A Conceptual Design Study of a Compact Photon Source (CPS) for Jefferson Lab

This study is in response to the PAC45 technical comments for full approval of C12-17-008 that requires a Compact Photon Source (CPS). However, other proposals and LoIs at Jefferson Lab may take advantage of the CPS (PR12-15-003, PR12-16-009, PR12-14-006).

The document describes the technical design concept of a compact, high intensity photon source capable of producing 1.5×10^{12} equivalent photons per second to be used with dynamically nuclear polarized targets.
The equivalent heat load for a pure photon beam impinging such targets corresponds to a photon flux originating from a 2.7 μA electron beam current striking a10% Cu radiator. Hence, the CPS design for Halls A/C should be able to absorb 30 kW in total (corresponding to 11 GeV beam energy and 2.7 μA beam current).

For polarized experiments the proposed solution has a twofold advantages compared to a traditional bremsstrahlung photon source:

a) Large gain in figure-of-merit (by a factor of ~30)
b) Much lower radiation levels: a factor of 1000 reduction in prompt radiation dose compared to a 2.7 μA (30 kW) electron beam current striking a 10% Cu radiator.

The most important aspects in the design and subsequent building of a CPS are:

a) Compatibility with Polarized Targets, including the magnetic field interference with the magnet holding the target polarization.
b) Radiation.
c) Cost.

Compatibility with Polarized Target

The CPS proposal describes a highly intense photon beam impinging upon a solid NH3 target sample dynamically polarized in the transverse direction at 1 K and 5 T. The photon beam has a very small exit aperture of 3 mm by 3 mm limiting possible beam motion. This implies that the standard procedure to raster the beam over the face of the target cup cannot be used. Thus an alternative approach is taken. To ensure that the sample is uniformly irradiated from the beam, it will be rotated about an axis parallel to the beam and simultaneously moved up and down. In this manner the beam spot will trace out

a spiral pattern very similar to the combination of the fast and slow rasters used in polarized solid target experiments with electron beams. There are, however, two potential drawbacks to this innovative concept. First, the rotation rate of the target (a few Hertz) is considerably slower than the 100 Hz electron beam raster. This will cause portions of the sample to briefly warm up to about 2 K. However, an in-depth analysis shows that the resulting loss of proton polarization should be negligible, since the time spent at the elevated temperature will be far shorter than the proton's spin-lattice relaxation time. Second, the radiation damage caused by e^+-e^- pair production will be non-uniform, with the downstream portion of the sample receiving more damage than the upstream. This could lead to a significant polarization gradient within the sample, a result that must be considered when designing the NMR coils.
The TAC evaluation of the proposal raised the issue that the proposed solution may compromise the desired 3% relative uncertainty of the target polarization. *In the document there is no discussion about this point, which remains an open issue.*

The CPS magnet will be located relatively close to the 5 Tesla solenoid of the polarized target whose mutual forces need to be taken into account in the design of the support structure.
Another magnetic consideration is the effect on field quality at the polarized target. The fields and gradients imposed on the polarized target will not be large but they must be compensated at the 10^{-4} level.
Those aspects are only mentioned in the document, thus *further studies to model the target environment and to design a compensation system are required.*

Radiation Studies

The proposed source has a dump inside the magnet. The CPS final design features a magnet, a central copper absorber, and hermetic shielding consisting of tungsten powder and borated plastic.
Radiation studies have been carried out assuming 1000 hours of operation with the following radiation requirements:

- Prompt dose rate in hall ≤ several rem/hr at 30 feet from device.
- Prompt dose rate at the site boundary ≤ 1 μrem/hr.
- Activation dose outside the device envelope at one foot distance ≤ several mrem/hr one hour after the end of a1000 hour run.
- Activation dose at the pivot in the experimental target area at one foot distance from the scattering chamber ≤ several mrem/hr one hour after the end of a 1000 hour run.

Radiation studies seem to be on a firm ground. I have crosschecked them with the RadCon group. The calculations confirm that a thickness of 50cm of tungsten powder will do the job of reaching tolerable radiation level.
A final tuning of the tungsten thickness and shape could help to minimize the radiation in the hall but already this current design achieve the desired dose limits for the experiment.
In conclusion: *The CPS meets the acceptable radiation level requirements for a typical run time of 1000 hours with the photon source located at 2-3m from the target.*

Note: in the document, the activation dose at one foot from the scattering chamber is evaluated one hour after the end of a1000 hour run. This is not, indeed, the relevant information that we need since operational maintenance tasks for a polarized target are required during the run and not at the end of a 1000 hour run. Calculations after a couple of days of operation, for instance, are more useful.

Cost

The technical design and installation in the existing hall infrastructure seems feasible, though it *still requires further design and engineering*.
The *preliminary estimated cost is on the order of $4M* and is dominated by the raw material costs of tungsten.

Final remark: the document narrative doesn't flow smoothly. Also there are several errors in the description of the figure captions. An attempt to improve the text should be made.