U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Project Assessment
CD-1 Review Report on the

# Super Cryogengic Dark Matter Search (CDMS)-SNOLAB Project

**at SLAC National Accelerator Laboratory**

**November 2015**

# EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the Super Cryogenic Dark Matter Search (CDMS)-SNOLAB project was conducted on November 3-5, 2015 at the SLAC National Accelerator Laboratory (SLAC). The review was conducted by the Office of Project Assessment (OPA), and chaired by Kurt Fisher, at the request of James Siegrist, Associate Director of Science for High Energy Physics (HEP).

The purpose of this review was to determine if the SuperCDMS-SNOLAB project fulfilled the requirements for Critical Decision (CD) 1, Approve Alternative Selection and Cost Range, and is ready to request CD-1 approval. The Committee judged that the project is technically sound and achievable. All CD-1 prerequisites have been met and the project team is well positioned to request CD-1 approval. Between CD-1 and CD-2 the project team should focus on understanding and reducing backgrounds.

***Technical***

The Committee judged that the project team should intensify their focus on backgrounds—including estimation, control, and reduction, as they limit the sensitivity of the high voltage (HV) detectors in the lower mass range. The project developed a detailed plan to produce detector towers that have evolved from the SuperCDMS-Soudan system, but have included additional requirements to enable them to reach the Mission Need goals of the Coordinated Second-Generation Dark Matter Experiments (DM-G2) initiative. For the iZIP detectors, several items remain to be demonstrated, but none represent major concerns.

The Committee judged that the specifications for vibrations, both at the seismic and microphonics levels were not clearly specified and need to be identified.

The collaboration has discussed dilution refrigerator options with three vendors, two of which can meet specified requirements. However, the dilution refrigerator procurement duration appears to be optimistic based on past experience with known vendors.

Finally, the Committee suggested that it would be highly desirable to reduce the detector's surface exposure to a number of days that would make the tritium and gamma backgrounds about equal. The collaboration should try to reduce the number of above-ground exposure days from120 to about 30 and to do more work underground.

***Environment, Safety and Health***

The Committee noted that a highly competent Project Safety Officer has been assigned to the project who is well-versed in project details and operational hazards. Also, the Project Safety Officer and ES&H colleagues have experience with similar projects in similar experiments (CDMS-II and SuperCDMS-Soudan projects). The host laboratory (SNOLAB) has the resources and experience to provide site-specific ES&H support.

***Cost and Schedule***

The Committee identified the total project cost (TPC) as estimated at $32.4 million, funded from three sources: DOE/HEP Major Item of Equipment (MIE) funding, $17.6 million; a National Science Foundation (NSF) Cooperative Agreement, $12.0 million; and a Canada Foundation for Innovation (CFI) grant to Queens University, $2.8 million. The overall project cost contingency is 41%—the DOE scope of work has 49% contingency, NSF has 41% contingency, and CFI has 6%. The project established a schedule contingency of 12 month between the planned CD-4 and the CD-4 Level 1 DOE Milestone.

A drilldown exercise was conducted and the bases of estimates were found to be well organized, the justification was well documented and detailed, and the schedule and bases of estimates were found to be well aligned.

***Management***

The Committee observed that the project is taking advantage of accelerated spending agreements with universities and subcontracting to move the project forward. It was noted that the project has a complicated management structure—multi-agency, multi-institutional, international; however, an experienced team is in place.

The organization structure is well defined. Meetings are planned at various levels of the project on a regular basis. The agencies' current funding plans allow some much needed flexibility.

The accelerated spending plans and agreements with universities also allow flexibility.

***Key Recommendations***

- Evaluate resources necessary to conduct detailed background simulations, estimates, and measurements by the end of 2015.
- Prior to CD-2, acceptance criteria for items being developed above ground and then brought underground should be specified.
- Add missing predecessors and successors in the schedule to properly establish the planned project completion date, critical path, and remaining schedule contingency should be completed prior to CD-1.
- Revaluate schedule contingency prior to CD-2.
- Prior to CD-2, develop a detailed Operations Program to complete the testing of the detector and infrastructure and determine the backgrounds.

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# 1. INTRODUCTION

In recognition of the need to advance the Direct Detection Dark Matter program of the Department of Energy (DOE) Office of High Energy Physics (HEP), Critical Decision (CD) 0, Approve Mission Need, for the Coordinated Second-Generation Dark Matter Experiments (DM-G2) was approved on September 18, 2012. The Mission Need Statement calls for a set of two to four independent, ground-based experiments that will perform direct searches for dark matter particles with one or more order-of-magnitude higher sensitivity than those currently deployed.

Following a period of research and development by several DM-G2 candidate experiments seeking to exploit different technologies, DOE/HEP and the National Science Foundation (NSF) Physics Division Particle Astrophysics Program (PA) jointly convened a review panel in December 2013 to assist with a down-select process. The SuperCDMS-SNOLAB experiment was selected in June 2014 by DOE and NSF as one of the DM-G2 candidates to proceed to fabrication, with anticipated support from both agencies in roughly equal proportions. The joint-agency review and down-select process served as a high-level Alternative Selection amongst a number of alternative technologies.

