# C-language port of the program SHIELD11

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## 1 Introduction

Calculation of radiation levels and shielding effectiveness is an important topic for the APS upgrade. Various tools exist for such calculations, the most accurate of which are Monte Carlo codes. These are also the most difficult and time-consuming to use.

One fast-running tool that allows quick checks and estimates is the SHIELD11 program, developed at SLAC by W. R. Nelson and T. M. Jenkins. It is described in admirable detail in [1]. SHIELD11 uses various empirical models for photon and neutron source terms. It also has the ability to model layered and angled shielding configurations, such as that illustrated in Fig. 1.

Although SHIELD11 is without a doubt still useful, the user interface is in need of an update to improve convenience and throughput. Hence, we've rewritten the code entirely in C and given it an easier-to-use interface, as task made much easier by the fact that the code is clearly written and well documented. This note describes the interface and basic use. For a deeper understanding of what SHIELD11 actually does, the reader is encouraged to review [1].

The new program is called `shield`. Input to `shield` consists of two files: the command file and the material data file. The former is a familiar set of namelist-style commands similar to those used in `elegant` [2] and other ASD software products. The latter is an SDDS [3] file that gives material properties such as density, radiation length, Moliere radius, and removal mean-free paths for different radiation components. Having these data in an external file allows the knowledgable user to add new materials without recompiling the code.

## 2 Command file

The command file consists of a series of namelist commands, as follows:

- Target definition. This is required.

```
&target
          STRING material = "Fe";
          double length_cm = 20.0;
          double radius_cm = 20.0;
          long include_attenuation = 1;
&end
```

- Primary shield definition. This is required.

```
&primary_shield
          STRING material = "Concrete";
          double thickness_cm = 60.0;
          double distance_cm = 400.0;
          double angle_deg = 90.0;
&end
```

- Secondary shield definition. This is optional and may be repeated.

```
&secondary_shield
          STRING material = NULL;
          double thickness_cm = 0.0;
&end
```

- Run command. This is required and initiates calculations.

```
&run
          double beam_energy_GeV = 1.0;
          double theta_min_deg = 0;
          double theta_max_deg = 90;
          double n_theta = 91;
          STRING output = NULL;
&end
```

`output` is the name of a user-supplied SDDS file to which the results of calculations are written.

As usual, the actual namelist syntax in the command file omits the type and semi-colons. E.g.,

```
&run
          beam_energy_GeV = 0.375,
          theta_min_deg = 45
          theta_max_deg = 135
          n_theta = 21
          output = "dose.sdds"
&end
```

# 3 Material data file

The material data file contains the columns listed in Table 1.

