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QASPR
QUALIFICATION ALTERNATIVES TO SPR

Modeling & Uncertainty Quantification of Electronic Devices within Radiation Environments

Qualification Alternatives to the Sandia Pulse Reactor (QASPR)

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Overview Of Topics

I. What is QASPR?

II. QASPR Approach

III. Identifying & Quantifying Uncertainties

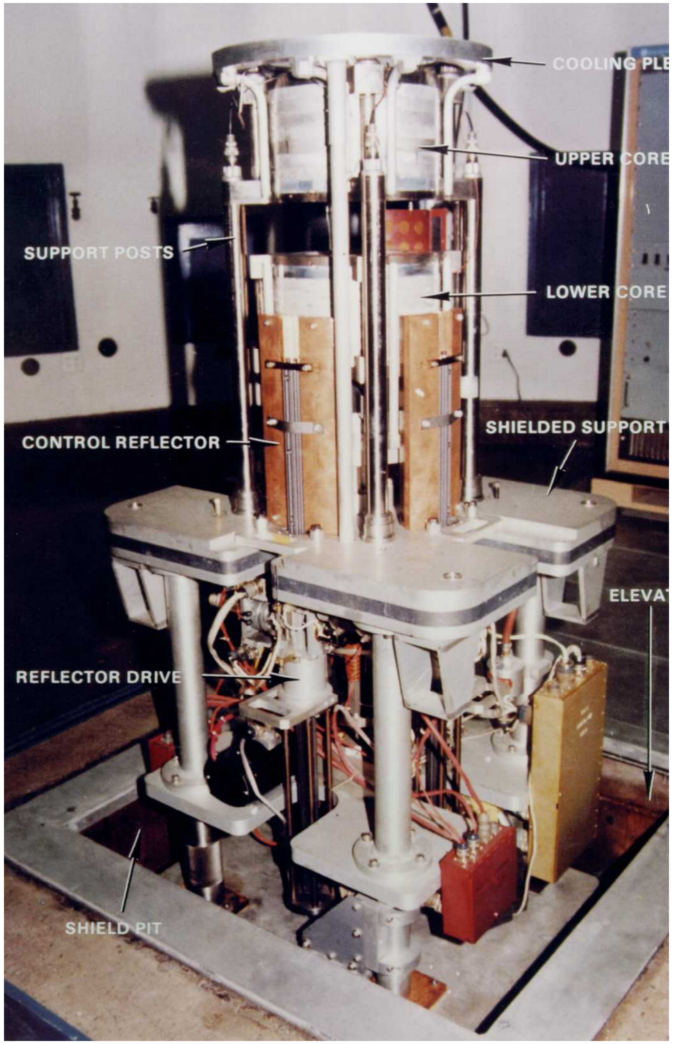
IV. Propagating Uncertainty

V. Best Estimate + Uncertainty

VI. Conclusion

Need: Qualify electronics for intense neutron bursts without a fast-burst reactor – μs time scales

SPR-III pulse reactor



Features:

5×10^{14} n^0/cm^2 in 76 μs

(1-MeV Si equivalent)

within 17-cm cavity

Status:

Permanent shut-down

in September 2006

per DOE policy on

special nuclear materials

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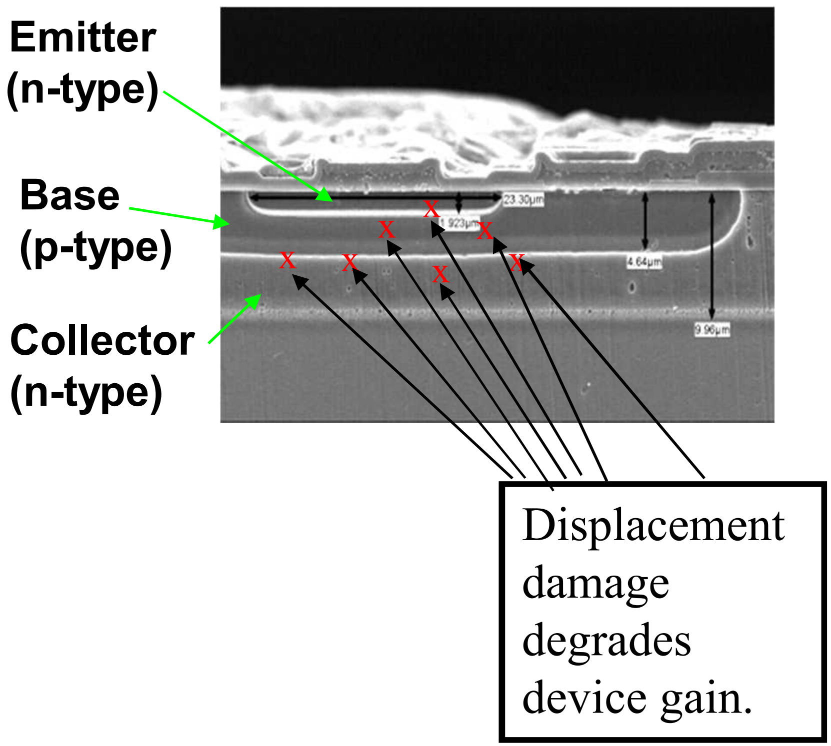
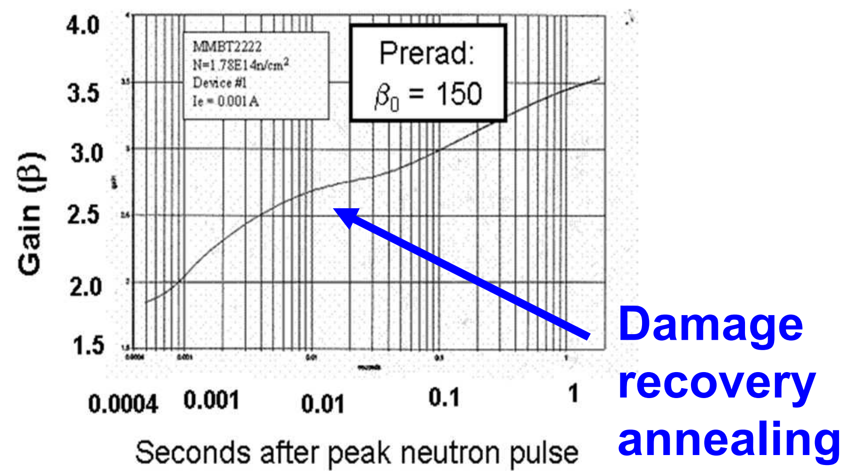
Short pulse neutron environments create damage in materials and devices