The SuperCDMS-SNOLAB experiment will utilize thoroughly shielded, ultra-pure germanium, and silicon detectors at cryogenic temperatures to search for nuclei that recoil in response to collisions with an impinging flux of dark matter particles known as Weakly Interacting Massive Particles (WIMPs). The instrument will be located deep underground in the SNOLAB facility near Sudbury, Ontario in Canada. NSF is responsible for the detector towers; DOE is responsible for cryogenics and shielding, infrastructure, electronics and data acquisition (DAQ), material assay, software and computing, calibration, and integration and testing. Both agencies will share responsibility for project management. In addition, the Canadian Foundation for Innovation (CFI) is making in-kind contributions in the areas of cryogenics and SNOLAB infrastructure.

The DOE contribution is to be realized as a Major Item of Equipment (MIE) project. The project will be managed by the SLAC National Accelerator Laboratory (SLAC) for DOE, and the University of California at Berkeley (UCB) for NSF (under a Corporative Agreement), in accordance with the principles of DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets. The CFI contribution is in the form of a grant to Queens University in Kingston, Ontario. SLAC and UCB have jointly appointed a single Project Director responsible for the execution of the entire fabrication project.

This DOE/SC review of the SuperCDMS-SNOLAB project, requested jointly by the Associate Director for HEP and the NSF Physics Division Director and conducted by the Office of Project Assessment (OPA), was held at SLAC on November 3-5, 2015. For DOE, this review served to assess whether the project is ready to seek approval for CD-1, Approve Alternative Selection and Cost Range. For NSF, the review served as a Conceptual Design Review and to assess the status and progress of the proposed NSF contributions.

The sections that follow describe the findings, comments, and recommendations resulting from this review.

# 2. TECHNICAL SYSTEMS EVALUATIONS

## 2.1 Science

### 2.1.1 Findings

The SuperCDMS-SNOLAB design meets the scientific goals for the DM-G2 initiative.

- Projected sensitivity limits are at least two orders of magnitude better than existing limits in the region below 5 GeV/$c^2$ WIMP mass.
- It is intended to reach down to 0.3 GeV/$c^2$ with silicon detectors operated in a special high voltage (HV) mode.
- In the region between 5 and10 GeV/c2 the limits are between one order and half an order of magnitude better than the existing limits.
- Use of multiple targets and methods with overlapping ranges will benefit the robustness of the experimental results and improve the ability to survey a broader spectrum of WIMP models.
- The collaboration made sufficient provisions in the design of cryogenic facilities and infrastructure to accommodate future upgrades to bring the experiment's ultimate sensitivity down to the neutrino floor by planning the space for 31 detector towers while they currently plan to build and deploy only five detector towers.
- For the region below 5 GeV, new detectors with background discrimination will be required to reach ultimate sensitivity. Collaboration with CRESST, EDELWEISS, and EURECA has been initiated as they have successfully built low-mass, dark-matter detectors with background discrimination. So there is a sound plan to reach the neutrino floor sensitivity in the entire low mass dark matter particle range.

The project is technically sound and achievable. The space in SNOLAB appears to be adequate, although somewhat tight during construction, so careful planning will be needed during the construction phase. Non-DOE in-kind contributions will come from CFI and NSF. The resources will be used for detectors, cryogenics, shielding, and infrastructure. The allocation of funding is well planned and should not create scheduling difficulties.

The conceptual design of the experiment is sufficiently mature for CD-1 approval and the developed cost model appears sound with over 40% contingency. The science goal section is very detailed. The collaboration identified a number of primary and a broad range of secondary science goals along with the technical design requirements to achieve the listed science goals:

- Target composition (combination of Si and Ge detectors for better reach and overlap)
- Detector Properties—the level of crystal purity must be satisfactory
- Base temperature will be 30 mK with plans to lower it to 15 mK for the future upgrades as needed for the correct phonon sensor operation and the low mass threshold
- Cryostat Capacity—the experiment can accommodate up to 31 detector towers in the existing cryostat

- Excellent phonon energy resolution that requires tight control of transition-edge sensor (TES) temperature
- CDMS-HV Detector Bias must be well-controlled for the lower mass threshold
- Ionization Energy Resolution requires low electronic noise to accommodate background discrimination
- Trigger threshold and trigger rates control is necessary for low mass threshold
- Background rates must be very low and high rejection factors are required
- Calibration rates must provide sufficient statistics for electron rejection power calibration and nuclear recoil acceptance calibration
- DAQ and trigger bandwidth should be able to handle calibration event rate
- Underground clean room with radon (Rn) suppression is required to suppress background build up during the experiment lifetime

### 2.1.2 Comments

While the current conceptual design contains sufficient detail to satisfy technical requirements needed to achieve science goals, there are a few areas that would benefit from additional investigation to build the best possible experiment at SNOLAB.

The phonon energy resolution impacts trigger and analysis threshold along with the resolving power against various x-ray lines. It depends on tight control of TES transition temperature and should be convincingly demonstrated early in the design.

