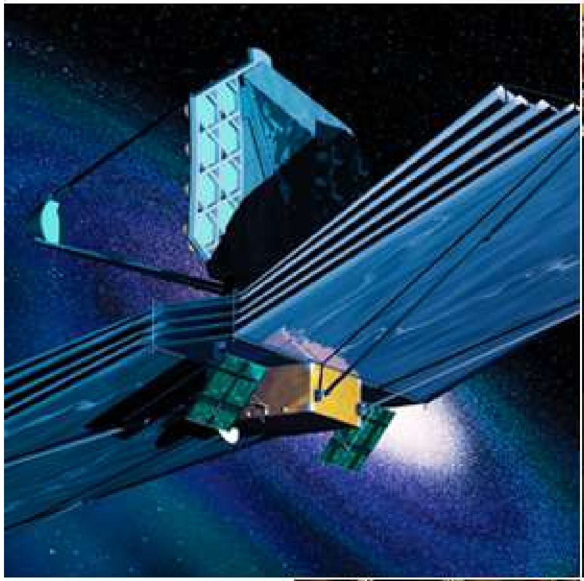

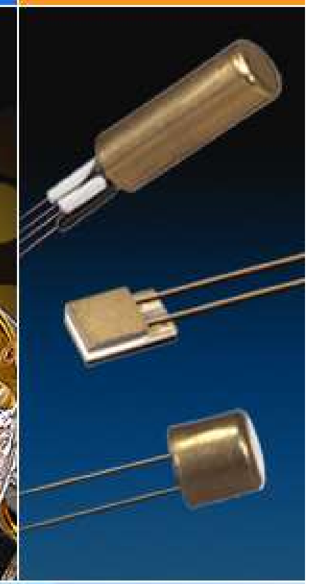

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High Level Gamma Radiation Effects on Platinum and Silicon Diode Cryogenic Temperature Sensors

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July 22, 2019, CEC-ICMC, Hartford, CT

Background - 1

- 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^{TM} 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

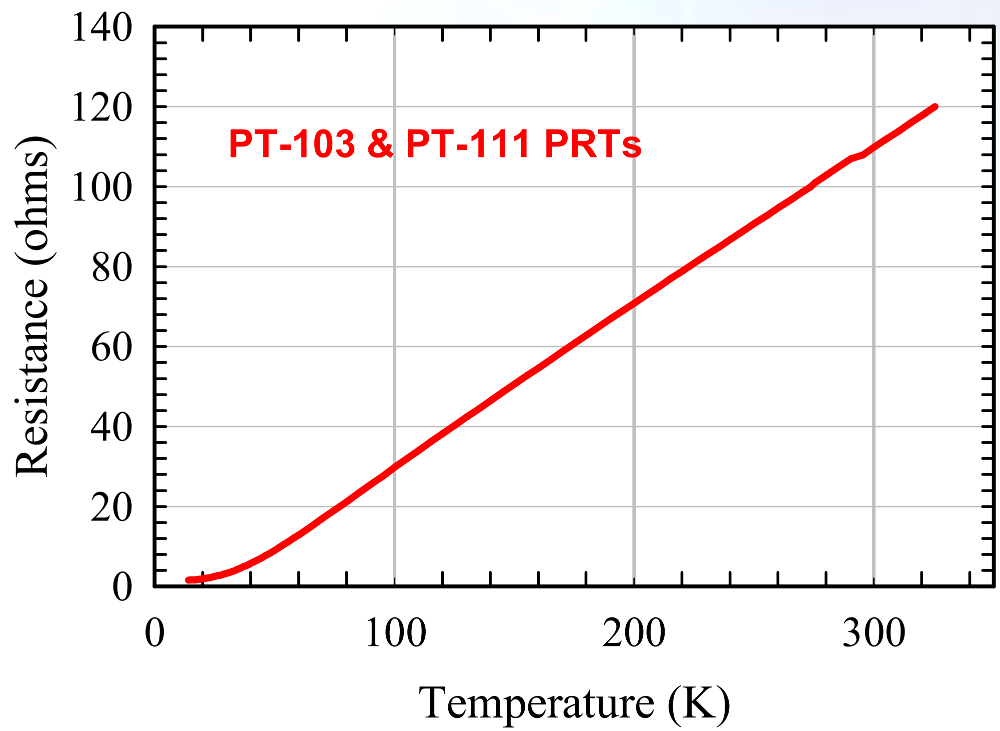
Platinum Resistance Thermometers (PRTs)