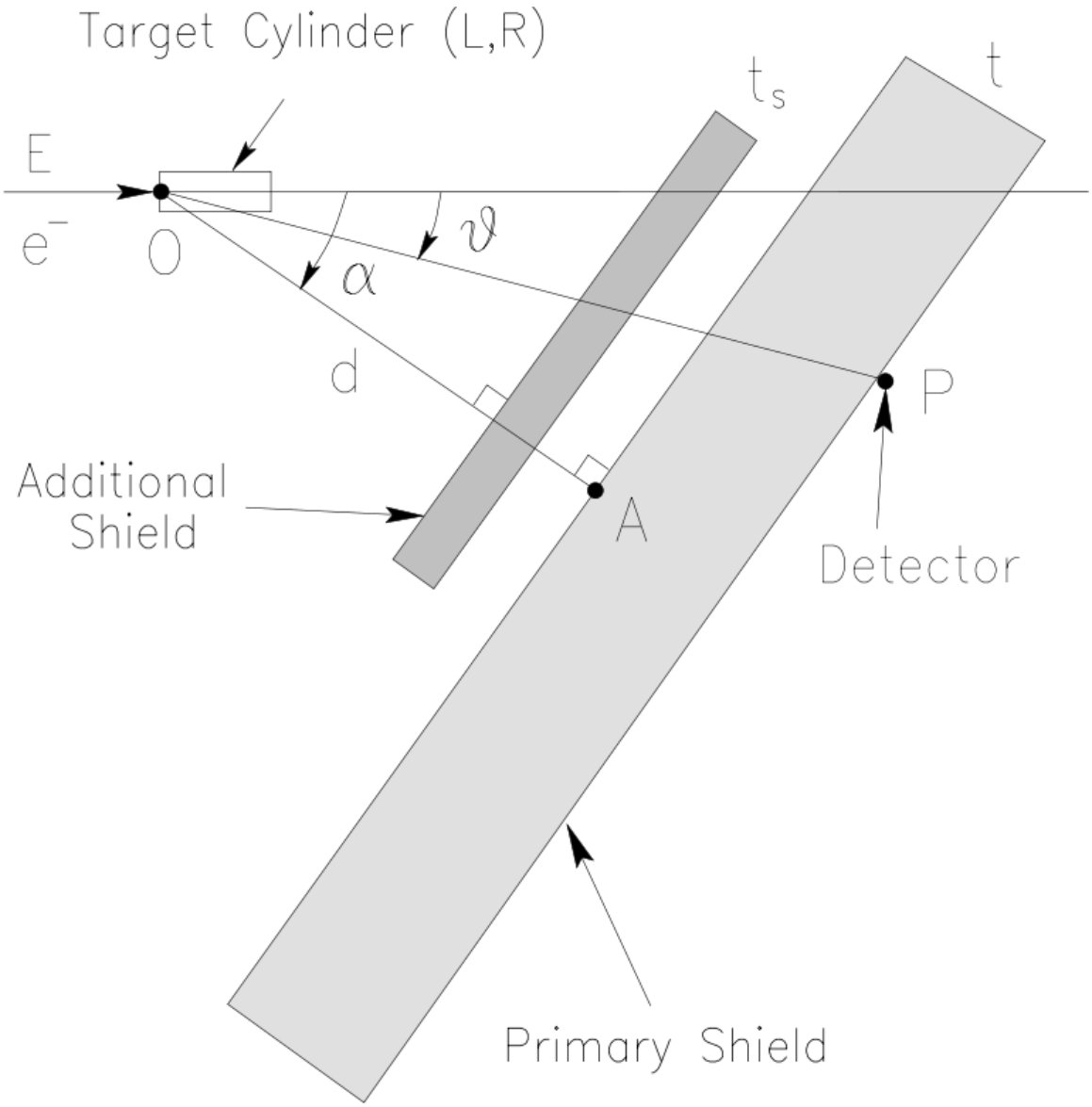


Figure 1: Shielding configuration used in SHIELD11. Figure shamelessly reproduced from [1] without permission.

Table 1: Columns in the shield material data file

| Name | Units | Type |
|---|---|---|
| Material | | string |
| Z | | long |
| A | g/mole | double |
| rho | $g/cm^3$ | double |
| X0 | $g/cm^2$ | double |
| R0 | $g/cm^2$ | double |
| XmfpGRNs | $g/cm^2$ | double |
| XmfpMIDs | $g/cm^2$ | double |
| XmfpHENs | $g/cm^2$ | double |
| XmfpGamD | $g/cm^2$ | double |
| XmfpGamI | $g/cm^2$ | double |

A sample file is listed here:

```
SDDS1
&column name=Material type=string &end
&column name=Z type=long &end
&column name=A type=double units=g/mole &end
&column name=rho type=double units="g/cm$a3$n" &end
&column name=X0 type=double units="g/cm$a2$n" &end
&column name=R0 type=double units="g/cm$a2$n" &end
&column name=XmfpGRNs, type=double, units="g/cm$a2$n" &end
&column name=XmfpMIDs, type=double, units="g/cm$a2$n" &end
&column name=XmfpHENs, type=double, units="g/cm$a2$n" &end
&column name=XmfpGamD, type=double, units="g/cm$a2$n" &end
&column name=XmfpGamI, type=double, units="g/cm$a2$n" &end
&data mode=ascii no_row_counts=1 &end
Concrete 13 26.98 2.35 26.7 11.1 30.0 55.0 120.0 42.0 120.0
Fe 26 55.85 7.87 13.84 10.7 47.0 145.0 145.0 33.6 145.0
Pb 82 207.19 11.35 6.37 14.2 97.0 200.0 200.0 24.0 200.0
```

These data are taken from a common block in SHIELD11.

# 4 Example for PAR

As an example, we looked at shielding for the PAR, which has 1.4-m thick concrete walls (at least that's what we get by scaling a drawing). The perpendicular distance from P3B2 (just downstream of the western high-dispersion point) to the wall is about 4.5 m. Assuming that the entire beam is dumped into this dipole (which may happen in beam loss scenario 3) and that the iron dipole yoke serves as the target, we can model the effectiveness of the lead wall proposed for the PAR enclosure.

