Dear spokesperson,

The Workshop on the Intermediate Neutrino Program (WINP) will be held at Brookhaven National Laboratory on February 4–6, 2015. The workshop organizers request that you fill out the enclosed template for describing your experimental plans by January 12, 2015 at 17:00 EST. These templates will be posted on the public WINP website and are intended to facilitate discussion on the best opportunities for neutrino experiments or R&D that can be accomplished in the intermediate time period (~5–10 years) at reasonable cost. Working group convenors may need input from you on an earlier time scale.

Steve Kettell
For the Organizing Committee

1. Name of Experiment/Project/Collaboration: SNO+
2. Physics Goals
    a. Neutrinoless double beta decay
    b. Solar neutrinos, reactor and geo- antineutrinos
3. Expected location of the experiment/project: SNOLAB
4. Neutrino source: 130Te, Sun, reactors, Earth
5. Primary detector technology: loaded liquid scintillator (LAB)
6. Short description of the detector

SNO+ re-uses the original SNO detector, but with the 12 m diameter acrylic vessel filled with liquid scintillator (LAB). The acrylic vessel is surrounded by a light-water shield, and all of this is viewed by an array of roughly 9000 PMTs. About 0.3% by mass of natural Te will be loaded into the liquid scintillator directly, using water and a surfactant, thus making it the first large-scale detector with a water liquid-scintillator mix.

7. List key publications and/or archive entries describing the project/experiment.
    arXiv:1405.3401
8. Collaboration
    a. Institution list
    University of Alberta, Armstrong Atlantic State University, Brookhaven National Laboratory, University of Californian, Berkeley/Lawrence Berkeley National Laboratory, University of Chicago, University of California, Davis, Dresden University of Technology, Laurentian University, Lancaster University, LIP Lisbon, University of Liverpool, Oxford University, University of Pennsylvania, Queen Mary University of London, Queens University, SNOLAB, University of Sussex, TRIUMF, University of Washington
    b. Number of present collaborators 150
    c. Number of collaborators needed. 150
9. R&D
    a. List the topics that will be investigated and that have been completed
    Te loading of LAB scintillator (completed)
    Purification of Te via re-crystallization (completed)
    Purification of surfactant (ongoing)

Improvements to light yield via wavelength-shifter (ongoing)
Advanced loading techniques for Te (beginning)

b. Which of these are crucial to the experiment.
All but the light yield improvement and the advanced loading techniques are crucial to Phase I (the 0.3% loading). For future, higher-loading runs, we will need to improve the light yield and thus both the wavelength-shifter studies and/or the advanced loading techniques will be important.

c. Time line
R&D on purification of the surfactant is ongoing but expected to be completed by Summer 2015.

d. Benefit to future projects
If successful, SNO+ paves the way to very high-sensitivity $0\nu\beta\beta$ searches by loading additional isotope. Up to 5% isotopic loading has already been demonstrated. Additionally, a smaller loading in a much bigger detector could also be done, perhaps getting to scales of tens or even hundreds of tons of isotope.

10. Primary physics goal expected results/sensitivity:
$T_{1/2} > 9\text{x}10^{25}$ y at 90% CL for five-year run, 5 σ discovery for $T_{1/2}<2.5\text{x}10^{25}$ y for ^{130}Te $0\nu\beta\beta$.

a. The primary systematic uncertainties are energy scale and resolution, both of which need to be known to about 1%, somewhat less precisely than what SNO achieved. The estimates for this come from analysis of simulated data sets. These uncertainties can be determined several ways: using *in situ* tagged backgrounds, by treating them as nuisance parameters in the fit (which will include a substantial fraction of $2\nu\beta\beta$ events), and with explicit radioactive calibration sources. Additional calibrations of the detector optics using laser and LED sources, efficiencies using a Cherenkov source, and overall light yield will be used to update a detailed detector simulation model. Additionally, backgrounds will be constrained by sideband analysis that will measure their levels outside the ROI, some of which can be done before deployment of the Te isotope in a "target-out" run. These constraints are not critical to the lifetime limits, but can be important for a discovery claim. If a bump in the ROI is found, the Te can be removed to determine whether the apparent signal is associated with the isotope or not.

b. CUORE, EXO-200, MAJORANA DEMONSTRATOR, KamLAND-Zen, NEXT are also pursuing neutrinoless double beta decay on similar timescales and with similar sensitivities, but in very different ways.

c. Much of what is being done for SNO+ is similar to work done by KamLAND and BOREXINO, and is a test-bed for deploying isotope in either a future, higher-loading version of SNO+ or a much larger scintillator or water-based liquid scintillator detector.

