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Cable SGEMP Code Validation Study

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Cable SGEMP Code Validation Study

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Abstract

This report compared data taken on the Modular Bremsstrahlung Simulator using copper jacketed (cujac) cables with calculations using the RHSD-RA Cable SGEMP analysis tool¹. The tool relies on CEPXS/ONBFP²⁻³ to perform radiation transport in a series of 1D slices through the cable, and then uses a Green function technique to evaluate the expected current drive on the center conductor. The data were obtained in 2003 as part of a Cabana⁴ verification and validation experiment⁵ using 1-D geometries, but were not evaluated until now. The agreement between data and model is not adequate unless gaps between the dielectric and outer conductor (ground) are assumed, and these gaps are large compared with what is believed to be in the actual cable.

Acknowledgements

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1. Introduction

The cable SGEMP (System Generated Electro Magnetic Pulse) code, CblSGEMP, was used to model radiation induced cable charge on two different coaxial cables. The code provided an understanding of how the cables would respond at a Modular Bremsstrahlung Source (MBS) at 190 keV and at 275 keV. The MBS simulator is typically an economical simulator for characterizing cable SGEMP due to its low energy spectrum. The CblSGEMP code, which is available in the Radiation Hardened System Design Toolset, is an extension of another radiation code called BOXIEMP2J, developed by L3 Communications (formerly JAYCOR).¹ The code performs quasi 2-D radiation transport modeling using the 1D Sandia codes CEPXS² and ONEBFP³. Presently, CblSGEMP can only model a single coaxial cable of cylindrical geometry as shown in Figure 1 in a very simplistic form.

In CblSGEMP the cable SGEMP computation is illustrated in Figure 1. We assume that the radiation is incident from the left as identified by the arrows. In order to calculate the total charge contribution on the center conductor of the cable, the cable is divided into a number of thin slabs along the direction of the incident radiation as shown. Each slab appears as a stack of materials of given thickness. In each slab the radiation absorbed in the various materials will generate electrons and photons from photoelectric, Compton scattering or pair production, depending on the energy of the radiation. The open circuit voltage at the center conductor with respect to the outer shield is determined by convolving the charges along each slab with the Green's Function solution of Poisson's Equation for the coaxial cable, and the cable capacitance per unit length is used to then determine the induced charge on the core wire. The total cable SGEMP drive is given in units of Coulomb/(m-cal/cm²).

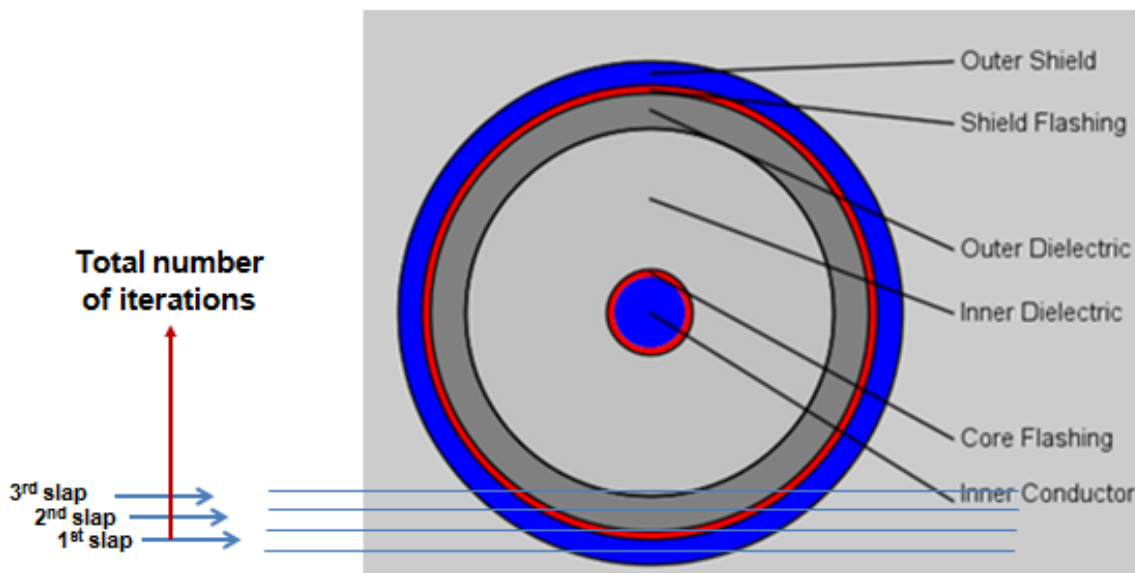


Figure 1 Cross section of a single coaxial cable defined by CblSGEMP.

2. Experimental Setup

These analyses are based on the Cabana Verification & Validation run⁵ on the Modular Bremsstrahlung Source (MBS) at L-3 Communications Pulse Sciences (the old Physics International), using the 200 and 300 keV (nominal) spectra in 2003. Prior papers focused on evaluating the test cassettes, not the solid jacketed cables. When modeling, MBS spectra with 190 keV and 275 keV endpoint energies are used. These spectra are distributed with RHSD-RA¹.

The experimental layout is shown in Figure 2. The two cables in question are looped around the outer edge of the exposure area. We focus on a standard copper jacketed (aka cujac) cable referred to as Cu141 and a stainless steel outer conductor variant referred to as CR141BSS.

