	Difference
		[kGy]	[K]	[K]	[mK]
1	TVO	22.7	76.83	77.20	370
			4.202	4.190	-12
	Cernox		76.31	77.20	890
			4.207	4.190	-17
2	TVO	45.9	76.78	77.20	420
			4.198	4.190	-8
	Cernox		76.19	77.20	1010
			4.209	4.190	-19
3	TVO	94.5	77.02	77.20	180
			4.212	4.190	-22
	Cernox		76.32	77.20	880
			4.210	4.190	-20
4	TVO	146.7	76.78	77.20	420
			4.198	4.190	-8
	Cernox		76.30	77.20	900
			4.214	4.190	-24
5	TVO	203.8	76.93	77.20	270
			4.176	4.190	14
	Cernox		76.52	77.20	680
			4.216	4.190	-26

ACKNOWLEDGEMENTS

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