Backgrounds need careful estimation, control, and reduction. Backgrounds are a critical part toward success of HV detectors. Background rates are dominated by cosmogenic tritium and unknown levels of $^{32}$Si. Cosmogenic tritium accumulates in the crystals during surface exposure. It seems there is still room to shorten the exposure above ground or shield the crystals more efficiently during production and testing. Estimates for the cosmogenic tritium critically depend on results from the IGEX experiment and no other experimental results exist. Simulations agree with expectations from IGEX, but within the same order of magnitude only. Any error in this estimation may potentially reduce the detector sensitivity in the lowest mass region by up to an order of magnitude. Unknown levels of $^{32}$Si may potentially jeopardize sensitivity of Si HV detectors. The collaboration should seek ways to better estimate and mitigate this background.

### 2.1.3 Recommendations

1. Considering the importance of the sub-GeV DM mass region, the collaboration should demonstrate the ability to tightly control TES transition temperature prior to CD-2.

2. Evaluate resources necessary to conduct detailed simulations, background estimates and measurements by the end of 2015.

3. Proceed to CD-1.

## 2.2 Detector Towers

### 2.2.1 Findings

The SuperCDMS-SNOLAB project developed a detailed plan to produce detector towers whose detectors meet the science requirements of the experiment.

The detector towers have evolved from the SuperCDMS-Soudan system, but have additional requirements to enable them to reach the goals of the DM-G2 initiative.

The system, as designed, can meet all the DM-G2 science requirements.

The approaches to extending the capabilities of the experiment to meet these requirements have been developed, and are technically reasonable. The project technical approach is reasonable, and should be achievable, but not all required performance elements have been achieved.

For the iZIP detectors, several items remain to be demonstrated, but none represent major concerns.

There are two key developments for the HV detectors that have not been demonstrated: increasing the detector breakdown voltage and decreasing the thermal threshold.

Programs are in place to develop and demonstrate these items.

### 2.2.2 Comments

If the microphonic susceptibility of the towers and system is not known, the impact of this problem will not be evident until the system is fully integrated at SNOLAB. If the microphonic susceptibility of the tower system is known, it can be provided to create a vibration specification on the rest of the system.

Long crystal polishing time is a major cosmogenic exposure element.

### 2.2.3 Recommendations

4. Explore the possibility of developing quantitative measurements of the microphonic susceptibility of the towers.

5. Explore better shielding during polishing, or pursue a faster polishing option.

## 2.3 Cryo/Shield, Infrastructure, and Installation

### 2.3.1 Findings

The collaboration has extensive experience in cryogenic design and the operation of dilution refrigerators. This suggests the collaboration understands the technical challenges, has a team in

place to address those challenges, and understands the integration and commissioning of the cryogenic systems.

The cryogenic engineer will assume “vertical responsibility” for the cryogenic systems throughout the project lifetime. This minimizes the risk during fabrication and integration into the project. If cryogenic problems arise during operations, the necessary expertise is in place to diagnose and repair the fault.

The collaboration has discussed dilution refrigerator options with three vendors, two of which can meet specified requirements. It is likely the unique challenges of this dilution refrigerator system can be addressed by vendors and there are vendors willing to supply reasonable bids on the refrigerator.

The cooling power of the dilution refrigerator at the mixing chamber and at each temperature stage is between 1.5 and 2 times what is estimated to be required. The cooling power specification of the dilution refrigerator system exceeds the heat-load estimate on the various cold stages in the refrigerator by a reasonable margin.

The cryogenic system is cryogen-free and utilizes a single vacuum space. This simplifies the design of the cryogenic and vacuum systems.

The outer radiation shields at 50 K and 4.5 K are cooled with circulating gaseous helium and liquid helium respectively. The shield design allows for the cool-down of the shields and sensor package, and maintaining the sensor package at design temperature.

$RuO_2$ thermometry will be used in and around the detector assembly. Radioassay of $RuO_2$ thermometers has been performed. The temperature sensors in the cold space have been assayed for acceptably low radioactivity and are suitable for use near the towers.

The specifications for vibrations, both at the seismic and microphonics levels were not clearly specified. Several sources of motions could introduce electronic noise into the system. Sources include episodic impulses from mine operations, nominal ground motions, and vibrations from mechanical equipment such as the cryo-coolers. There were no specifications for the allowable acceleration spectral density at the towers.

Instrumentation will be fully monitored with provisions for remote operation. The sensor package was developed from the collaboration’s prior experience. The package allows for monitoring the cool-down, normal operations, and exceptional events. The remote monitoring and operation allows remote investigation of the experiment.

Presently planned neighboring experiments in the same hall at SNOLAB will have minimal impact on the project. It appears the installation and operation of these other projects will not adversely impact the SuperCDMS project so long as the floor space usage is planned.

### 2.3.2 Comments

The dilution refrigerator procurement duration appears to be optimistic based on past experience with known vendors. The sense of the Committee was that a year or greater is a more realistic procurement duration.

Demonstration of sufficient cooling powers at intermediate temperature stages of the dilution refrigerator, especially the 250 mK stage, is important. The 250 mK shield sinks a reasonably large amount of heat in this design, and this heat load is a somewhat unusual requirement for the dilution refrigerator. The commissioning tests of the refrigerator will verify this cooling power.

Given the sensitivity of the existing experiment in regards to temperature variations, the development program should quantify temperature stability requirements. There is a Key Performance Parameter (KPP) for the maximum temperature, but not the temperature stability. Temperature variations feed into the calibration plans.