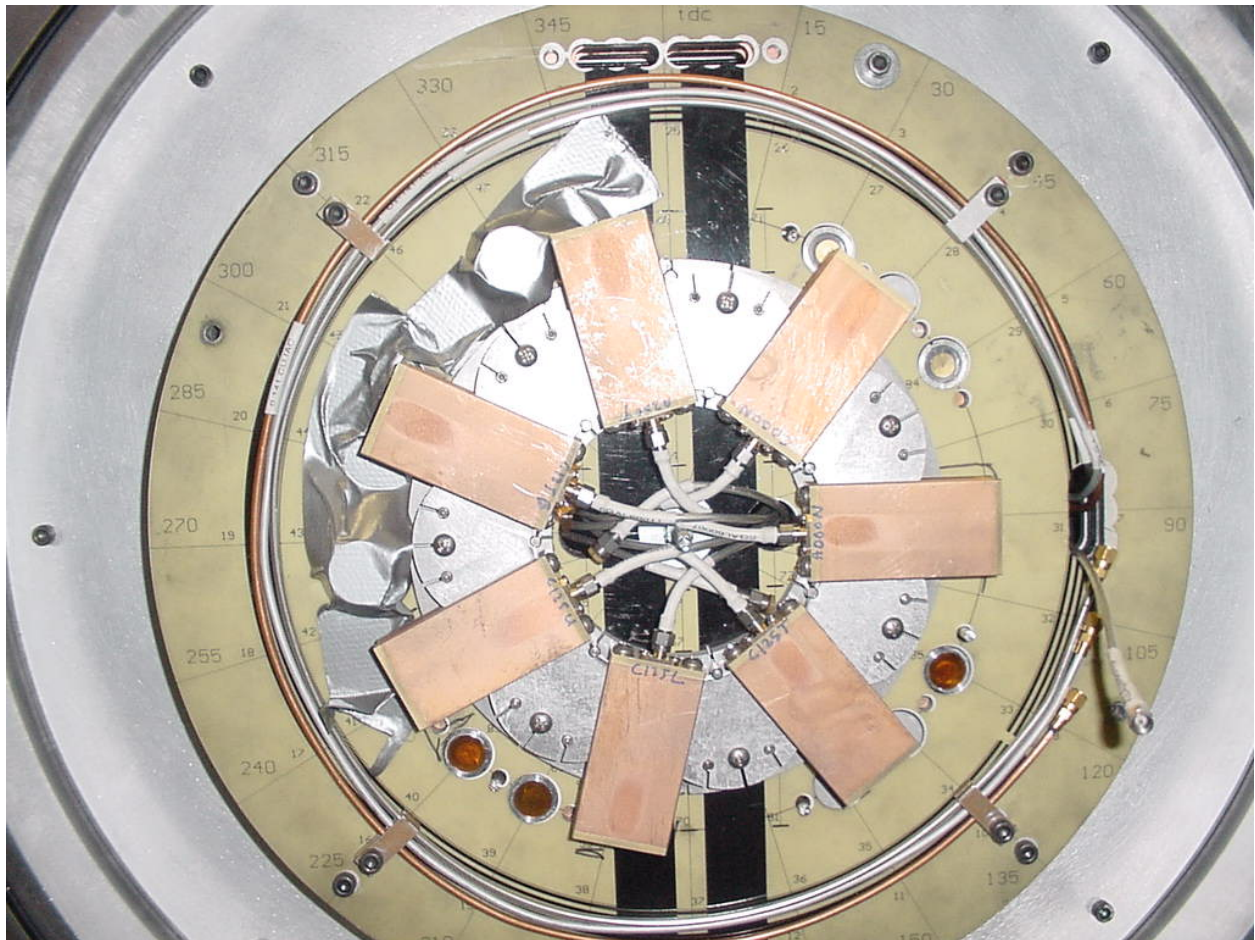


Figure 2 Cabana V&V test layout. Cujac cables are 1 m long around the outer periphery of the exposure area.

3. Data

3.1. Dose Conversion Factors

All calculations were performed with RHSD-RA Version 4.0¹ with the following exception. The original dosimetry was obtained from gold and copper calorimeters, and the data were normalized to dose gold, so a correction is needed for dose Si. Correction factors were generated by performing photon transport using the CEPXS/ONEBFP Adept⁶ code through the 32-mil-thick Al front plate into 1 mil thick Au and Si to get the dose kerma. Adept will report the kerma (kinetic energy released per unit mass) for the calorimeters which RHSD-RA will not as it will only report dose. Table 1 shows the correction factors. For reference, similar calculations using RHSD-RA dose calculations gave correction factors of 0.0778 and 0.0850. These differences, while not insignificant, would not affect the conclusions later.

Table 1 Dose conversion factors for MBS spectra

Spectrum	Avg E MeV	Kerma Au MeV-cm ² /g- γ	Kerma Si MeV-cm ² /g- γ	Kerma Au rad/cal/cm ²	Kerma Si rad/cal/cm ²	Si/Au
MBS 190 keV	1.16e-2	3.73e-2	4.09e-3	1.35e6	1.48e5	0.110
MBS 275 keV	1.76e-2	5.35e-2	5.06e-3	1.27e6	1.20e5	0.0945

3.2. Normalized Results

Table 2 summarizes the results. Figure 3 shows the data traces for these two cables and the background noise traces for the 200-keV spectrum for a typical shot. Figure 4 shows similar data for the 300-keV exposures. In a perfect world, the air and vacuum data should agree perfectly. While they are close in magnitude, there is enough difference to suggest that there are some gaps in the cables that might be contributing to the signals. All sets of data were repeated for 5 shots with $\leq 5\%$ standard deviation. Figure 5 shows the data repeatability across the 5 shots after normalization to dose rate. The cables are all 1 m long, so technically, these results are per m.