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



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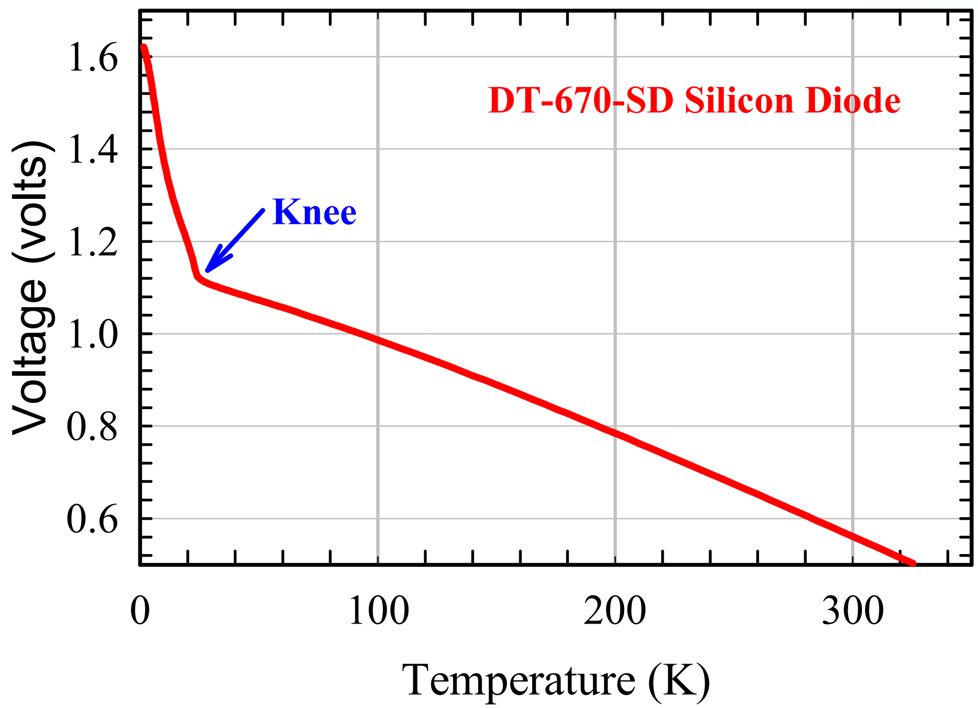
Silicon Diode Thermometer (SiDT)

Model DT-670-SD SiDT

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



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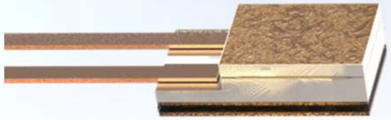
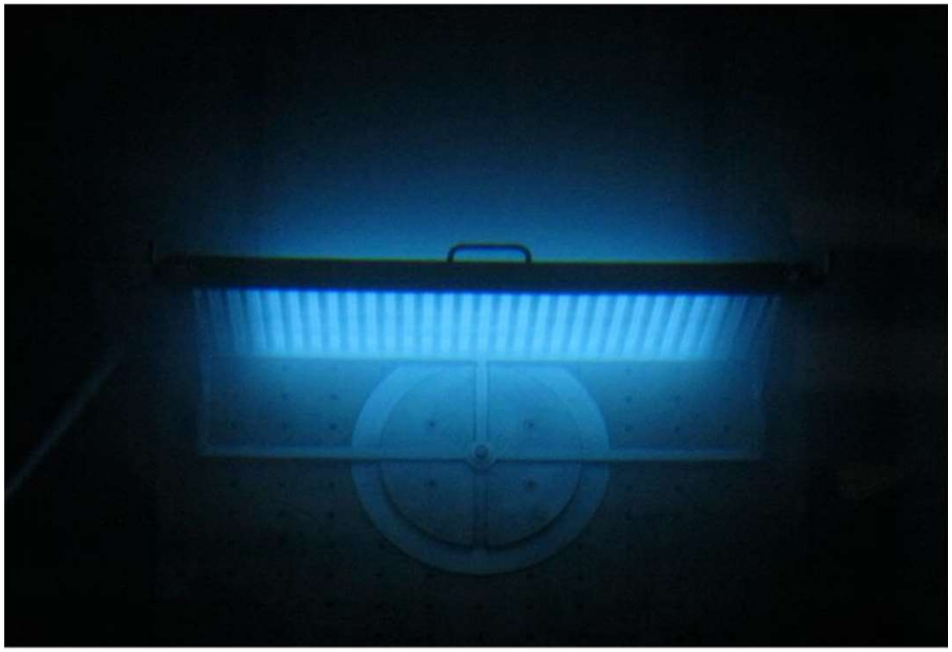
Experimental design