11. Secondary Physics Goal: Table below shows precision on solar neutrino spectra, under assumptions of BOREXINO-level backgrounds and negligible backgrounds from leaching of Pb and Po from acrylic vessel.

Source	1-year (stat)
pep	9.1%
^{8}B	7.5%
^{7}Be	4%
pp	~3%
CNO	~15%

BOREXINO has similar solar neutrino goals but size and depth of SNO+ should provide better statistical precision.

On reactor antineutrinos, SNO+ can measure Dm212 to 2.5% precision in under 4 years of running, which is comparable to current world-average precision.

For geoneutrinos, we expect 30 events/year, 80% from the continent, 20% from the mantle.

12. Experimental requirements
    a. Provide requirements (neutrino source, intensity, running time, location, space) for each physics goal

       $0\nu\beta\beta$ requirements:
       - 0.3% loading of Te for 5 years unless more is available
       - Detected light yield of >200 pe/MeV
       - Reduction of cosmogenic isotopes in Te by 10^4
       - LAB purity at BOREXINO levels
       - U, Th in scintillator cocktail water at average of SNO H_2O and D_2O levels
       - Surfactant U, Th levels at average of SNO D_2O and SNO H_2O levels
       - Reduction of Bi backgrounds via Bi-Po coincidences within ROI of >x50

       Solar neutrinos
       - Light yield of >300 pe/MeV (without Te load)
       - Same scintillator radioactivity requirements as $0\nu\beta\beta$
       - 1-3 years running time, before and after $\beta\beta$ run.

13. Expected Experiment/Project time line

    Winter 2015 Water-fill running
    Fall 2015 Scintillator plant commissioning, start of scintillator fill/solar neutrino running
    Winter 2016 Scintillator/solar neutrino running
    Fall 2016 Te-loading and $0\nu\beta\beta$ data
    Spring 2019 end of Phase I (0.3%) $0\nu\beta\beta$ data, start of upgrade (see below)
14. Estimated cost range
    - US funding = $20M in-kind for existing SNO detector, plus ~$250k of new capital costs.
    - Canadian funding = $12 M, plus in-kind contribution of SNOLAB infrastructure and remainder of existing SNO detector ($100 M?)
    - UK funding = $500k for calibrations and additional isotope
    - Operations cost: about $200k/year from US; $1M/year total
15. The Future

    There are three upgrade paths envisioned for SNO+, representing different phases of the experiment.

    The simplest upgrade path, from the standpoint of needed engineering, is to purchase and load additional isotope. The technique for loading up to 5% natural Te has been demonstrated on small scales, but to go higher than 0.5% or so will require additional R&D to ensure the required light yield of

200 pe/MeV or better. Current R&D has shown that new wavelength shifters, such as perylene, may increase the light yield by up to 50%, which allow higher loadings. With our required light yield, at 0.5% loading, and with our assumptions about existing background levels, SNO+ would likely have the best sensitivity to $m_{\beta\beta}$ of the current generation of experiments.

An alternative to loading additional isotope, or one that could be done in addition to extra isotope, is the construction of a "bag" or "balloon" like that used by KamLAND-Zen. The bag would contain the isotope within the SNO+ fiducial volume, thus creating more "usable" Te. The bag would need to be ultra-clean and even so, some additional fiducial volume cut would be made inside the bag. Such a bag would roughly triple the amount of usable isotope.

A third, and more distant upgrade, would be the replacement of the existing SNO+ PMT array with modern, high quantum efficiency PMTs. Such a new PMT array could be plug-in replaceable (and thus completed relatively quickly) and would roughly double the total light yield, thus allowing even more isotope to be loaded.

If SNO+ is successful, then the possibility of a much larger detector with far more isotope is opened up. Such a larger detector could be constructed in SNO+ cavity, or in a new detector located (for example) at Homestake. To obtain improved sensitivity this way would require rejection of the background from ^{8}B neutrinos, which would require directional reconstruction using Cherenkov light. Such a technique might be most practically done in a water-based liquid scintillator detector.