Table 2 Vacuum and Air exposure data for two cable types and two MBS spectra

	200 Air	200 Vacuum	300 Air	300 Vacuum
	pV/m/rad(Si)/s	pV/m/rad(Si)/s	pV/m/rad(Si)/s	pV/m/rad(Si)/s
Cu141	3.73	3.08	7.75	7.83
CR141BSS	8.97	7.81	16.6	16.8

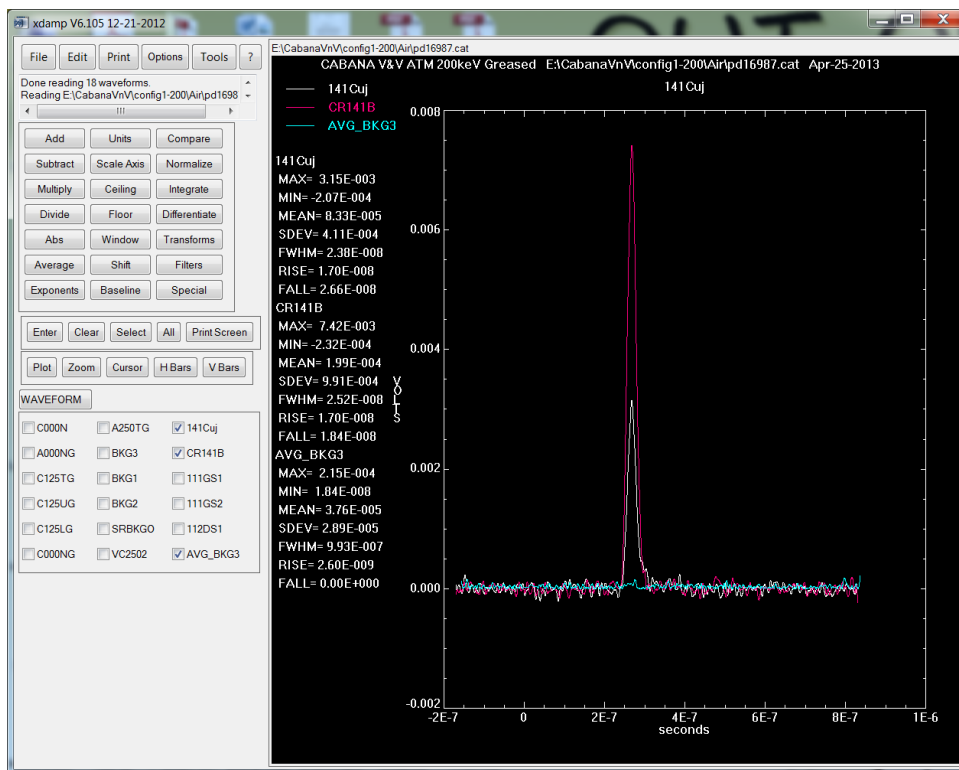


Figure 3 Data and background noise for cable signals at MBS with 200 keV spectrum in Air.

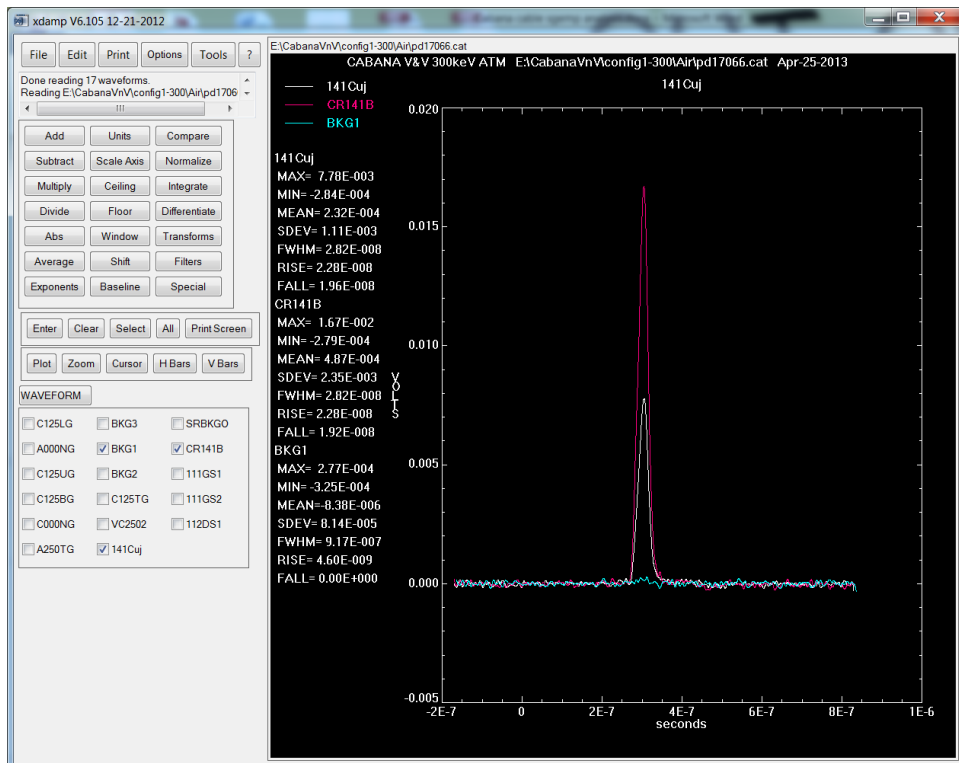


Figure 4 Data and background noise for cable signals at MBS with 300 keV spectrum in Air.