- 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 ≈ 10 Gy/s
  - Room Temperature irradiation
  - Unpowered during irradiation



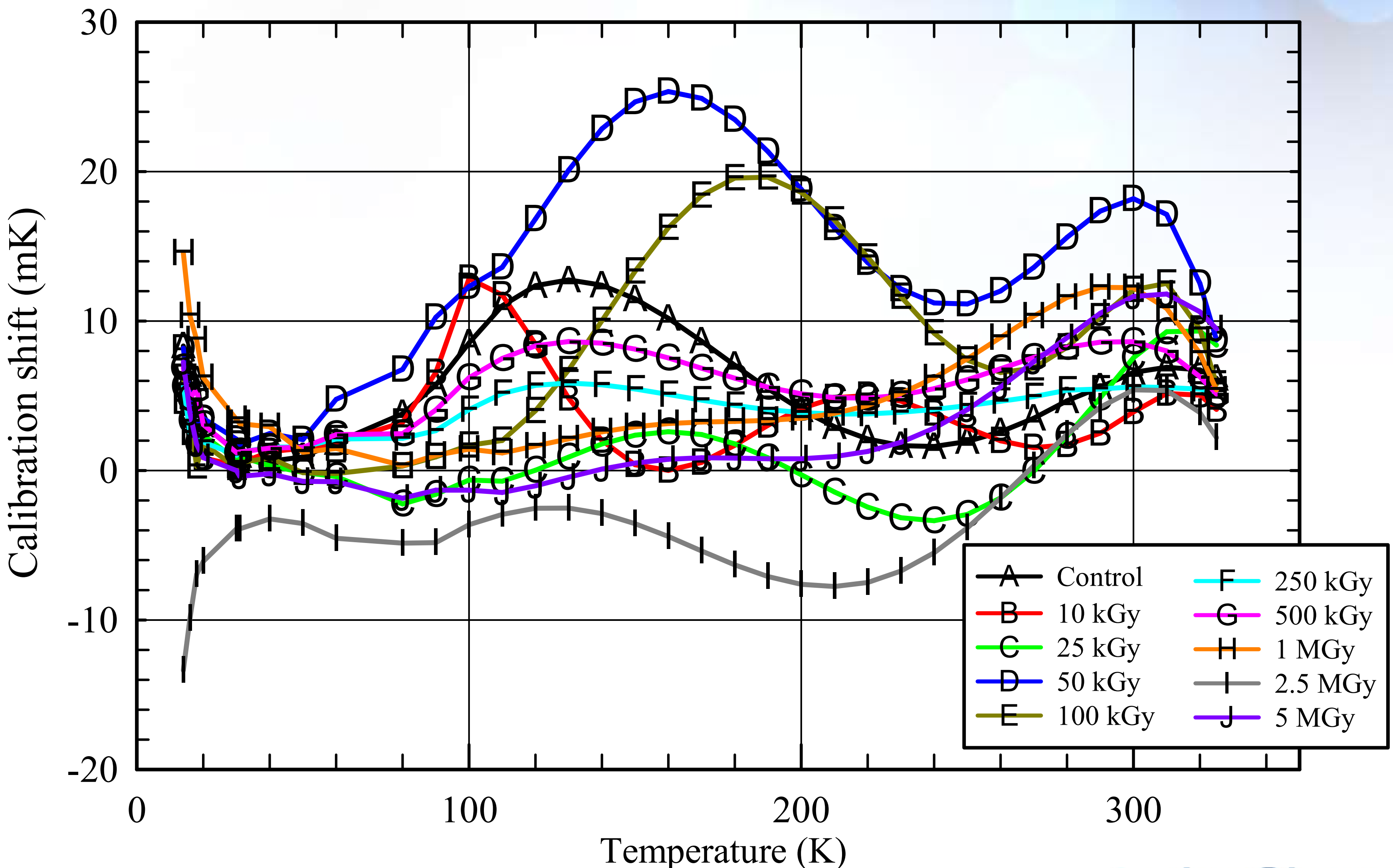
Measurements