Requirements drive the need to qualify devices and systems

Neutrons create displacement damage

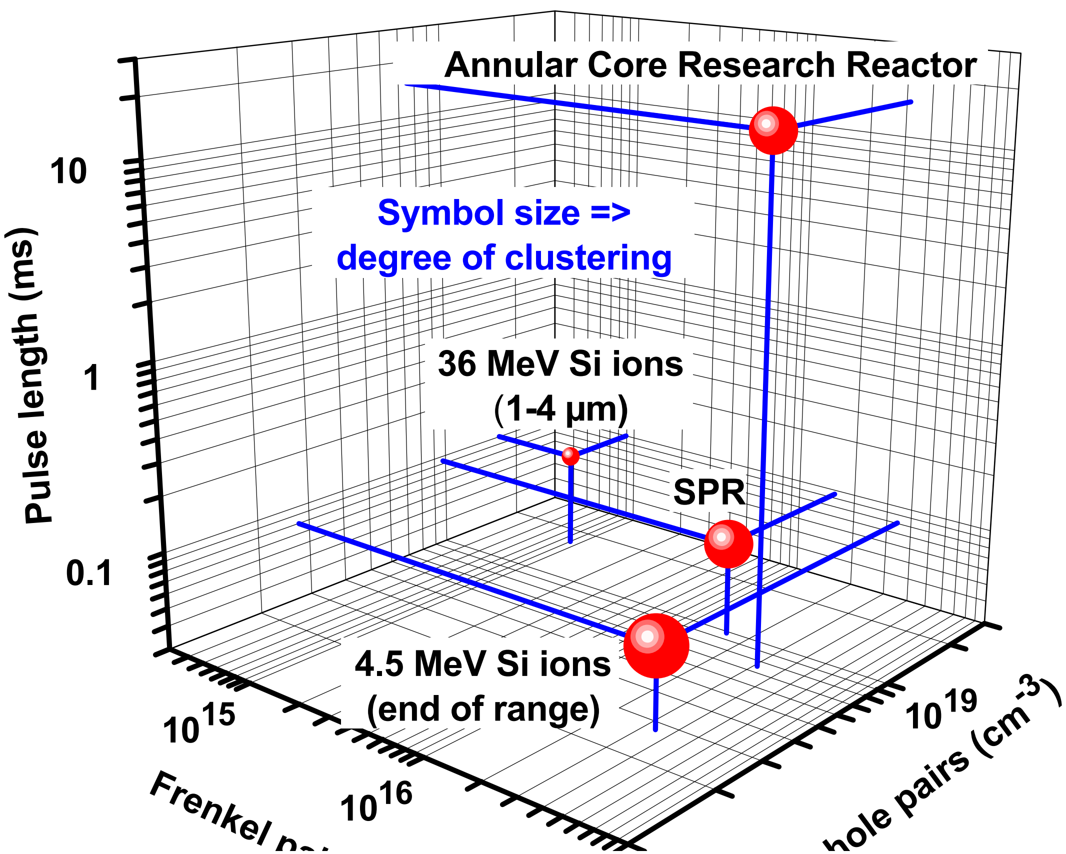




Solution: The QASPR approach

Merging Experiments, Modeling, and UQ

I. Irradiation testing in alternative facilities still available



II. Science-based modeling to go from tests to response

Neutron (& gamma) production SPR, IBL, ACRR, etc.

↓

Transport of radiation particles

↓

Defect production & ionization in electronic materials

↓

Time evolution of defects

↓

Carrier behavior and resultant device operation

↓

Circuit operation

III. Quantify uncertainty in simulation and experiment – make quantified comparisons

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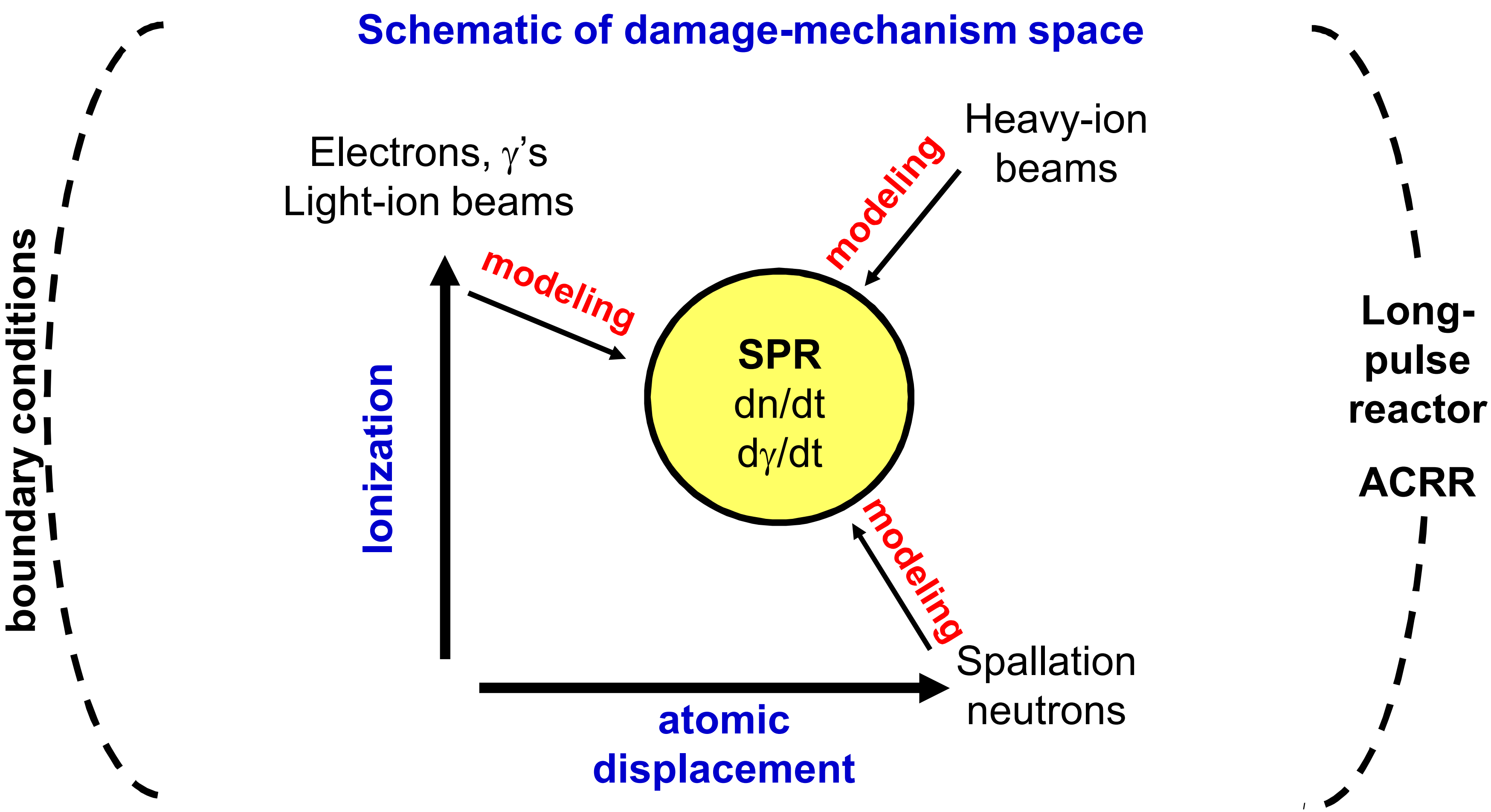
Augment testing at alternative facilities with computational modeling & uncertainty quantification



