High Level Gamma Radiation Effects on Platinum and Silicon Diode Cryogenic Temperature Sensors

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High Energy Physics applications are driving radiation hardness requirements in cryogenics.

Applications such as ITER and the FCC require SC magnets to steer particles and they require cryogenic systems for use to below 4.2 K, including thermometry.

Depending upon location, radiation estimates for the FCC have ranged from 5 MGy to 10 GGy.

It’s not the goal to irradiate the supporting infrastructure, but it invariably happens.
Background - 2

- **Cernox™ Temperature Sensors**
  - Very good in radiation and magnetic field
  - Need individual calibration, more complex instrumentation

- **Desire for cheaper solution**
  - Interchangeability
  - Simpler instrumentation

This work examines the effects of high level gamma radiation on Platinum and Silicon Diode Temperature Sensors
Platinum Resistance Thermometers (PRTs)

Model PT-103
- 14 K - 873 K
- 70 K – 873 K interchangeability
- Wire-wound, 100 Ω
- Ceramic encapsulated

Model PT-111:
- 14 K - >650 K
- 70 K – 673 K interchangeability
- Wire-wound, 100 Ω
- Glass encapsulated
Silicon Diode Thermometer (SiDT)

Model DT-670-SD SiDT

- 1.4 K – 325 K Interchangeability
- Really a transistor
- Not good in magnetic fields
Experimental design

- **Sensors**
  - PRTs – 40 of each model divided into 10 groups
  - SiDT – 20 sensors divided into 10 groups

- **9 irradiation levels + 1 control group**
  - 10 kGy, 25 kGy, 50 kGy, 100 kGy, 250 kGy, 500 kGy, 1 MGy, 2.5 MGy, 5 MGy

- **Performed at SNL Gamma Irradiation Facility**
  - Linear Array Co-60 source
  - Dose rate $\approx 10$ Gy/s
  - Room Temperature irradiation
  - Unpowered during irradiation
Measurements

- **Calibrate → Irradiate → Calibrate**
  - Calibrations performed in Lake Shore’s Temperature Calibration Facility
  - PRTs: 58 points spanning 14 K – 325 K temperature range,
    SiDTs: 71 points panning 1.4 K – 325 K temperature range

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>Uncertainty (± mK)</th>
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<tr>
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<td>PT-103 / PT-111</td>
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<td>DT-670-SD</td>
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- PRT results given as Calibration shifts calculated as \( \Delta T = \Delta R / S_T \)
  where \( \Delta R = (R_{\text{final}} - R_{\text{initial}}) \) and \( S_T \) = Temperature Sensitivity

(Similar for SiDTs with Resistance replaced by voltage)
PT-103 PRT: Average ΔT after irradiation

Temperature (K) vs. Calibration shift (mK) for different irradiation levels.
PT-111 PRT: Average ΔT after irradiation

No change after 2 years
DT-670-SD SiDT: Average ΔT after irradiation

- **Control** (A)
- 10 kGy (B)
- 25 kGy (C)
- 50 kGy (D)
- 100 kGy (E)
- 250 kGy (F)
- 500 kGy (G)
- 1 MGy (H)
- 2.5 MGy (I)
- 5 MGy (J)

**Calibration shift (mK)**

**Temperature (K)**

- Linear with T
- Saturation
DT-670-SD SiDT: Average ΔT after irradiation

Temperature (K)

Control
10 kGy
25 kGy
50 kGy
100 kGy
250 kGy
500 kGy
1 MGy
2.5 MGy
5 MGy

Calibration shift (mK)
DT-670-SD ΔT after calibration + 2 years at 298 K

Tested a subset of devices for thermal annealing

Significant Recovery toward pre-irradiation state
DT-670-SD ΔT after calibration + 2 years at 298 K

Very stable below 40 K – little thermal annealing
Discussion – PRT models

- **PT-103**
  - No discernable effects from irradiation up to 5 MGy
  - Recalibration results within uncertainty limits

- **PT-111**
  - Recalibration results within uncertainty limits
  - Some darkening of glass at three highest irradiation limits
  - Changes in glass may have caused slight increase in thermal resistance in 14 – 20 K range and resulted in ionic shunting at higher temperatures
  - No change after 2 years post-irradiation
Discussion – DT-670-SD SiDT

- More complicated behavior
  - Large, positive temperature offsets above 50 K
  - Smaller, negative temperature offsets below 30 K
  - Significant thermal annealing above 50 K after storage
  - No thermal annealing below 40 K after storage

- Might be best explained by radiation interaction via Compton effect creating:
  - Shallow state defects that create ionic shunting at higher T
  - Deep state defects that modify the p-n junction dynamics or create new scattering centers at low T
Conclusions

- Tested: 40 PT-103, 40 PT-111, and 20 DT-670-SD
- Gamma radiation: Co-60, 10 Gy/s from 10 kGy to 5 MGy
- PRTs show excellent behavior over 14 K - 325 K range
  - Usable as an interchangeable thermometer from 70 – 325 K
- DT-670-SD SiDT
  - Large, positive $\Delta T$ offsets above 50 K
  - Small, negative $\Delta T$ offsets below 30 K and 50 krad dose
  - Significant thermal annealing above 50 K; little below 40 K
  - Usable as an interchangeable SiDT for 1.4 K – 30 K range in radiation doses up to 50 kGy