# Effect of Irradiation on Nonlinear Optical Recirculation Cavity Performance

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**Service Provided:** Penn State Breazeale Reactor

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## Introduction and Background

In applications such as the production of hydrogen ions for accelerators in spallation neutron sources, including the Oak Ridge National Laboratory's Spallation Neutron Source (SNS), charge stripping of hydrogen ions using high-power lasers represents an attractive technical approach. The use of laser–ion interaction in conjunction with a laser recirculation cavity using the method termed Recirculation Injection by Nonlinear Gating – RING (Fig. 1, [1]) holds promise for greatly improved efficiency, but the high-radiation environment raises concerns about the longevity of the key components of such a system, especially the nonlinear crystal used for frequency conversion.

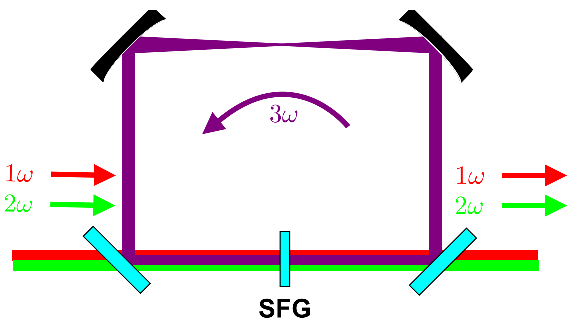


**FIGURE 1. RING principle [1] adapted to laser ion stripping. Fundamental frequency (ω) and the second harmonic (2ω) laser pulses are injected into the cavity and rejected from the cavity using a pair of dichroic mirrors. A sum-frequency generation (SFG) crystal generates the third harmonic pulse (3ω), which is recirculated in the cavity with all mirrors designed to be highly reflective for the third harmonic.**

A critical requirement for achieving high enhancement factors with a recirculation cavity is low loss. In RING, besides the usual diffraction, scattering, and limited reflectivity of cavity mirrors, limited transparency of the nonlinear crystal used for frequency conversion represents another important source of loss. When placed in a high-radiation environment such as that present in the SNS, degradation of the performance of any of the RING optics could ensue, resulting in the loss of enhancement. A typical high-radiation environment at the stripping section of the SNS tunnel consists of fast neutrons, which are accompanied by gamma-rays; the dose is expected to be 5 Gy/year once the stripping foils are replaced with a laser based stripping system. Shielding RING from other possible radiation types, such as lower energy X-rays, could be accomplished effectively, but the effect of highly penetrating neutrons and gamma rays on cavity performance needs to be studied in more detail before the possible deployment of this technology in such high-radiation environments.

## Description of the Experiment

We conducted surrogate experiments to irradiate the beta-barium borate (BBO) crystal used in the RING technique in SNS-like conditions at the Pennsylvania State University's Breazeale Nuclear Reactor (PSBR). A large fast-to-thermal neutron flux ratio (Fig. 2) is important in this surrogate experiment, as the SNS conditions are consistent with a large fast-to-thermal neutron flux ratio. The importance of this condition can be understood if one considers the BBO composition. BBO contains a considerable fraction (~6 a/o) of $^{10}$B, which exhibits a large thermal neutron cross-section, for the $^{10}$B(n,α)$^{7}$Li reaction, which generates large

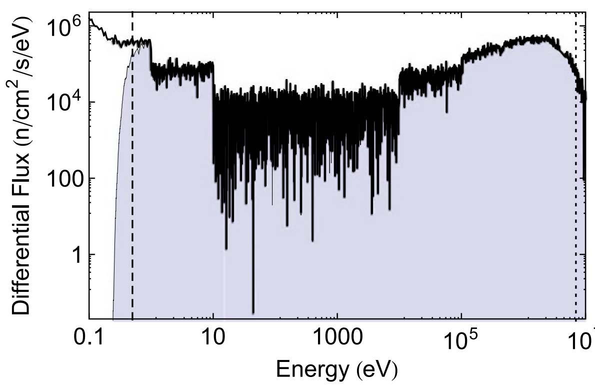


**FIGURE 2. The neutron spectrum of the Penn State Breazeale Nuclear Reactor at the in-core, R1 location for the pneumatic transfer system. The shaded region shows the spectrum used to irradiate the BBO crystal, which is obtained by the attenuation of the PTR R1 spectrum by a 1.27 mm-thick Cd sheet. Cd effectively removes neutrons with energies ≤0.5 eV (dashed line), but is negligible on neutrons with energies ≥1 eV. The neutron flux has been normalized to the measured total flux at neutron energies >7 MeV (dotted line), with reactor operating at 300 kW power.**

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amounts of heat from the energy deposition of the α-particle into the BBO crystal. This reaction is not representative of the true damage mechanisms associated with fast neutrons, such as elastic and inelastic scattering.

## Results and Discussion

We conducted an in-core irradiation experiment in which a sample BBO crystal has been irradiated with fast neutrons and gamma-rays, accompanied with the Monte Carlo analysis of the irradiation dose and its comparison with typical conditions at the SNS. The results (Fig. 3) suggest that our design of the laser recirculation cavity exhibits a radiation hardness consistent with maintaining enhancement factors of the order of 10 over >10 years [2]. This is a significantly better performance compared to that currently observed with carbon foils, where the foils have to be changed multiple times a year. Even in situations where only a small degradation of performance of RING can be tolerated, the replacement of the BBO crystal is not a significant concern, and we expect this technology to be a major contender for hydrogen ion stripping applications.

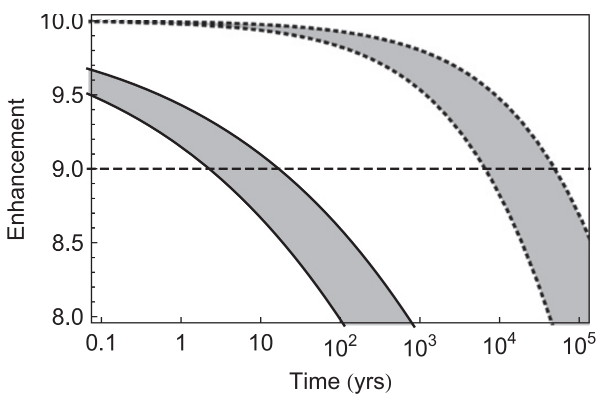


**FIGURE 3. Expected variation of the enhancement factor for a RING cavity with pre-irradiation cavity loss of 10, for linear model (dotted) and quadratic model (solid). Shaded is the range of the expected enhancement, reflecting the uncertainty associated with mixed irradiation by fast neutrons and gamma-rays. The dashed line indicates the enhancement factor drop of 10% from its pre-irradiation value.**

## References:


1. I. Jovanovic, M. Shverdin, D. Gibson, C. Brown, Nucl. Instrum. Methods A 578, 160 (2007).
2. M. Saitta, R. Tikhoplav, I, Jovanovic, Nucl. Instrum. Methods A 664, 294 (2012).