From a drawing of the PAR dipole, we chose rough dimensions of a 20 cm thickness and a 20 cm radius for the target. Much depends on the parameters of the target, and this choice should be looked at more carefully.

In addition to the 1.4-m-thick concrete wall, we included a lead wall of varying thickness. Figure 2 shows the predicted gamma dose, while Fig. 3 shows the predicted neutron dose. These are evaluated at 1 degree increments (as seen from the target) along the outer wall. Note that, unlike SHIELD11, plots and analyses can be made using SDDS tools immediately after running `shield`.

As we'd expect, the additional lead shielding has a strong effect on the gamma dose. If a thicker target were used, the maximum dose (i.e., with no additional lead shielding) would be less, even though we've turned off "target attenuation." The reason is that the target attenuation model pertains to *additional* attenuation of the neutron source term. The model for the gamma source term includes attenuation by default. Interestingly, with a thicker target the maximum dose drops but the dose with significant lead shielding is fairly similar.

We also note that the additional lead shielding has an effect on the neutron dose. This might be surprising, but seems to make sense given that in (as described in the SHIELD11 manual) neutrons are accompanied by an ionizing radiation component that they generate through various mechanisms. This component is referred to as "Indirect Gamma" (`GamIDose` in the output file). Hence, the neutron dose should be affected, since energy from the neutron component is being converted into gamma dose.

# 5 Conclusion

We've ported the SHIELD11 code to C and provided an easier-to-use interface. A sample problem was run for the PAR that supports previous results about the amount of shielding needed. However, this needs more expertise than is exhibited in this note.

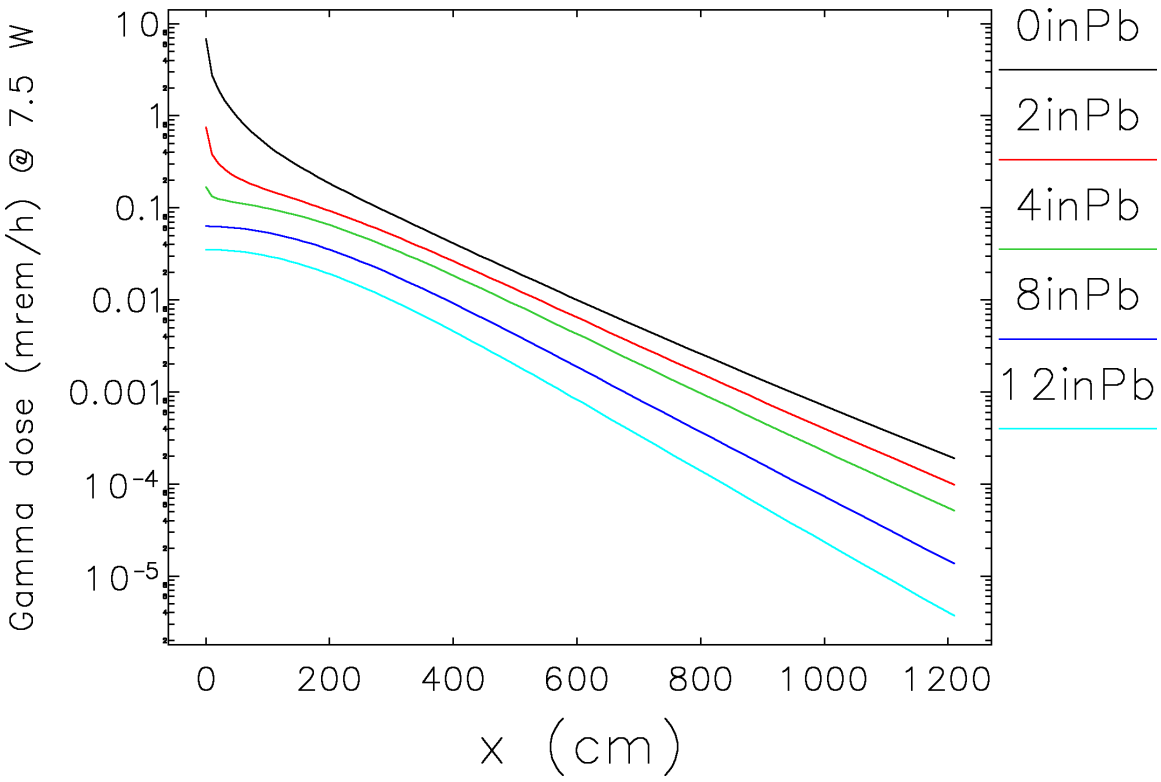


Figure 2: Gamma dose at 7.5 W beam power (20 nA for 375 MeV) outside the south shield wall for various thicknesses of lead, where the lead is assumed to completely line the inside of the wall.