- 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

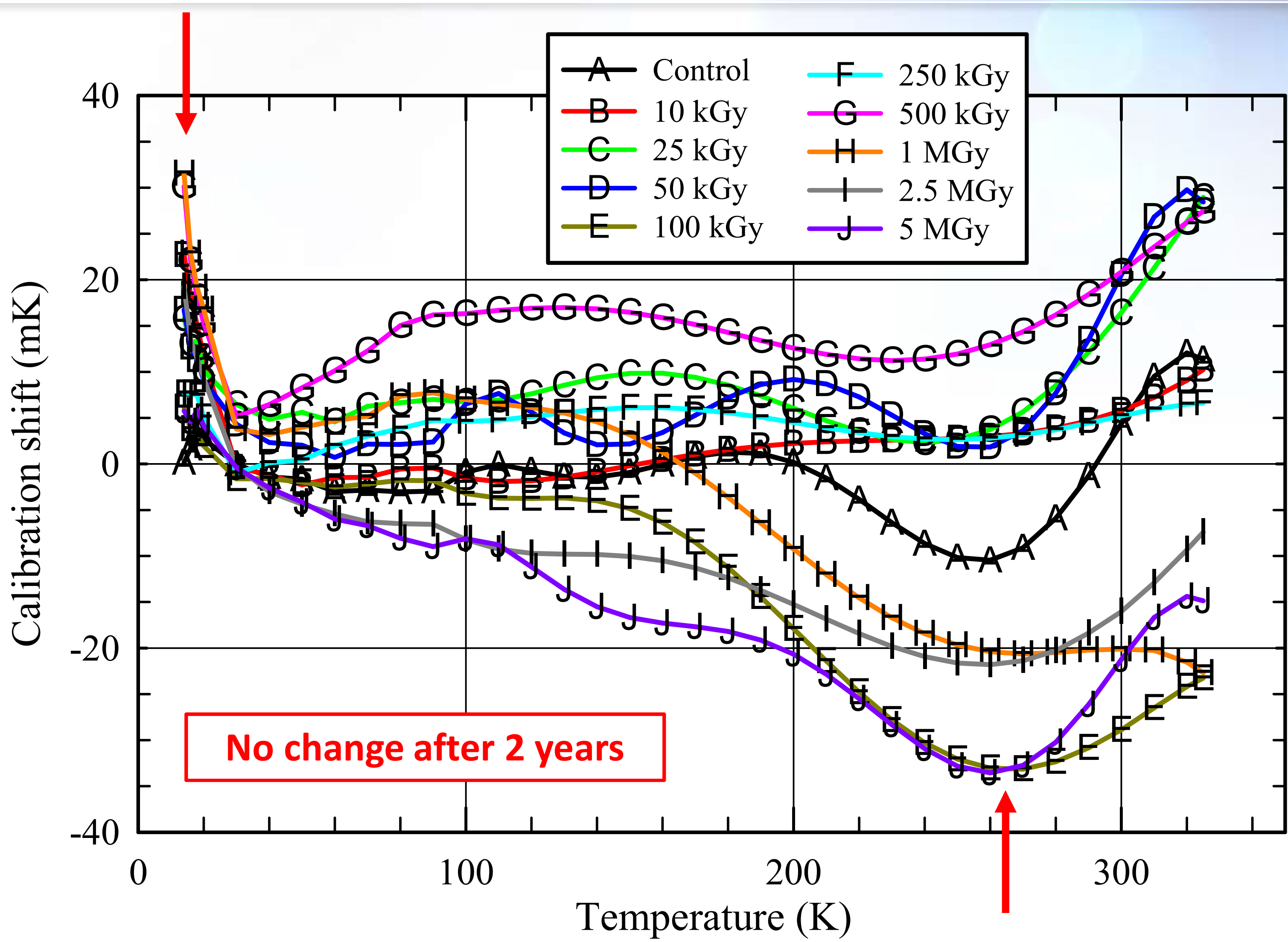
Temperature (K)	Uncertainty (± mK)	
	PT-103 / PT-111	DT-670-SD
1.4	--	7
4.2	--	5
10	--	6
20	9	9
30	9	31
50	10	37
100	11	32
200	17	33
300	24	35