UQ-Relevant Terms

- **Calibration:**
  - Use existing test data (model development) to improve physics model parameter settings in simulation code.

- **Validation:**
  - Assess agreement between simulation data and <u>new</u> test data (validation).
    - *Not using same test data from calibration*.

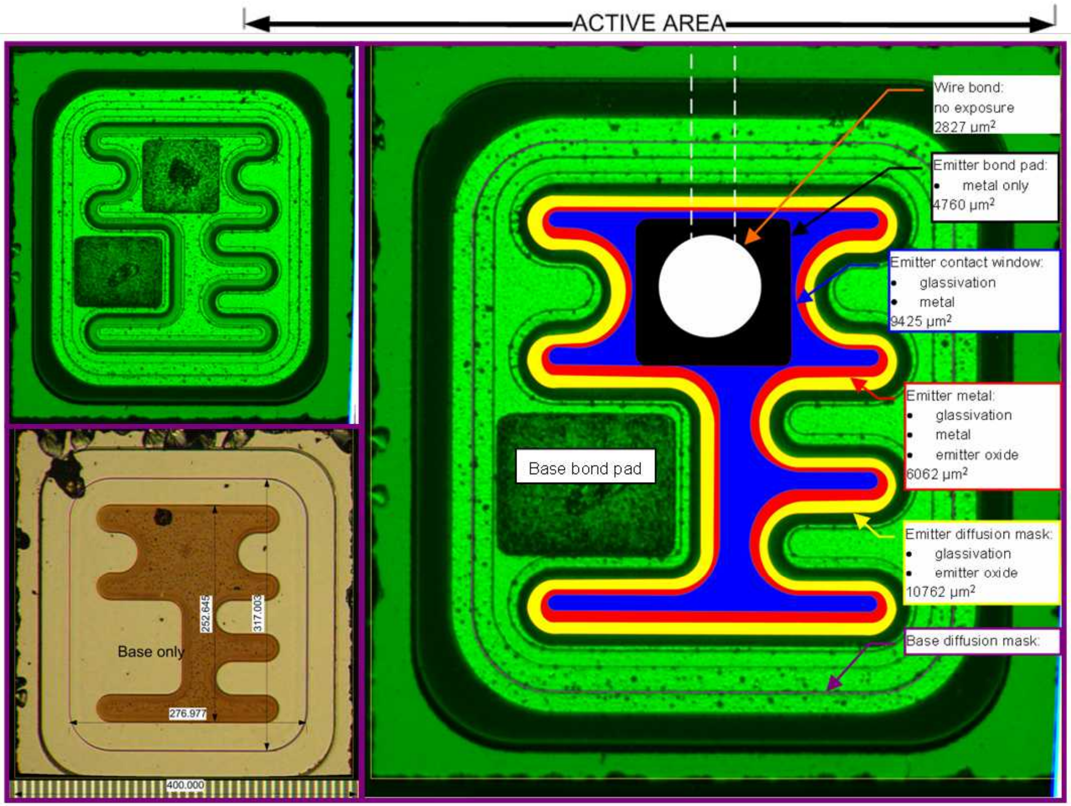
- **Uncertainty quantification:**
  - Estimate uncertainty in test data.
  - Propagate input parameter uncertainty through code(s), and estimate uncertainty in simulation data.

- **Related topic – Verification:**
  - Assess mathematical correctness of simulation code(s).

Categories of Uncertainty

- Physics parameters
  - cross-sections
  - diffusion parameters
- Device model
  - doping characteristics
  - device areas
- Device performance (electrical) measurements
  - current measurements
- Radiation environments
  - Ni activity
  - Si calorimeter integral data
- Model form (fidelity)
  - Psuedo-1D Charon vs. 2D Charon
  - Oxide
- Numerical/computational
  - not varying since small compared to other uncertainties

Device Characterization Uncertainty



Optical die photos of a BJT (Fairchild MMBT2222A) used to measure various features. This information is used to target areas for SIMS and SRP analysis, provide scaling factors for device modeling, and for ion beam irradiation experiments. Linear accuracy is 2%; area accuracy is 4%. Care is taken to avoid digital photo distortion.

Top left: As received die.

Bottom left: Die that has been deprocessed (unlayered) to bare silicon and junction stained. Brown area is the emitter diffusion. Scale at bottom is a NIST standard (µm units)

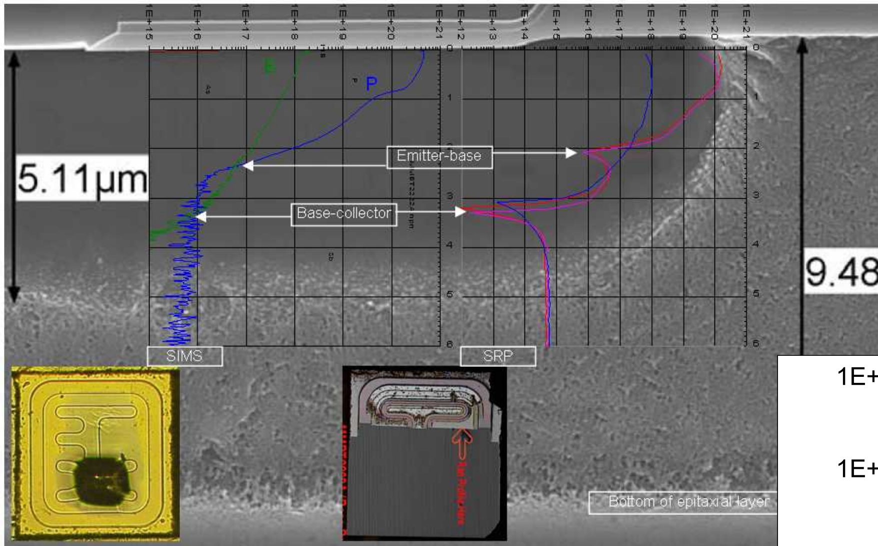
Right: Die map of different regions that lie over the emitter diffusion. The areas are identified by their outer borders. Interpretation of ion beam irradiation experiments using device models require measurement of the area for each combination of glassivation, metallization, and thermal oxide layers present over emitter diffused portion of this device.