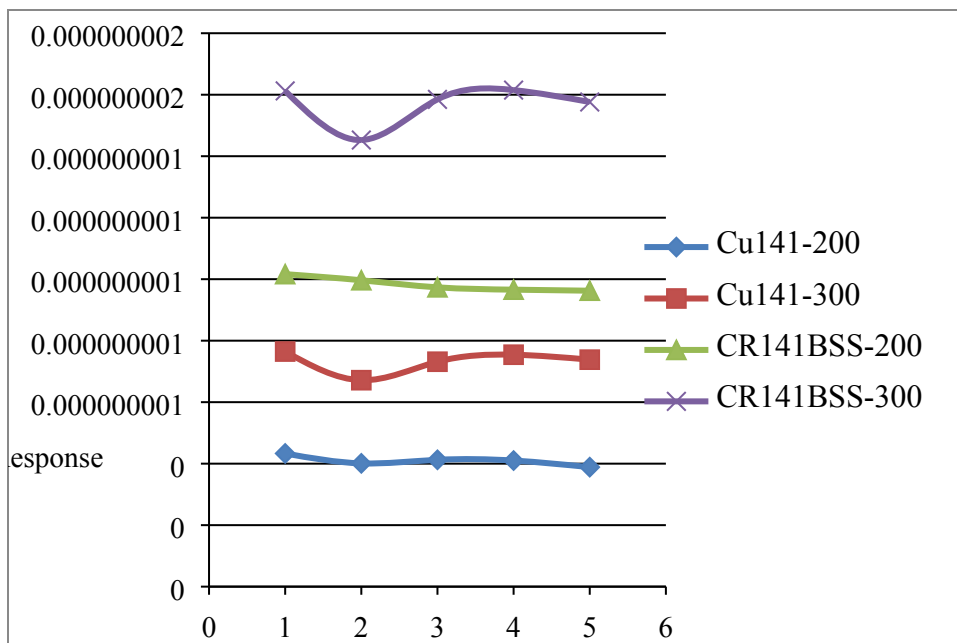


Figure 5 Plot of data repeatability for the two cases and both spectra.

4. CableSGEMP modeling

The modeling uses either a 190 keV or a 275 keV spectrum in the RHSD-RA distribution. The calculations include a 32-mil Al window that separated the MBS from the test chamber as a Faraday shield and vacuum container.

4.1. Baseline Cu141 calculation

According to the cable analysis report from Analytical Solutions⁷, the baseline cujac consists of a center conductor composed of steel, with a copper and then a silver coating. The dielectric is Teflon®, and the outer conductor is copper. The outer copper is 11.75 mils thick, the Teflon® is 40.8 mils thick, the silver is 0.472 mils (12 microns) thick, the copper is 4.5 thick, and the inner conductor is 47.7 mils diameter so the steel core is 18.9 mils in radius. RHSD-RA cannot model all three layers, so the copper between the steel and silver was omitted and the steel treated as 23.4 mils radius to keep the conductor diameter correct. There is also a 20-mil aluminum backscatterer in the calculation to account for the base plate in Fig. 1.

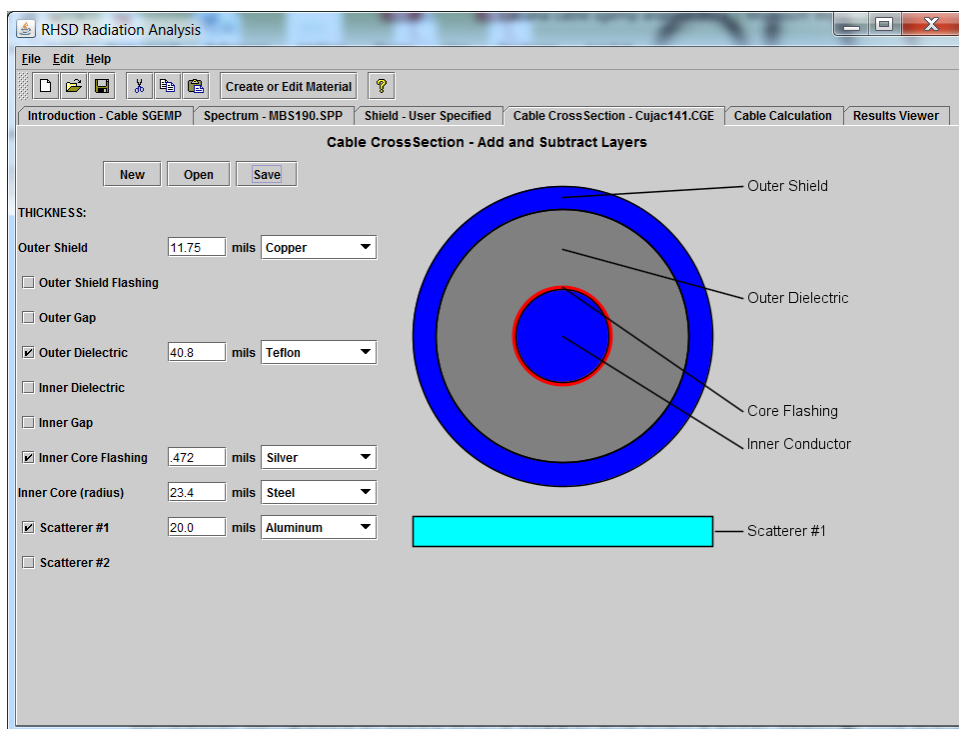


Figure 6 Screen shot of baseline Cu141 input.