  - PRT results given as Calibration shifts calculated as $\Delta T = \Delta R / S_T$
    where $\Delta R = (R_{final} - R_{initial})$ and S_T = Temperature Sensitivity
    (Similar for SiDTs with Resistance replaced by voltage)

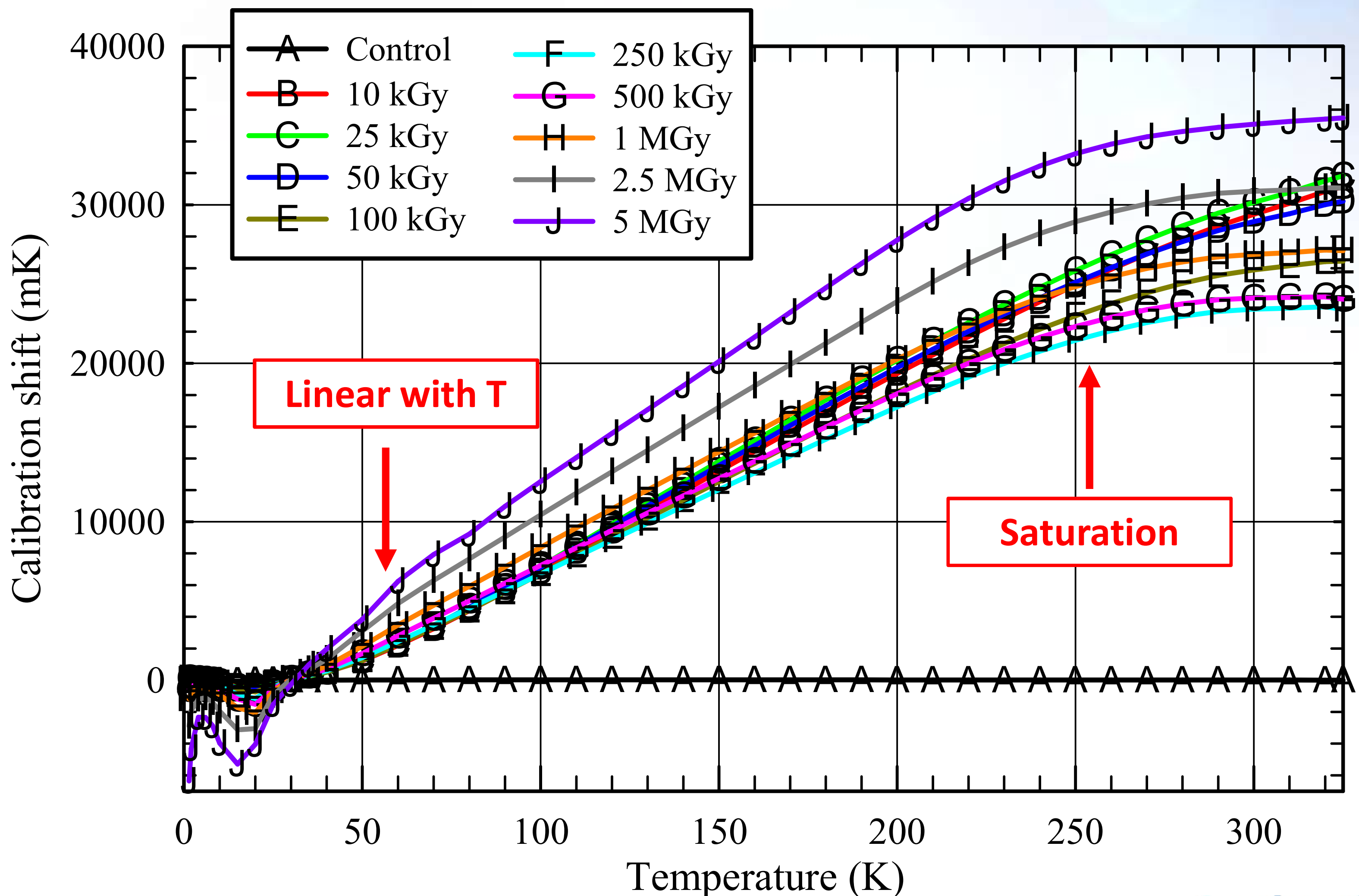
PT-103 PRT: Average ΔT after irradiation