Scanning Electron Microscope measurements of dimensions ~5% uncertainty

layer thickness features.
e is taken to avoid effects
tive diffusions; the layers'
etration depths when

Area measurements using optical die have ~4% uncertainty

Dopant measurements have 20% uncertainty



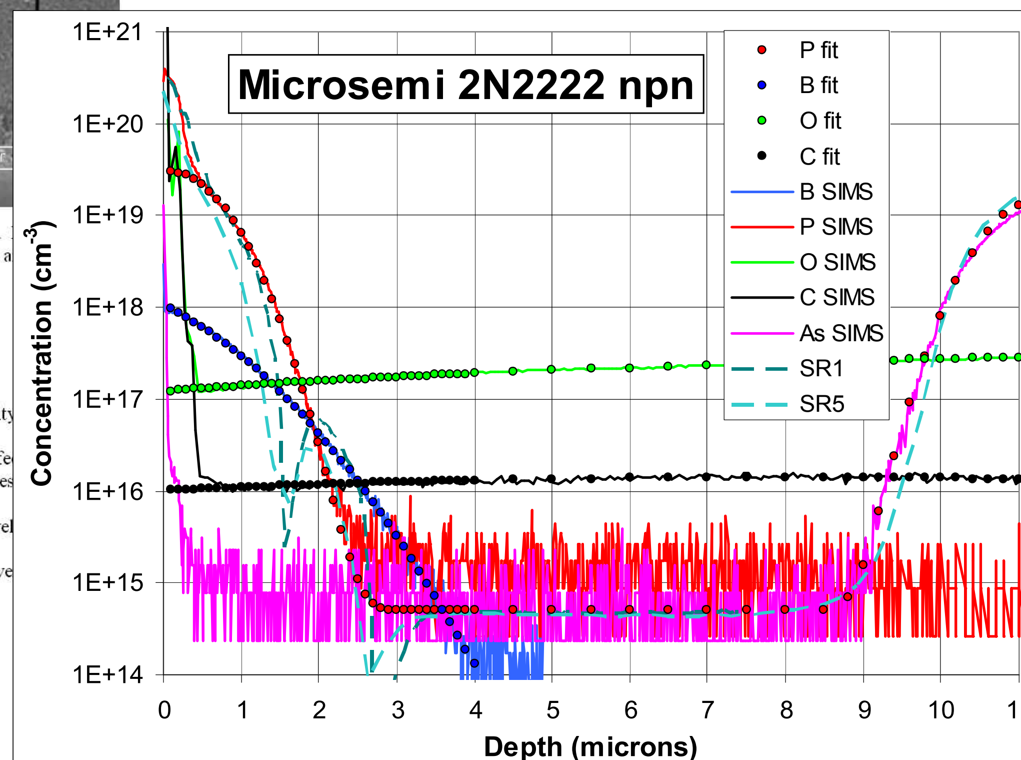
Secondary ion mass spectroscopy (SIMS) and spreading resistance (SRP) for Fairchild MMBT2222A npn.
superimposed on junction stained cross section. In this case the base-collector junction depths from SIMS a
shallower than from the junction stain (5.11 µm), which is an indicator only.

Left plot: SIMS metallurgical base-collector junction depth (3.40 µm) from dopant (P, B) concentrations
Absolute concentration accuracy = 40%; depth scale accuracy = 5% (crater profilometry) ~ 0.15 µm)

Right plot: SRP electrical base-collector junction depth (3.25 µm) from free charge carrier concentrations
Absolute concentration accuracy = 20%; depth scale accuracy = 3% (bevel angle)

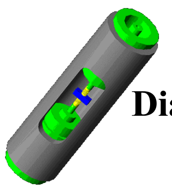
Note SIMS / SRP accuracies are affected by:

1. Dopant type (SIMS ion implanted standard used, mass interference, signal to noise / SRP carrier density
   carrier mobilities for P and B doped Si, even when other dopants are present)
2. Dopant /carrier concentration gradient with depth (SIMS sputter rate variations / SRP space charge effe
   higher doped, sharp junctions (emitter-base) are more precise than lower doped, more Gaussian profiles
   ones (e.g. base-collector)
3. Size of the measured feature (SIMS signal to noise and raster alignment with small features / SRP bevel
   required and feature edge effects). Minimum size: SIMS ~ 40 µm, SRP ~ 25 µm width.
4. Sample topology. Small steps in Si surface at edge of diffusions from device processing. Possible ove
   to limitations of selective etches used for deprocessing prior to analysis. Corrections can be applied.



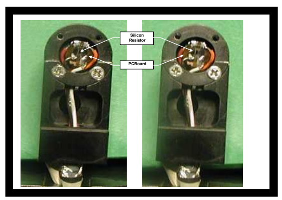
Improvements in dosimetry/analysis support for uncertainty characterization for QASPR