Assays should be performed on the cryogenic wire and other instrumentation components inside the shielding envelope. All components near the towers are potential sources of backgrounds, and should be assayed.

The number of cryogenic gold-plated copper joints at low temperature is large and thus considerable care should be taken in order to reach the 15 mK specification. There is a risk that, while the dilution refrigerator cooling power is adequate, the thermal conductance from the mixing chamber to the sensors is poor. The large number of joints is a special concern. Careful attention should be paid to this aspect of the cryogenic design.

The use of, e.g., domed heads on the outer vacuum vessel of the SNOBOX, should be explored. The current conceptual design of the cover includes stiffening ribs. A simpler design may suffice.

Careful attention should be paid to electrical grounding. A ground plan should ensure signal currents only flow along the corresponding signal wires.

Floor space at SNOLAB will be tight, especially during assembly and disassembly. The collaboration should think strategically about the placement of infrastructure and other components. The floor plan of the site did not include all the support equipment for the other projects sharing the space. A realistic floor plan should be developed including those other projects.

### 2.3.3 Recommendations

6. Prior to procurement, explore larger dilution refrigerator options in order to provide a better safety factor for reaching the mixing-chamber 10 mK base temperature with the required cooling power necessary to achieve 15 mK at the detectors. While the current dilution refrigerator cooling-power specification is greater than the estimated heat load, the Committee judged a larger safety factor would be highly desirable and this option should be explored with the vendors.

7. Prior to CD-2, develop an understanding of the effects of vibrations on the detector designs. The collaboration is aware that vibrations could introduce electronic noise. The collaboration should quantify the allowable motions and the expected in situ motions to the extent possible. This will allow a determination of the extent of remediation required.

8. Prior to CD-2, develop temperature stability specifications for the mixing chamber and 250 mK shield. Temperature variations of these two dilution refrigerator temperature stages introduce variations in the calibrations. The collaboration should quantify the allowable temperature variations.

9. Prior to CD-2, explore cryogenic testing locations that would provide an overburden to minimize exposure time and thus allow more thorough cryogenic testing without activation time pressures. The conceptual testing plan calls for tests at ground level. During these tests, cold box components will become activated, with the activation increasing with exposure time at ground level. If the testing could be done under an appropriate overburden, the tests could be extended without the activation time pressure. The collaboration should explore options for such a testing site.

10. Prior to CD-2, an acceleration criterion should be added to the crane procurement specification. The current specifications include a position-accuracy specification. The load is delicate, and this should be augmented by a specification on the allowable crane accelerations.

11. Prior to CD-2, acceptance criteria for items being developed above ground and then brought underground should be specified. Work on detector components is much more difficult underground. Hence, there should be a clear set of criterion for whether a detector component is ready to be brought underground, and a single person responsible for checking-off the acceptance criterion.

12. Prior to CD-2, interfaces between subsystems should be clearly delineated, along with subsystem responsibilities. The project subsystems are reasonably well defined, but responsibility for the interfaces between subsystems is not. The responsibility for the interfacing between subsystems should be clearly assigned.

## 2.4 Electronics, DAQ/Trigger, Computing

### 2.4.1 Findings

The Readout Electronics (WBS 1.5) covers components from the detector tower connector through the Vacuum Interface Board, Detector Control and Readout Card (DCRC), and Signal Distribution Unit. The front-end including the superconducting quantum interference devices (SQUIDs) for phonon readout and the high electron mobility transistors (HEMTs) for ionization readout are part of the detector tower structure and are in WBS 1.1.

The Fuzz Button connector is a promising option to be tested. Initial solution of using Mill-Max pins and Samtec connectors will not work because of high radioactivity.

The circuit board heat sink and overall heat load need to be evaluated. The effectiveness of the heat sink needs to be studied and evaluated with a testing setup. The thermal model needs to be updated and evaluated.

DCRC Revision D will be available in December 2015 for testing. Timely validation of the Revision D will enable detector tower testing and DAQ development.

DAQ and Trigger (WBS 1.6) were designed with the flexibility to handle calibration, data taking, and environmental monitoring needs of SuperCDMS-SNOLAB project.

The plan to use a single DAQ framework at all test facilities and SNOLAB will facilitate the fast development of DAQ software and the training of users.

The Level 1 Trigger in firmware, using the Finite Impulse Response filter, is a new development. It has the potential to reduce the trigger threshold.

For Software and Computing (WBS 1.8), resources are distributed across the collaboration at several institutions and can meet the simulation and analysis needs.

Offline computing infrastructure is developed early in the project. The collaboration has been effective in leveraging software and infrastructure developed previously at SLAC and Pacific Northwest National Laboratory (PNNL).

### 2.4.2 Comments

The interface connectors, cables, heat sinks, and DCRC Revision D (WBS 1.5) remain to be tested. A full system test including a detector tower should be a high priority before CD-2.

The offline computing resource (WBS 1.8) is front-loaded. Long-term viability and low maintenance cost are expected. The establishment of a collaboration-wide software/computing infrastructure early in the project development could be a significant advantage in task and data management with distributed resources.