PT-111 PRT: Average ΔT after irradiation



DT-670-SD SiDT: Average ΔT after irradiation



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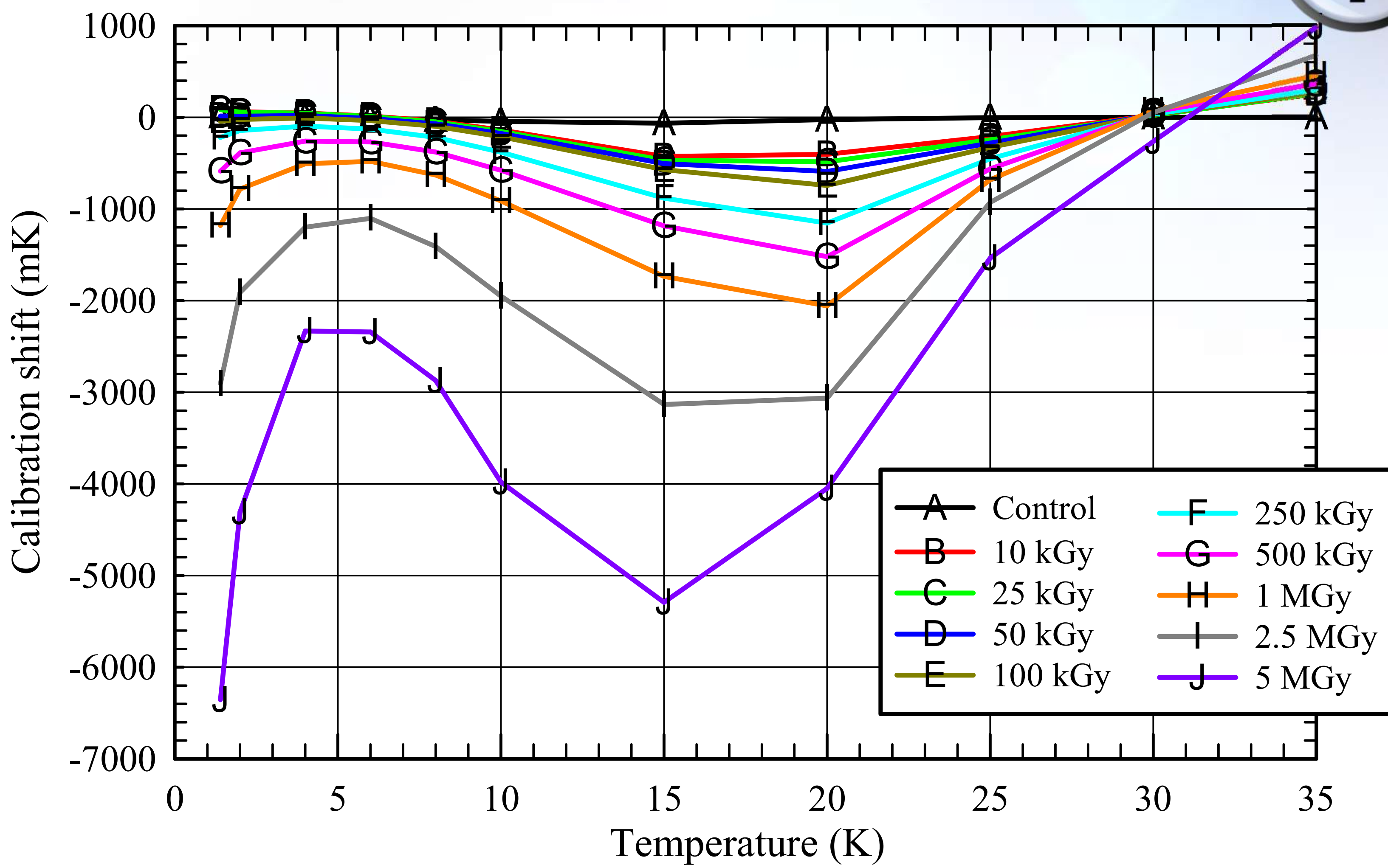
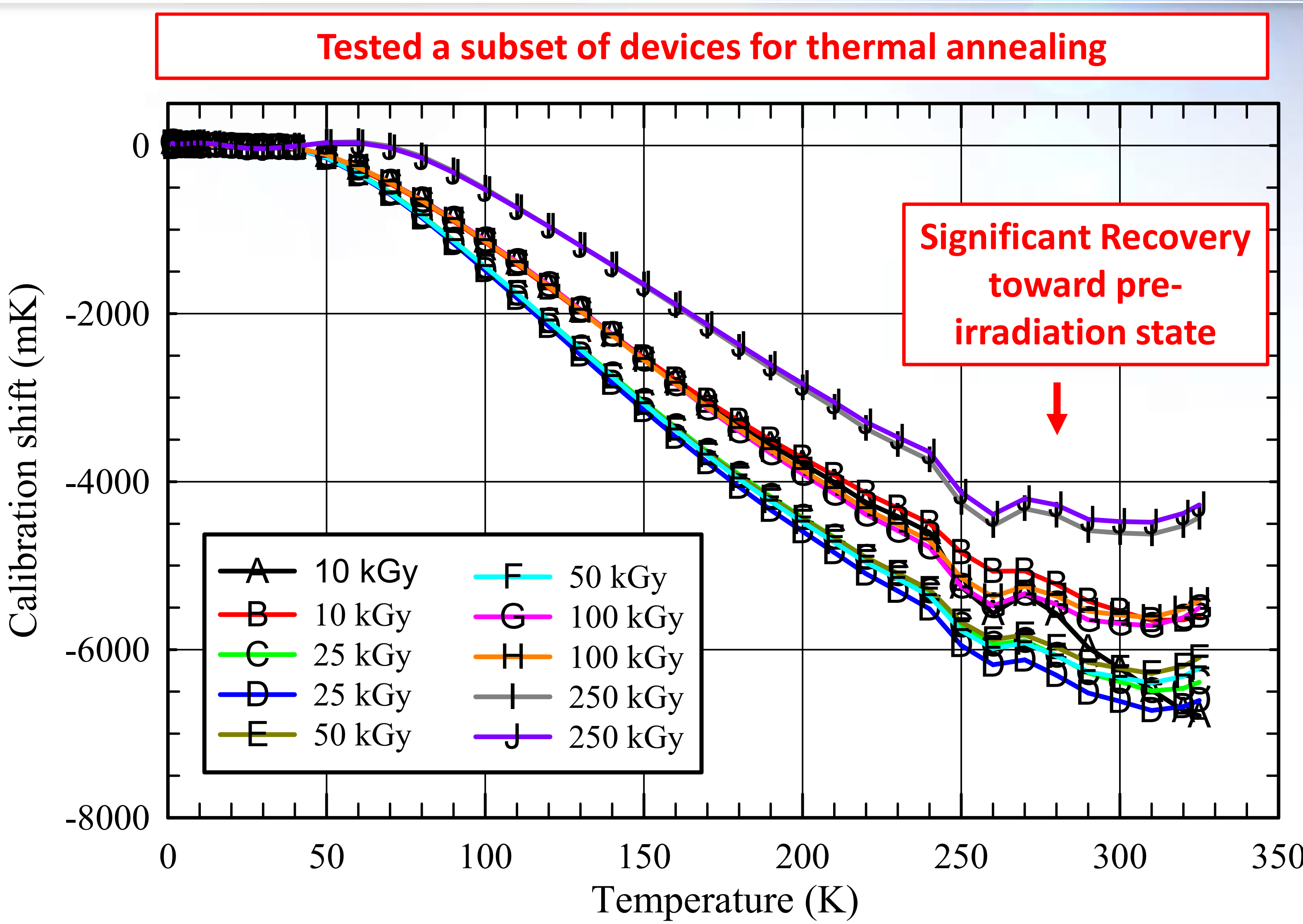
DT-670-SD SiDT: Average ΔT after irradiation