Here is part of the output file for reference.

```
Attenuator 1: 32.0 mil Aluminum 2 Aluminum
3.20000E+01 2.19456E-01 2.70000E+00 0.00000E+00 1 1
13027 1.00000E+00
CABLE GEOMETRY DATA
Outer Shield: 11.75 mil Copper 6 Copper
1.17500E+01 2.67411E-01 8.96000E+00 0.00000E+00 1 1
29 1.00000E+00
Outer Shield Flashing: None 0
```

```

Outer Gap = 0.0000E+00 mil                                0          0.00000E+00
Outer Dielectric:  40.8 mil Teflon                        36          Teflon
  4.08000E+01  2.07264E-01  2.00000E+00  2.10000E+00      2      1
  6  2.40180E-01          9  7.59820E-01
Inner Dielectric: None                                    0
Inner Gap = 0.0000E+00 mil                                0          0.00000E+00
Inner Core Flashing:  0.472 mil Silver                    8          Silver
  4.72000E-01  1.25882E-02  1.05000E+01  0.00000E+00      1      1
  47  1.00000E+00
Inner Core:  23.4 mil Steel                                46          Steel
  2.34000E+01  4.65384E-01  7.83000E+00  0.00000E+00      2      1
  6  1.00000E-02          26  9.90000E-01
REAR SCATTERER DATA          1
Rear Scatterer 1:  20.0 mil Aluminum                      2          Aluminum
  2.00000E+01  1.37160E-01  2.70000E+00  0.00000E+00      1      1
  13027  1.00000E+00
DOSES IN TEST MATERIALS FOR 1.0 cal/cm2 FLUENCE
                                INCIDENT ON          INCIDENT
                                ATTENUATORS          ON CABLE
Dose - rad(Si)                  7.9183E+06          1.9615E+05
Fluence - cal/cm2              1.0000E+00          7.3053E-01

```

CALCULATION OF CABLE SGEMP
 INPUT SPECTRUM: MBS190
 FLUENCE = 1.0000E+00 cal/cm2

```

External incident fluence      = 1.0000E+00 cal/cm2
Full width at half max pulse  = 3.0000E-08 secs
Detector dose incident on cable = 1.9615E+05 rad(Si)
Cable capacitance              = 1.1722E-10 farads/m

```

SGEMP CABLE RESPONSE
 Cable open circuit voltage = -3.0053E+00 volts
 Cable short circuit current = -1.1743E-02 amps/m

SGEMP CABLE RESPONSE NORMALIZED TO DOSE RATE INCIDENT ON CABLE
 Cable open circuit voltage = -4.5964E-13 volts/(rad(Si)/sec)
 Cable short circuit current = -1.7960E-15 (amps/m)/(rad(Si)/sec)

To calculate the experimental response that was measured into 50 Ω , first calculate the Norton current driver resistance by $V_{oc}/I_{sc} = R_{Norton} = 256 \Omega/m$, then evaluate the net resistance by combining R_{Norton} and the 50 Ω in parallel to get 41.8 Ω/m . The voltage measured on the oscilloscope will be $ISC \cdot 41.8 = -7.51E-14 \text{ V/m/rad(Si)/s}$. This is to be compared with the data value of $3.73E-12 \text{ V/m/rad(Si)/s}$. Unfortunately the polarity is wrong, not to mention the amplitude. The first sensitivity calculation is to change to the MBS 210 keV spectrum and evaluate spectral uncertainties.

CALCULATION OF CABLE SGEMP
 INPUT SPECTRUM: MBS210
 FLUENCE = 1.0000E+00 cal/cm2

External incident fluence	=	1.0000E+00 cal/cm2
Full width at half max pulse	=	3.0000E-08 secs
Detector dose incident on cable	=	1.8181E+05 rad(Si)
Cable capacitance	=	1.1722E-10 farads/m

SGEMP CABLE RESPONSE

Cable open circuit voltage	=	3.3226E+00 volts
Cable short circuit current	=	1.2983E-02 amps/m

SGEMP CABLE RESPONSE NORMALIZED TO DOSE RATE INCIDENT ON CABLE

Cable open circuit voltage	=	5.4827E-13 volts/(rad(Si)/sec)
Cable short circuit current	=	2.1423E-15 (amps/m)/(rad(Si)/sec)

Which evaluates to $8.95\text{E-}14 \text{ V/m/rad(Si)/s}$. Now the sign is correct, but the magnitude is still far off. This implies that the geometry is very sensitive to the spectrum is in this region, however the repeatability data from Fig. 4 seems inconsistent with that conclusion.

Next add a 0.5 mil gap around the center conductor taking that thickness out of the Teflon® and return to the 190 keV spectrum.