## 6 Acknowledgment

Thanks to B. Micklich for providing the SHIELD11 code—which must be laboriously pieced together from a listing in a PDF—and for helpful discussion.

## 7 Revision Notes

- None.

## References

[1] R. W. Nelson and T. M. Jenkins. The SHIELD11 Computer Code. Technical Report SLAC-R-737, SLAC, February 2005.

[2] M. Borland. elegant: A flexible sdds-compliant code for accelerator simulation. Technical Report LS-287, Advanced Photon Source, September 2000.

[3] M. Borland. A self-describing file protocol for simulation integration and shared postprocessors. In *Proc. of PAC 1995, Dallas, TX*, 1995.

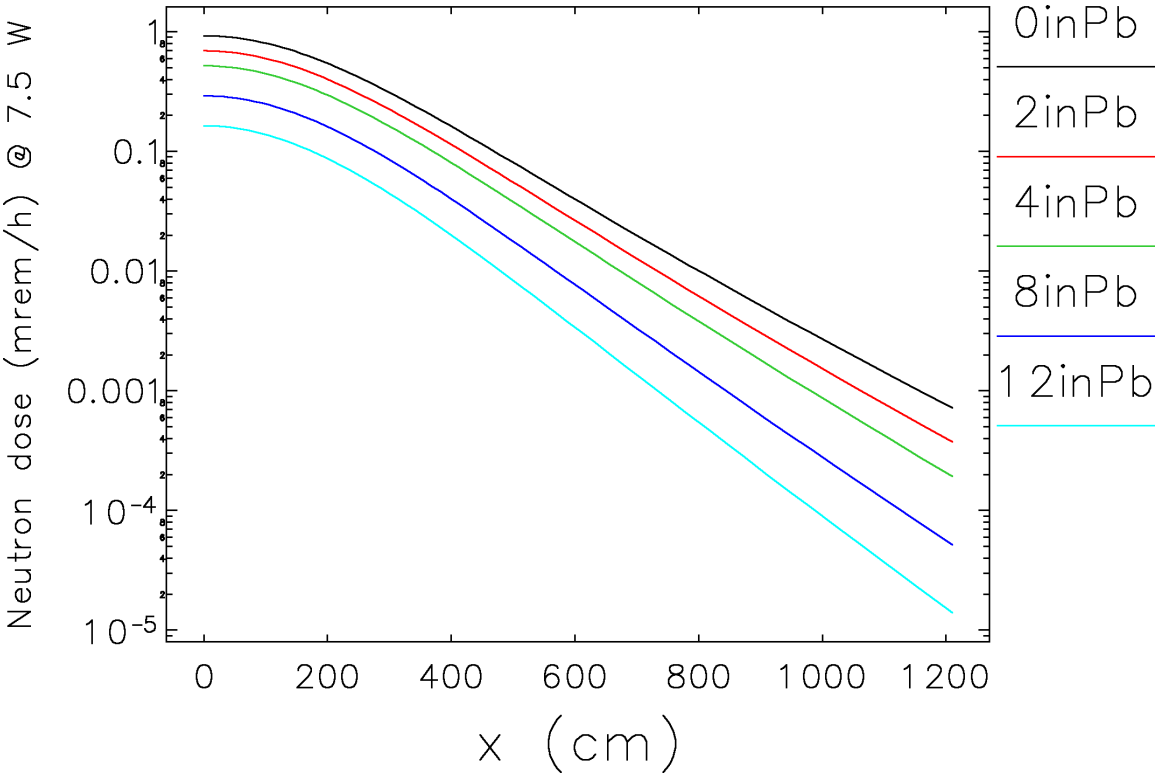


Figure 3: Neutron dose at 7.5 W beam power (20 nA for 375 MeV) outside the south shield wall for various thicknesses of lead, where the lead is assumed to completely line the inside of the wall.