### 2.4.3 Recommendation

13. Proceed to CD-1.

## 2.5 Backgrounds, Calibrations, and Simulations

### 2.5.1 Findings and Comments

The project is making good progress and the Committee anticipates success showing a significant sensitivity improvement in the study of WIMPs, especially in the range of low masses. Given the

background estimates, there is more than a factor of 10 improvement in sensitivity for certain dark matter parameters. The project is especially interesting for WIMP masses between 1 and 9 GeV. Below 4.5 GeV, the Ge HV detectors are best with the Ge iZips providing the sensitivity above 4.5 GeV. If the Si HV background is as expected, it will extend the low-mass region below 0.8 GeV.

The shielding responsibility is split between DOE and CFI. The plan seems fine although the split is between design and procurement. This might produce possible confusion if the design does not fit within the procurement budget.

The potential of improving the energy resolution to 10 eVt was very exciting, opening a number of physics opportunities.

The Committee observed some potential collaboration tension. Certain questions elicited a hushed response indicating the issue may be controversial. It appeared to the Committee that some of the collaboration felt uncomfortable discussing certain technical issues.

The KPP regarding background "Projected bulk background for Ge HV Detectors" is not very specific. Is this a projection based on the background model or is it based on data from a commissioning run? The energy range for which this number would be calculated was not clear. In general, the KPPs were identified as applying to the project where no turn-on or commissioning was included. This seems unreasonable. The key feature of this project is its low background. A demonstration that the apparatus meets some background level must be part of its assessment. That cannot be done without running it for at least a short period of time.

The leadership for the background includes some good mid-career physicists. The collaboration, however, has been studying the background of these detectors for a very long time. The review would have benefitted from a long-time experienced person.

No evidence of a project engineer was presented. This seems like a necessary position with so many participating groups, and someone needs to be responsible for making sure everyone is building the same device. Along those lines, the collaboration needs an installation manager, preferably one who is permanently at SNOLAB, to coordinate activities on-site. The Committee did not see this position discussed anywhere.

A periodic task-leader meeting would also benefit the organization. A meeting where the key technical issues of the project are discussed between all the experts would facilitate effective decision making by the project office.

Although the Committee did have a couple of concerns, overall the project is in good shape and the Committee recommended the project proceed to CD-1.

***Backgrounds***

Initial plans for Rn and dust control were presented. Assay and simulation programs were described. These plans need to continue to evolve and improve as they are all components within a background model. Detailed lists of assayed and simulated items should be compiled.

There should have been a presentation of a SuperCDMS-Soudan/SuperCDMS-SNOLAB background comparison with an explanation of the improvements that reduce the gamma background by a factor of approximately 100. That is a very large improvement and a summary of where the improvements come from would be very informative.

Si-32 is potentially a very high background for the Si detectors, perhaps as high as approximately 200 counts/keV kg y. This would have a major impact on the low-mass WIMP Si HV program as it will reduce the sensitivity at masses below about 0.8 GeV. The collaboration should embark on an effort to understand the origin of Si-32 in Si detectors and how it might be controlled.

Tritium, produced by cosmic rays while the material is above ground, is the largest background contribution. It would be highly desirable to reduce the surface exposure to a number of days that would make the tritium and gamma backgrounds about equal. The Committee suggests that a reduction of cosmic ray exposure to about 30 days instead of 120 would be about right.

Cosmogenic x-ray lines, like Fe, Co, Zn, Ge were not included in the background model. The argument was that the region of interest (ROI) will exclude those lines. However, whether the lines are present or not impacts the choice of the ROI. They should be estimated and included in the global discussion of background.

The background contribution of the electronics near the detectors is still a goal, not a final number. This is the biggest uncertainty for the radiogenic background contribution.

The collaboration should consider a serious investment to develop underground facilities to purify and prepare detector materials, as well as to fabricate detectors in an underground cleanroom with low radon air. This facility should also have underground access to the deep site where the experiment will be located. Such a facility could then take advantage of the high radio purity of refined materials to make low background detectors that avoid surface and cosmogenic backgrounds.

***Calibration***

A calibration plan that clearly ties the planned calibration measurements to the precision required for the scientific goals is needed. A thorough assessment of the background due to potential activation of materials by a neutron source should be performed.

***Simulation***

Only high-level summaries of simulation were presented. It is critical to demonstrate that the simulations have predictive power; that is, there needs to be a validation plan. Comparisons to past CDMS data sets and/or calibration might serve this role. Only in passing at the review's end did the Committee see simulated spectra, and that was too late to consider the plots.

### 2.5.2 Recommendations

None.

# 3. ENVIRONMENT, SAFETY and HEALTH

## 3.1 Findings

The Preliminary Hazard Assessment Report (PHAR) developed for the SuperCDMS-SNOLAB project demonstrates a systematic and qualitative hazard analysis process that identifies and guides the tracking and management of ES&H risks.

The PHAR provides a comprehensive assessment of the ES&H hazards associated with: 1) assembly/integration and testing (I/T) of components, and 2) operation of the experiment at the SNOLAB facility. It identifies key ES&H risks (cryogen/oxygen deficiency, electrical safety, lead, airborne toxics, and equipment/material handling). These have been characterized and ranked on the "SuperCDMS-SNOLAB Hazard List", with mitigation strategies devised. The project safety team intends to continually evaluate these and other risks as conditions and operations evolve.