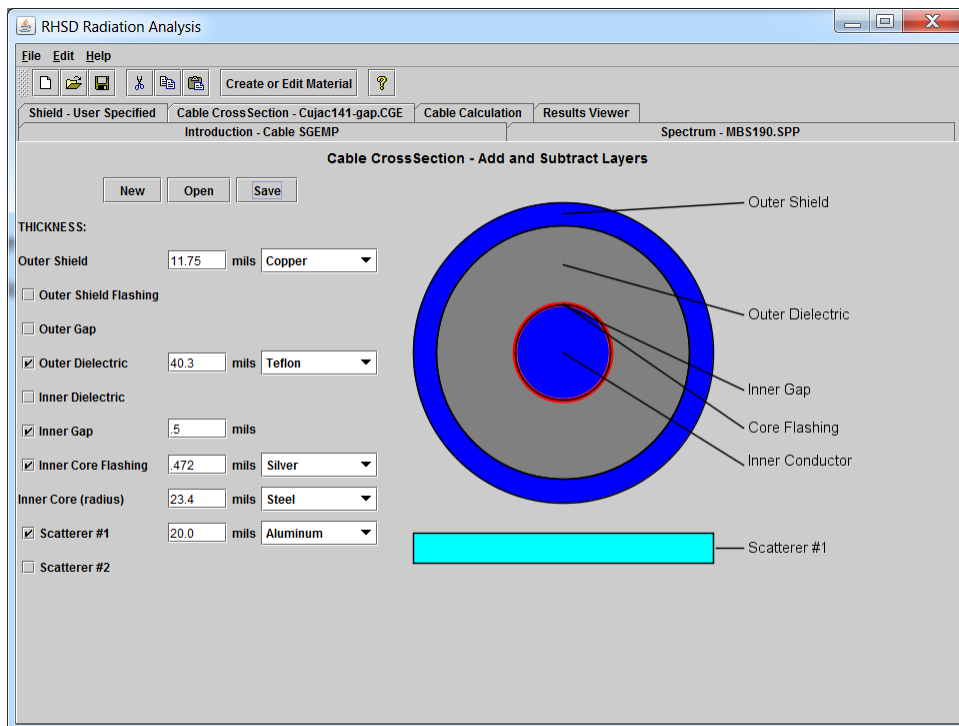


Figure 7 Screen capture for cable with gap.

CALCULATION OF CABLE SGEMP
 INPUT SPECTRUM: MBS190
 FLUENCE = 1.0000E+00 cal/cm2

External incident fluence	=	1.0000E+00 cal/cm2
Full width at half max pulse	=	3.0000E-08 secs
Detector dose incident on cable	=	1.9615E+05 rad(Si)
Cable capacitance	=	1.1460E-10 farads/m

SGEMP CABLE RESPONSE

Cable open circuit voltage	=	5.0834E+02 volts
Cable short circuit current	=	1.9418E+00 amps/m

SGEMP CABLE RESPONSE NORMALIZED TO DOSE RATE INCIDENT ON CABLE

Cable open circuit voltage	=	7.7747E-11 volts/(rad(Si)/sec)
Cable short circuit current	=	2.9699E-13 (amps/m)/(rad(Si)/sec)

Which results in a net response of 1.13E11 V/m/rads(Si)/s, above the observed value. If one assumes that the true cable is a linear combination of the gapless and gapped cable, 33.5% of the cable would have significant gaps to match the data. This seems extreme for this type of cable because of the flexibility of Teflon®.

Next consider the hotter 275 keV MBS spectrum and perform the same two calculations. For a gapless cable:

CALCULATION OF CABLE SGEMP
 INPUT SPECTRUM: MBS275
 FLUENCE = 1.0000E+00 cal/cm2

External incident fluence	=	1.0000E+00 cal/cm2
Full width at half max pulse	=	3.0000E-08 secs
Detector dose incident on cable	=	1.4951E+05 rad(Si)
Cable capacitance	=	1.1722E-10 farads/m

SGEMP CABLE RESPONSE

Cable open circuit voltage	=	2.6612E+01 volts
Cable short circuit current	=	1.0398E-01 amps/m

SGEMP CABLE RESPONSE NORMALIZED TO DOSE RATE INCIDENT ON CABLE

Cable open circuit voltage	=	5.3399E-12 volts/(rad(Si)/sec)
Cable short circuit current	=	2.0865E-14 (amps/m)/(rad(Si)/sec)

With a net response of 8.73E-13 V/m/rad(Si)/s. With a gap the code yields:

CALCULATION OF CABLE SGEMP
 INPUT SPECTRUM: MBS275
 FLUENCE = 1.0000E+00 cal/cm2

External incident fluence	=	1.0000E+00 cal/cm2
Full width at half max pulse	=	3.0000E-08 secs

Detector dose incident on cable = 1.4951E+05 rad(Si)
 Cable capacitance = 1.1460E-10 farads/m

SGEMP CABLE RESPONSE

Cable open circuit voltage = 5.9094E+02 volts
 Cable short circuit current = 2.2574E+00 amps/m

SGEMP CABLE RESPONSE NORMALIZED TO DOSE RATE INCIDENT ON CABLE

Cable open circuit voltage = 1.1858E-10 volts/(rad(Si)/sec)
 Cable short circuit current = 4.5297E-13 (amps/m)/(rad(Si)/sec)

Resulting in a response of 1.90E-11 V/m/rad(Si)/s. Using the same linear combination concept as before, the gap would be present in 37.9% of the cable. This agrees reasonably well with the 33.5% of the lower energy spectrum, but still seems somewhat excessive given the cable design.