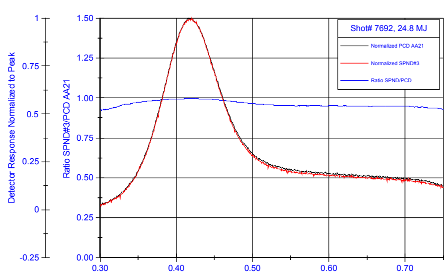
Time Profile



Diamond PCD

New Si calorimeter



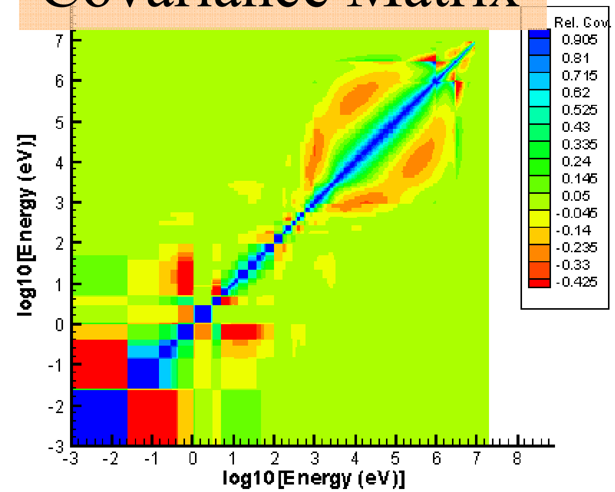


Uncertainty estimate

200% ⟶ 25%

Spectrum

Covariance Matrix



Uncertainty estimate

~ 5%

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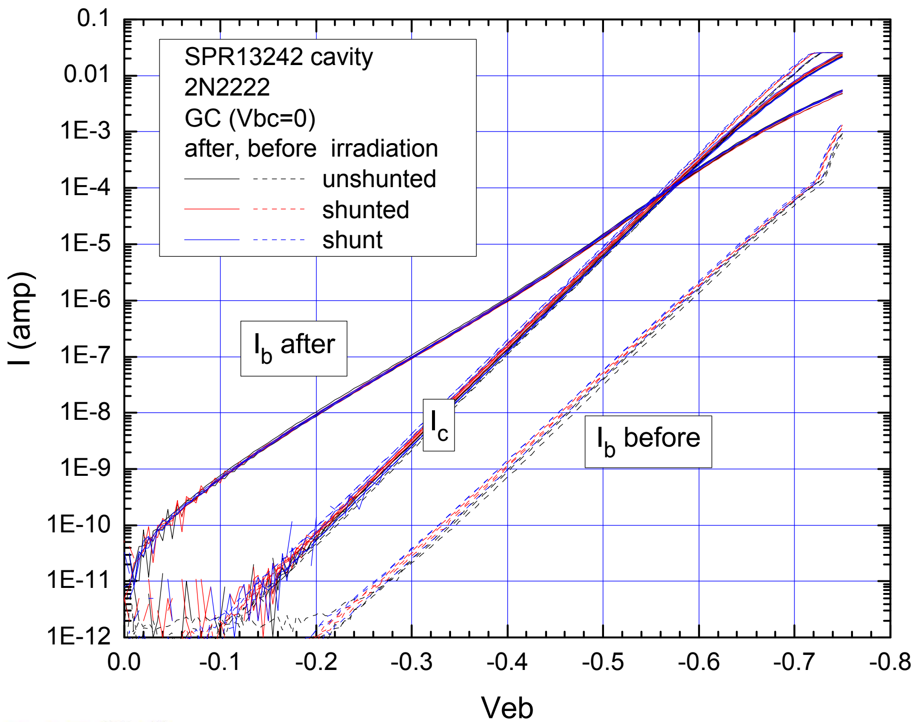
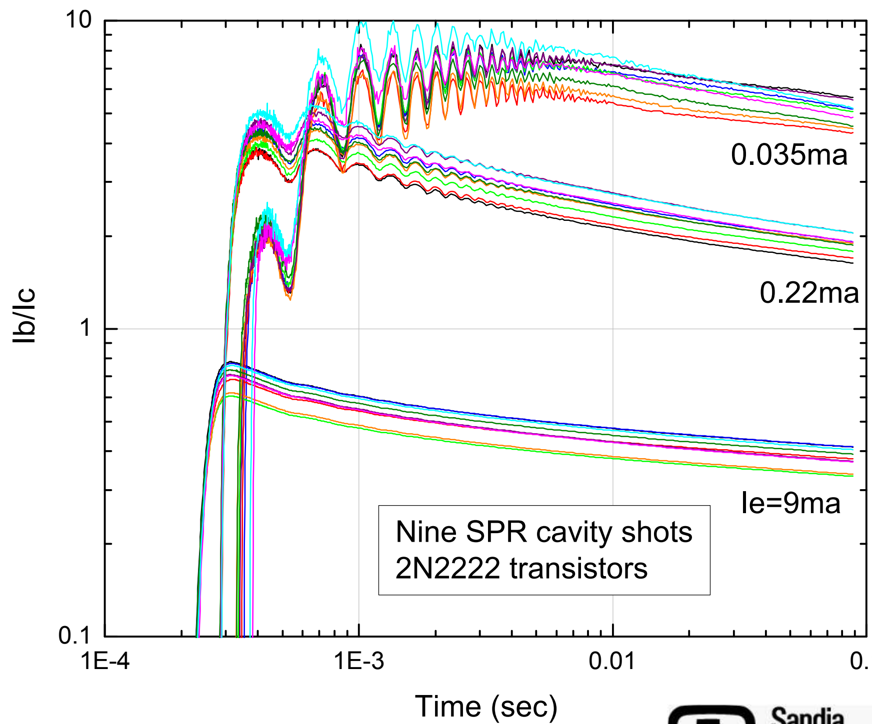
Radiation Test (Experimental) Data

Test data consists of time resolved voltage & current during & after irradiation and pre & post measurement of IV characteristics or Gummel curves.