Multiple organizations are involved in the project (including SLAC, Fermilab, PNNL, SNOLAB, and many universities). The project's Integrated Safety and Environmental Management (ISEM) Plan describes how the SuperCDMS-SNOLAB project will implement ES&H, and includes descriptions of the conduct of work at SLAC, collaborating institutions, and SNOLAB, respectively.

The project ISEM plan is sufficiently constructed and detailed to guide work planning management of the project. The Work Planning and Control (WPC) process will be applied at all sites associated with the project. Work authorizations are based on demonstration of ability, and work release will be required before any activity can begin. Work at SNOLAB will follow SNOLAB requirements, except where SLAC or Fermilab ES&H requirements are more restrictive. Where they differ, the Project Safety Officer will coordinate agreement. It should be noted that project ES&H presence will be maintained through Project Safety Officer participation at various team meetings, including membership on the Change Control Board.

National Environmental Policy Act (NEPA) review and determination are complete for SLAC, Fermilab, and PNNL. SNOLAB review of environmental impact and requirements has been initiated via Gateway Reviews.

## 3.2 Comments

A highly competent Project Safety Officer has been assigned to the project who is well-versed in project details and operational hazards. The Project Safety Officer and colleagues from the collaborating organizations have experience with similar projects in similar experiments (e.g., CDMS-II and SuperCDMS-Soudan projects). The project can be expected to benefit from SLAC's and collaborating organizations' successful application of the system safety model and risk assessment protocol on similar projects. SNOLAB has the resources and experience to provide site-specific ES&H support. It is generally recognized that collaboration is needed to orient all personnel to ISM principles and SuperCDMS-specific procedures.

There is a heightened concern regarding electrical safety, equipment/material handling, occupational health hazards (airborne toxics and lead), fall protection, and oxygen deficiency hazards that could be encountered during the project.

The PHAR can be improved by the inclusion or elaboration of the following issues:

- Addresses the hazards associated with hoisting and rigging of critical experimental components, but does not explicitly discuss training and qualification requirements for equipment operators.
- Includes electrical safety, but there is no elaboration on the control of exposure to stored energy (Lockout/Tagout) or the inspection of non-NRTL (Nationally Recognized Testing Laboratory) electrical equipment.
- The potential for confined space entry hazards is not currently addressed.
- Mine safety orientation/training requirements are not currently addressed.

It should be noted that SNOLAB requires that all personnel who will work with stored energy systems and/or operate hoisting and rigging equipment be trained, and that personnel undergo mine safety orientation and training.

The Committee affirms that the project: 1) properly addresses the Environment, Safety and Health (ES&H) aspects of the project, 2) meets all of the CD-1 prerequisites, and 3) is positioned to request CD-1 approval.

## 3.3 Recommendations

14. Prior to CD-2, review the PHAR to ensure that—where applicable—crane operation training requirements are addressed.

15. Prior to CD-2, review the PHAR to ensure that—where applicable—lockout/tagout (LOTO) requirements are addressed.

16. Prior to CD-2, determine mine-specific training requirements and accountability for delivery of training to project staff who will work in the SNOLAB mine spaces.

17. Prior to CD-2, establish the extent to which inspection of non-NRTL (nationally recognized testing laboratory) electrified equipment must be conducted.

18. Prior to CD-2, review configuration of project equipment to establish where (if any) Confined Space Entry requirements may be applicable.

# 4. COST and SCHEDULE

## 4.1 Findings

| PROJECT STATUS | | |
|---|---|---|
| Project Type | DOE-MIE / NSF-Cooperative Agreement/ | |
| CD-1 | Planned: Jan. 2016 | Actual: |
| CD-2 | Planned: July 2017 | Actual: |
| CD-3 | Planned: Nov. 2017 | Actual: |
| CD-4 | Planned: Q4, FY2020 | Actual: |
| TPC Percent Complete | Planned: 12% | Actual: 12% |
| TPC Cost to Date | $4.3M (DOE 2.5M, NSF-1.5M) | |
| TPC Committed to Date | $0M | |
| TPC | $32.4M (DOE-17.6M, NSF-12M, CFI-2.8M) | |
| TEC | $19.8M (DOE-9.94M, NSF-7.23M, CFI-2.65M) | |
| Contingency Cost (w/Mgmt Reserve) | $8.03M(DOE-4.9M, NSF-3M, CFI-0.2M) | 100% to go |
| Contingency Schedule on CD-4 | 12 months | 100%. |
| CPI Cumulative | N/A | |
| SPI Cumulative | N/A | |

The SuperCDMS-SNOLAB cost range was determined by using AACEI (Association for the Advancement of Cost Engineering International) classification (DOE Guide 413.3-21 Chap. 4). The classifications were assigned at Level 2 of the WBS. The estimated average of classification assigned was Class 3. The Total Project Cost (TPC) cost range is $29.270 to 39.455 million. The cost range for each funding agency's scope of work is: DOE, $15.975 to 21.544 million; NSF, $10.979 to 14.481 million; and CFI, $2.316 to 3.430 million.