4.2. Stainless steel jacketed cable calculations

Now consider the other cujac cable tested designated CR141B-SS with a stainless steel outer conductor and a Cu inner conductor. The stainless steel was 12.2 mils thick, the Teflon® insulator was 38.5 mils thick, the silver flashing was 0.397 mils thick, and the copper core was 17.2 mils radius⁸. The input screen is shown in Fig. 7.

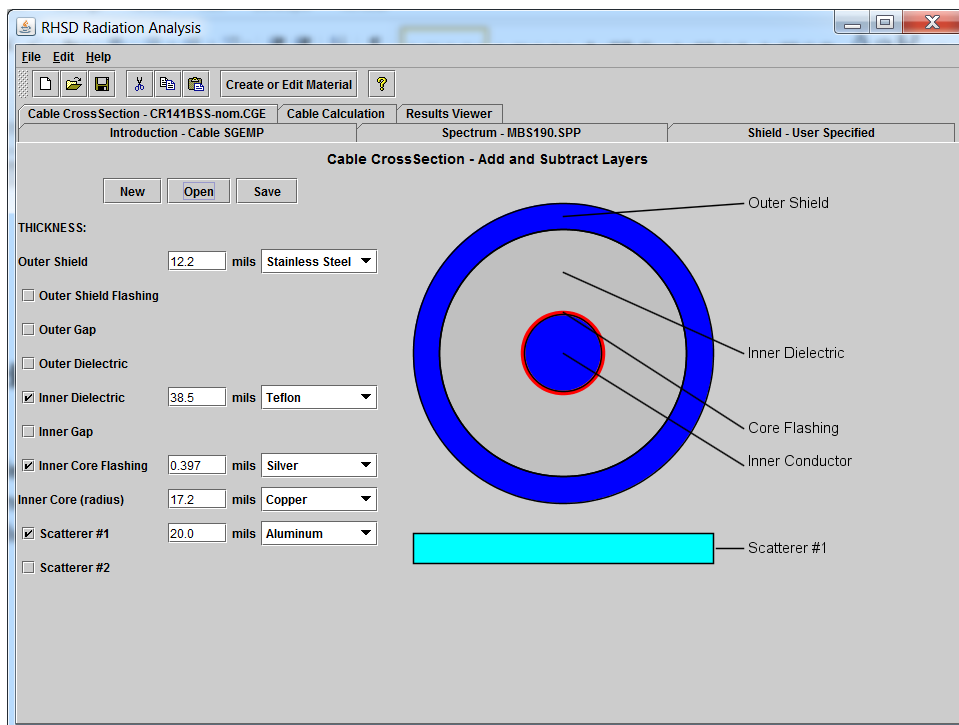


Figure 8 Screen capture for CR141B-SS cable geometry input.

Attenuator 1:	32.0 mil Aluminum	2	Aluminum
	3.20000E+01 2.19456E-01 2.70000E+00 0.00000E+00		1 1
	13027 1.00000E+00		

CABLE GEOMETRY DATA

```

Outer Shield: 12.2 mil Stainless Steel      3      Stainless Steel
1.22000E+01 2.45425E-01 7.92000E+00 0.00000E+00      6      1
6 1.00000E-02      14 1.10000E-02      22 7.40000E-02
26 7.56000E-01      28 1.30000E-01      41 1.90000E-02
Outer Shield Flashing: None      0
Outer Gap = 0.0000E+00 mil      0      0.00000E+00
Outer Dielectric: None      0
Inner Dielectric: 38.5 mil Teflon      36      Teflon
3.85000E+01 1.95580E-01 2.00000E+00 2.10000E+00      2      1
6 2.40180E-01      9 7.59820E-01
Inner Gap = 0.0000E+00 mil      0      0.00000E+00
Inner Core Flashing: 0.397 mil Silver      8      Silver
3.97000E-01 1.05880E-02 1.05000E+01 0.00000E+00      1      1
47 1.00000E+00
Inner Core: 17.2 mil Copper      6      Copper
1.72000E+01 3.91444E-01 8.96000E+00 0.00000E+00      1      1
29 1.00000E+00
REAR SCATTERER DATA      1
Rear Scatterer 1: 20.0 mil Aluminum      2      Aluminum
2.00000E+01 1.37160E-01 2.70000E+00 0.00000E+00      1      1
13027 1.00000E+00

```

CALCULATION OF CABLE SGEMP

INPUT SPECTRUM: MBS190

FLUENCE = 1.0000E+00 cal/cm2

```

External incident fluence      = 1.0000E+00 cal/cm2
Full width at half max pulse  = 3.0000E-08 secs
Detector dose incident on cable = 1.9866E+05 rad(Si)
Cable capacitance              = 1.0077E-10 farads/m

```

SGEMP CABLE RESPONSE

```

Cable open circuit voltage      = 2.3085E+00 volts
Cable short circuit current     = 7.7542E-03 amps/m

```

SGEMP CABLE RESPONSE NORMALIZED TO DOSE RATE INCIDENT ON CABLE

```

Cable open circuit voltage      = 3.4862E-13 volts/(rad(Si)/sec)
Cable short circuit current     = 1.1710E-15 (amps/m)/(rad(Si)/sec)

```

Which results in a response of 5.01E-14 V/m/rad(Si)/s.