DT-670-SD ΔT after calibration + 2 years at 298 K



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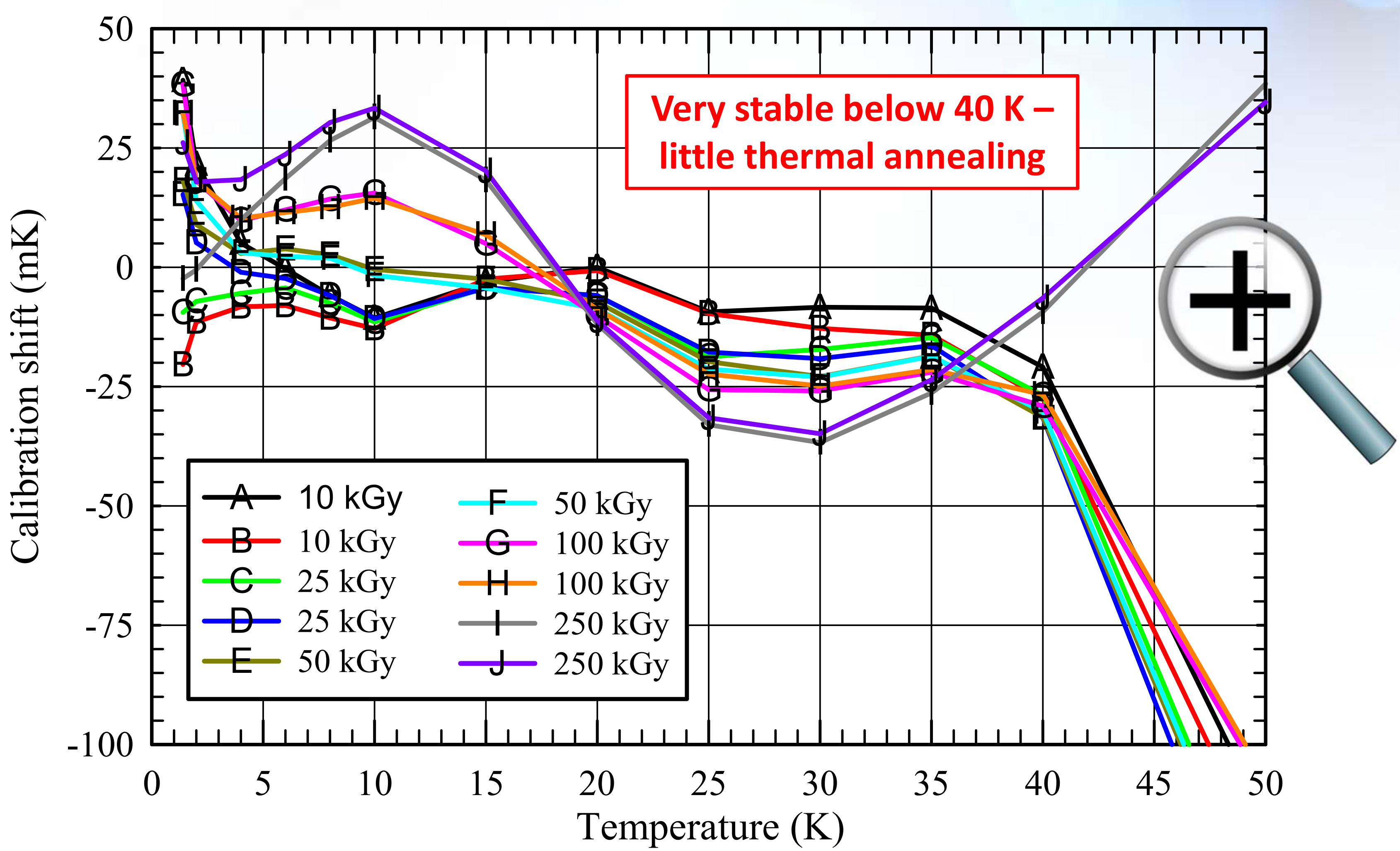
DT-670-SD ΔT after calibration + 2 years at 298 K



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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 ΔT offsets above 50 K**
  - **Small, negative ΔT 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**