The project used approved resource, overhead, and escalation rates from the various institutions to develop their estimate. The TPC is estimated at $32.4 million funded from three sources: DOE, $17.6 million; NSF, $12.0 million; and CFI, $2.8 million. The project team identified the funding for specific parts of scope from DOE, NSF, and CFI. Each funding organization has been assigned a lead institution to manage the funding: DOE, SLAC; NSF, UC Berkeley; and CFI, Queens University in coordination with SNOLAB.

The overall project cost contingency is 41% ($8.03 million)—DOE's scope of work is at 49% ($4.90 million); NSF, 41% ($2.98 million), and CFI, 6% ($.15 million). The contingency was developed based on a bottom-up maturity risk estimate and a top-down estimate based on the Risk Register. The project established a schedule contingency of 12 months between the

planned CD-4 and the CD-4 Level 1 DOE Milestone. In the Preliminary Project Execution Plan (PPEP), the project's Level 1 milestones has CD-1 in June 2016, CD-2 in July 2017, CD-3 in November 2017, and CD-4 in the fourth quarter FY 2020.

The project developed a Primavera (P6) resource loaded schedule by using the Basis of Estimate (BOEs) created by the project's Level 2 and 3 managers. The schedule contains the following:

- 1,384 activities and 43 milestones.
- 49 activities have constraints, 1,848 logic links.
- Contains both on-project and off-project resources.
- Various codes have been used to "slice and dice" the resource loaded schedule.
- Targeted CD review timeframes for DOE (with NSF) and the SNOLAB gateway process.

The project schedule is structured with 11 top-level WBS elements down to detailed individual tasks. The scope covers labor and material effort from CD-1 through project completion at CD-4 The project's cost estimate is in FY 2015 dollars. The schedule has been artificially constrained in places to meet the available funding profiles.

The project is using Cobra as their cost processor to develop the fully loaded and escalated estimate. Cobra will also be used to perform Earned Value Management. The project has identified three Control Account Managers (CAMs) to plan, coordinate, and report the progress of the project's work scope.

The project stated that all the scope and effort required to achieve the draft Threshold and Objective KPPs contained in the PPEP are reflected in the current P6 schedule.

The project provided a complete set of BOE documents containing both labor and materials justification for WBS elements 1.1-1.11. These documents were at either Level 3 or 4.

## 4.2 Comments

The project used the AACEI classification (DOE Guide 413.3-21) methodology to establish the cost range by assigning the classifications at the Level 2 WBS. The TPC cost range was estimated at $29.270 to 39.455M. The methodology used and cost range established is reasonable for this project. The Committee judged that project's estimated TPC of $32.4 million with an overall cost contingency of 41% is considered adequate at this stage of the project.

The project team is taking advantage of accelerated spending agreements between universities and subcontracting Principal Investigators—(so far UC Berkeley, Stanford, Santa Clara University, and expecting Texas A&M, UMN, UC Denver, and Caltech) to move the project forward.

The initially planned FTE profiles seem to be reasonable at this stage of the project.

The Committee observed that additional schedule cleanup is needed. The project was aware that the schedule required work. The following are examples of actions required:

- Several open-ended activities without a predecessor or successor were found. This puts in question whether the planned project completion date is accurately reflected. Appropriate predecessor or successors should be added prior to CD-1.
- Schedule constraints should be minimized in order to show a clear critical path prior to CD-2.
- Long duration activities should be decomposed into smaller tasks to allow for easier progress measurement (i.e., design, procurement, etc.) prior to CD-2.
- Continue to develop the milestones in the schedule to ensure all of the PPEP Level 1 and 2 milestones are included. Also, add sufficient Level 3 and 4 milestones to indicate project progress.

The project currently has twelve months of schedule contingency based primarily on informed expert opinion rather than quantifiable analysis. The risk register has a high number of risks that are qualitatively ranked to have a high and moderate schedule impact. The project team should quantify the schedule impacts and re-estimate the project schedule contingency to give a more defensible explanation for the requested schedule contingency prior to CD-2.

A drilldown exercise was conducted with the project team on WBS 1.11, 1.1.3.4, 1.1.4.3, 1.2.3, and 1.9.1 BOEs. A comparison of the information in the schedule and the BOE on both materials and labor was completed. In addition, the BOE justification documentation was examined. The BOEs were found to be well organized, their justification well documented and detailed, especially in the detector fabrication area. In addition, the schedule and BOEs were found to be well aligned for both materials and labor.

An inconsistency was seen in the WBS 1.2.3 BOE with the Soudan cost summary justification. There was an additional SNOBOX worksheet provided as justification that aligned with both the BOE and the schedule. It is believed the Soudan cost summary spreadsheet was outdated and erroneously left on the BOE site, therefore the Committee ignored it as a BOE justification document. The project should consider removing that sheet.

## 4.3 Recommendations

21. Add missing predecessors and successors in the schedule to properly establish the planned project completion date, critical path, and remaining schedule contingency should be completed prior to CD-1.

22. Revaluate schedule contingency prior to CD-2.

# 5. PROJECT MANAGEMENT

## 5.1 Findings

This project is a significant scale-up from SuperCDMS-Soudan with the need for a significant reduction in the background.