Gummel curves



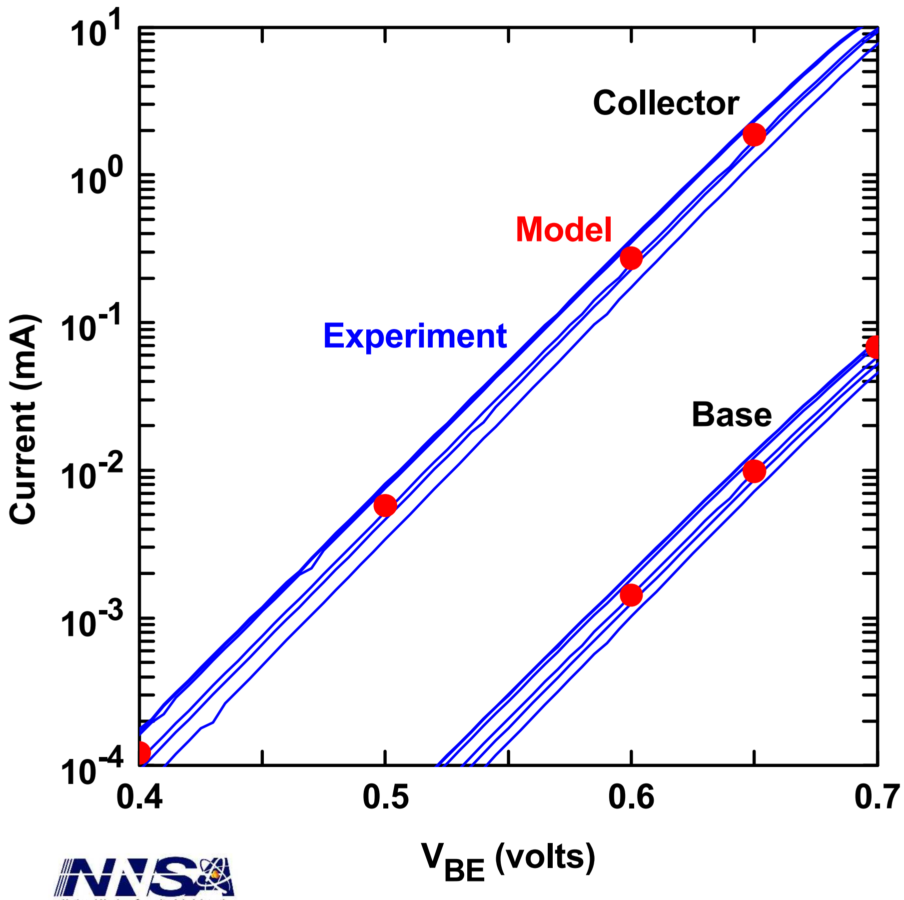
Inverse gain vs time



Experimental variability & uncertainty are important in UQ

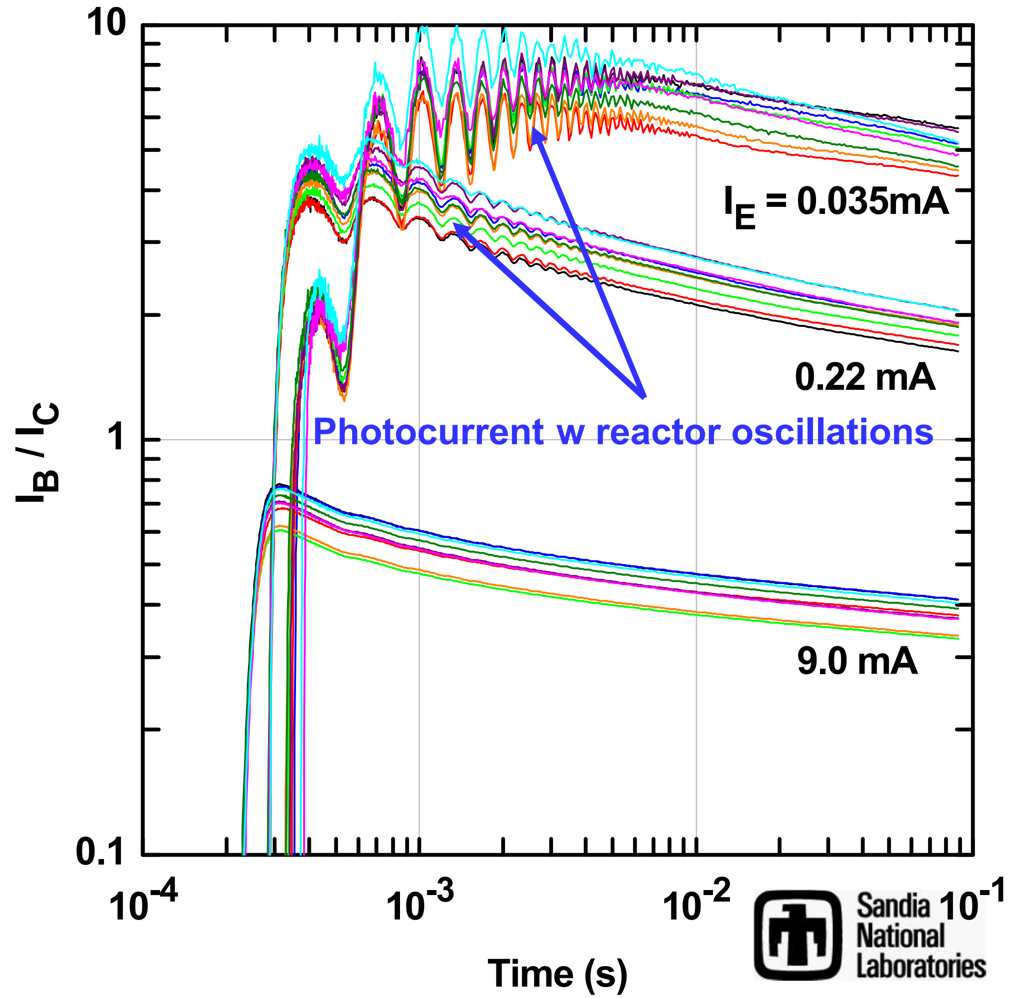
Device-to-Device

Pre-rad Gummels of 7 n-p-n BJTs
Single wafer



Shot-to-Shot

9 SPR-cavity shots w 3 n-p-n BJTs/shot Single lot of wafers corrected for n^0 fluence variation



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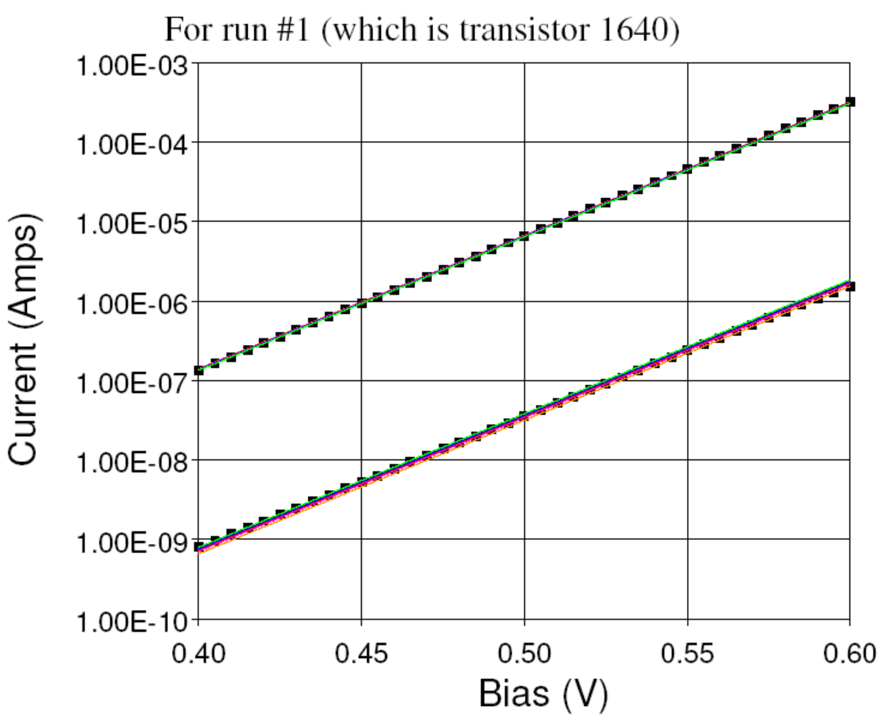
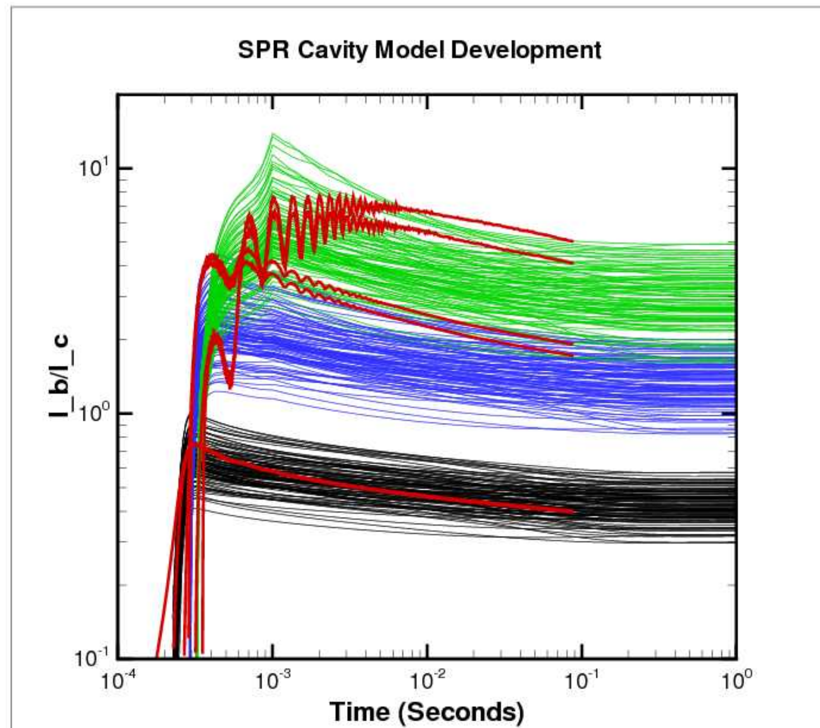
Uncertainty is Being Reduced through Calibration