With a 0.5-mil gap around the inner conductor the calculation gives:

CALCULATION OF CABLE SGEMP

INPUT SPECTRUM: MBS190

FLUENCE = 1.0000E+00 cal/cm2

```

External incident fluence      = 1.0000E+00 cal/cm2
Full width at half max pulse  = 3.0000E-08 secs

```

Detector dose incident on cable = 1.9865E+05 rad(Si)
Cable capacitance = 9.8159E-11 farads/m

SGEMP CABLE RESPONSE

Cable open circuit voltage = 5.7956E+02 volts
Cable short circuit current = 1.8963E+00 amps/m

SGEMP CABLE RESPONSE NORMALIZED TO DOSE RATE INCIDENT ON CABLE

Cable open circuit voltage = 8.7524E-11 volts/(rad(Si)/sec)
Cable short circuit current = 2.8637E-13 (amps/m)/(rad(Si)/sec)

Resulting in a response of 1.23E-11 V/m/rad(Si)/s. Using the linear combination of gap and gapless calculations to match the data would require 72.8% of the cable to have a gap which is clearly not plausible.

Next, the gapless 275 keV calculation yields:

CALCULATION OF CABLE SGEMP

INPUT SPECTRUM: MBS275
FLUENCE = 1.0000E+00 cal/cm2

External incident fluence = 1.0000E+00 cal/cm2
Full width at half max pulse = 3.0000E-08 secs
Detector dose incident on cable = 1.5426E+05 rad(Si)
Cable capacitance = 1.0077E-10 farads/m

SGEMP CABLE RESPONSE

Cable open circuit voltage = 3.7256E+01 volts
Cable short circuit current = 1.2514E-01 amps/m

SGEMP CABLE RESPONSE NORMALIZED TO DOSE RATE INCIDENT ON CABLE

Cable open circuit voltage = 7.2453E-12 volts/(rad(Si)/sec)
Cable short circuit current = 2.4336E-14 (amps/m)/(rad(Si)/sec)

For a gapless response of 1.04E-12 V/m/rad(Si)/s. The gapped calculation yields:

CALCULATION OF CABLE SGEMP

INPUT SPECTRUM: MBS275
FLUENCE = 1.0000E+00 cal/cm2

External incident fluence = 1.0000E+00 cal/cm2
Full width at half max pulse = 3.0000E-08 secs
Detector dose incident on cable = 1.5426E+05 rad(Si)
Cable capacitance = 9.8159E-11 farads/m

SGEMP CABLE RESPONSE

Cable open circuit voltage = 6.6025E+02 volts
Cable short circuit current = 2.1603E+00 amps/m

SGEMP CABLE RESPONSE NORMALIZED TO DOSE RATE INCIDENT ON CABLE
Cable open circuit voltage = $1.2840\text{E-}10$ volts/(rad(Si)/sec)
Cable short circuit current = $4.2013\text{E-}13$ (amps/m)/(rad(Si)/sec)

For a response of $1.80\text{E-}11$ V/m/rad(Si)/s and a corresponding linear combination requiring 91.8% gap response to match the data.

5. Conclusions

First, the data are highly repeatable and noise free. However, the air and vacuum exposure values do not quite agree and this indicates that there are some gaps in the system that we cannot model perfectly but that are important.

The cujac cable calculated response is quite sensitive to details of the spectrum and the geometry indicating that the cable response is near a null. Whenever such a near-null situation is found, calculations tend to be unreliable because of the difficulty of knowing absolutely everything about the cable and environment. However, the observation that the data are quite repeatable (Fig. 4) calls this extreme sensitivity into question.

For both cable types and both spectra, the calculated response with the best available gapless cable model does not agree well with the data as shown below in Table 3. Surprisingly, the calculations with a 0.5-mil gap around the inner conductor in Table 4 agree better with the data and are mildly conservative.

Table 3 Comparison of gapless calculations with Air data.

	200 Data	200 Calc	Ratio	300 Data	300 Calc	Ratio
	V/m/rad(Si)/s	V/m/rad(Si)/s		V/m/rad(Si)/s	V/m/rad(Si)/s	
Cu141	3.73E-12	-7.51E-14	-0.020	7.75E-12	8.73E-13	0.113
CR141B	8.97E-12	5.01E-14	0.006	1.66E-11	1.04E-12	0.063

Table 4 Comparison of gapped calculations with Air data.

	200 Data	200 Calc	Ratio	300 Data	300 Calc	Ratio
	V/m/rad(Si)/s	V/m/rad(Si)/s		V/m/rad(Si)/s	V/m/rad(Si)/s	
Cu141	3.73E-12	1.13E-11	3.029	7.75E-12	1.90E-11	2.453
CR141B	8.97E-12	1.23E-11	1.372	1.66E-11	1.80E-11	1.083

Case 8 in the RHSD V&V documentation evaluated pretty much this geometry and decided that some small gaps would be sufficient to explain the results as we are largely in a null region.

It is worth noting that these cables were positioned at the outer edge of the exposure area. While the dosimetry locations were nearby, there is always the possibility that the doses are different than measured at the actual location (Figure 2). Also, the spectrum may be somewhat different than assumed closer to the center of the diode. Given the nearly null response, these effects could also explain the discrepancy, but are difficult to evaluate.

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