- Dopant profile uncertainty
  - Unirradiated operating performance measured
  - Models run to optimize fit to measured performance by adjusting dopant profiles

- Physics parameters uncertainty
  - Irradiated operating performance measured
  - Model runs to optimize fit to transient performance by adjusting poorly known physics parameters





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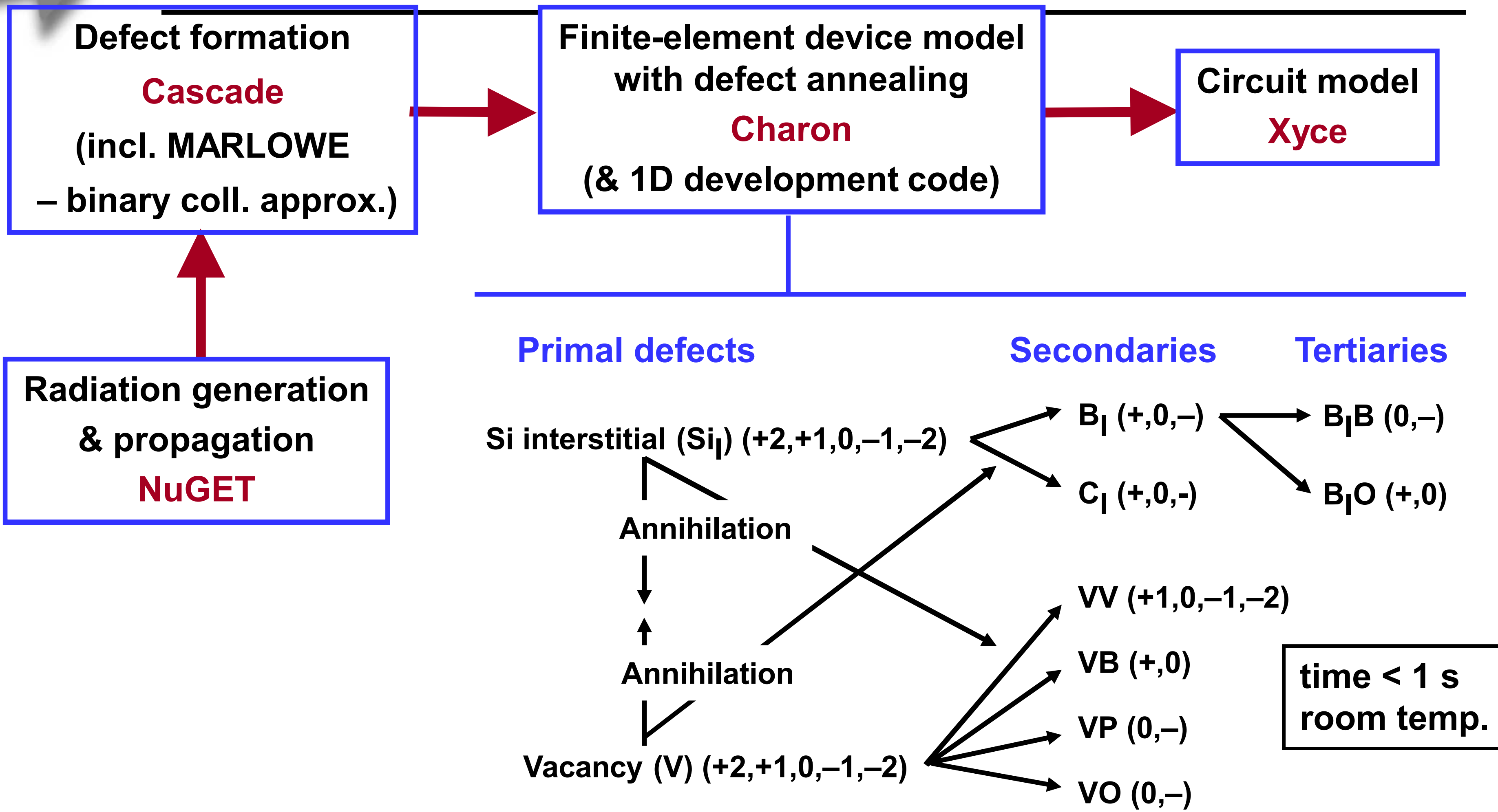
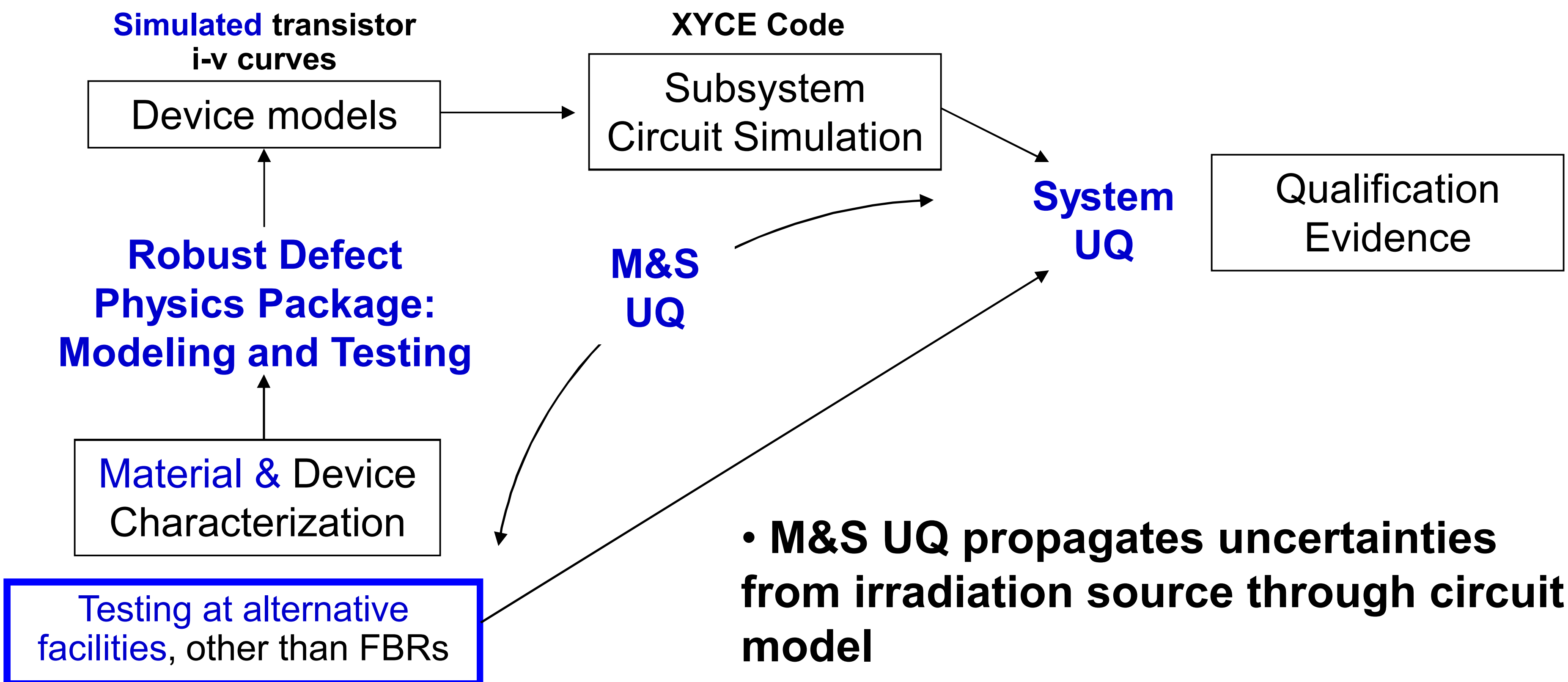
Codes in primary computational sequence



Defect-physics approach:

Use defect species well founded on experiment or *ab-initio* theory
Adjust poorly known physics parameters for consistency with testing

The QASPR qualification approach will include device testing and device/subsystem modeling



- **M&S UQ propagates uncertainties from irradiation source through circuit model**
- **System UQ estimates bias to include with best estimate plus uncertainty SPR calculations**

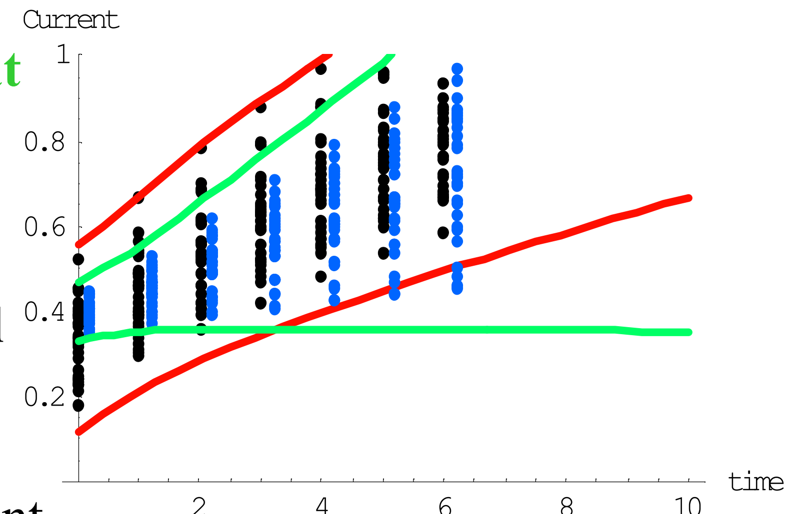
Propagating Uncertainty

- On the order of 150-200 uncertain parameters throughout QASPR for device (those that have been identified)
- We cannot "blindly" propagate uncertainty for all parameters
  - setting conservative bounds on all variables may produce meaningless results
  - limited by time and budget
- Limit the number variables based on reduction rationale
  - sensitivities of parameters
  - strong correlations between parameters
  - reduction of bounds with calibration
  - some expert judgment – will be formalized with sensitivity analyses

End Game: Best Estimate + Uncertainty

Device Process

- •Characterize as-built device parameters and conduct unirradiated testing **(Experiment)**
- •Calculate unirradiated device operating performance to finalize device model **(Modeling)**
- **•Conduct device performance experiments at alternate facilities (Experiment)**
- **•Predict device performance at alternate facilities (Modeling)**
- **•Use device computational and experimental results to determine any systematic bias in modeling (UQ)**
- •Predict device performance in SPR environment **(UQ+Modeling)**
- •Adjust SPR prediction using systematic bias to construct best estimate plus uncertainty **(UQ)**



Red lines/Black dots – simulation data
Blue lines/Green dots– test data

Conclusion

- QASPR integrates a wide range of modeling and experiments with UQ to provide a best estimate + uncertainty of electrical device/circuit response within a radiation environment

- This effort spans eight Sandia centers and exemplifies a trend toward inter-organizational integration in pursuit of larger objectives.

Supplementary Slides

The QASPR development plan requires different types of data to be collected

Model development	Validation	Prototype	Model development ??
Determine relevant physics Develop relevant diagnostic techniques Develop (or adapt) needed codes Develop uncertainty techniques	Collect validation data Verify and Validate models Quantify uncertainty	Conduct prototype - Characterize as-built devices - Test at alternative facilities - Simulate performance at alternative irradiation facilities - Calculate best estimate plus uncertainty - Compare QASPR result with prototype test data	**Refine and expand**
Establish alt facility damage relationships			

Data Types

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