The organization structure is well defined. Meetings are planned at various levels of the project on a regular basis.

The project is using various frameworks to define relationships between institutions: Memorandum of Agreement (MOA); Memorandum of Intent (MOI); subcontract (SC); sub-award (SA); and maybe Cooperative Research and Development Agreement (CRADA).

The project team attempted to address the difficult nature of managing a large collaborative project via numerous management related schemes such as the Institutional Council, SLAC Project Management Advisory Group (PMAG), SuperCDMS-SNOLAB Executive Committee, Level 2 managers/advisors, Background Czar, etc.

Decisions are made at the lowest level if possible—the spokesperson participates in discussions with Project Management. The Project Director has final decision making power; if the agency-designated project management entities (i.e., SLAC and UC Berkeley) disagree they can replace him.

An initial risk registry has been developed. The output from this document will be used to do Monte Carlo cost and schedule analysis in preparation for CD-2. The risks have been qualitatively ranked according to an assessment of the impact in the risk register. The schedule impacts for items in the risk register have been qualitatively ranked. Quantitative assessments will occur in the future. The current risk register only contains threats. No opportunities have been identified.

The Change Control Board (CCB) located in the PPEP consists of the SuperCDMS-SNOLAB Project Director, Project Manager (who also acts as chair), Deputy Project Managers, NSF Project Principal Investigator, SuperCDMS Spokesperson, the ES&H Officer, and the Level 2 Manager for WBS 1.7 Background Control and Material Selection.

The project ends with the infrastructure and detectors installed at SNOLAB but not tested or commissioned.

Funding advances by several universities allowed the detector tower WBS element to start production of NSF deliverables.

## 5.2 Comments

There is a complicated management structure—multi-agency, multi-institutional, international—yet it seems to be working well. An experienced project team is in place.

The organization structure is well defined. Meetings are planned at various levels of the project on a regular basis.

The agencies' current funding plans allow some much needed flexibility. The accelerated spending plans and agreements with universities also allow flexibility.

Decision making seems to be made by the Management Team. While they are competent and experienced, it may be better to enlarge the SuperCDMS-SNOLAB Executive Committee consisting of the Management Team and the Level 2 managers with regular meetings.

This Executive Committee could also be the CCB including experts from all the technical areas of the project.

Before CD-2, the project team should develop a detailed Operations Program to complete the testing of the detector and infrastructure and determine the backgrounds.

The project team is encouraged to complete an exercise to survey the project for opportunities that may be included in the risk registry, which currently only has threats.

## 5.3 Recommendation

23. Proceed to CD-1.

# Appendix A Charge Memo

U.S. Department of Energy
and the
National Science Foundation

OCT 14 2015

MEMORANDUM FOR STEVE MEADOR, DIRECTOR,
DOE OFFICE OF PROJECT ASSESSMENT

FROM: JIM SIEGRIST
ASSOCIATE DIRECTOR OF SCIENCE
FOR HIGH ENERGY PHYSICS

DENISE CALDWELL
DIRECTOR, DIVISION OF PHYSICS, NSF

SUBJECT: REQUEST TO REVIEW SUPERCDMS-SNOLAB PROJECT

We request that your Office organize and conduct for the Department of Energy (DOE) Office of High Energy Physics (HEP) and the National Science Foundation (NSF) Physics Division an Independent Project Review (IPR) of the entire SuperCDMS-SNOLAB project on November 3-5, 2015 at the SLAC National Accelerator Laboratory (SLAC). For DOE, this review will serve to assess whether the project is ready to seek approval for Critical Decision - 1 (CD-1), *Approve Alternative Selection and Cost Range*. For NSF, the review will serve as a Conceptual Design Review and assess the status and progress of the proposed NSF contributions.

In recognition of the need to advance HEP's dark matter program, CD-0, *Approve Mission Need*, for the COORDINATED SECOND-GENERATION DARK MATTER EXPERIMENTS (DM-G2) Project was approved on September 18, 2012. The Mission Need Statement calls for a set of two to four independent, ground-based experiments that will perform direct searches for dark matter particles with one or more order-of-magnitude higher sensitivity than those currently deployed.

Following a period of research and development by several DM-G2 candidate experiments seeking to exploit different technologies, DOE and NSF jointly convened a review panel to assist them in a down-select process. The SuperCDMS-SNOLAB experiment was selected by DOE and NSF as one of the DM-G2 candidates to proceed to fabrication, with anticipated support from both agencies in roughly equal proportions. The joint-agency review and down-select process served as a high-level Alternative Selection amongst a number of alternative technologies. The DOE contribution is to be realized as a Major Item of Equipment (MIE) project. The project will be managed by SLAC for DOE and the University of California at Berkeley (UCB) for NSF, in accordance with the principles of DOE Order 413.3B. SLAC and UCB have jointly appointed a single Project Director responsible for the execution of the entire fabrication project.

The SuperCDMS-SNOLAB experiment will utilize thoroughly shielded, ultra-pure germanium and silicon detectors at cryogenic temperatures to search for nuclei that recoil in response to collisions with an impinging flux of dark matter particles known as Weakly Interacting Massive Particles (WIMPs). The instrument will be located deep underground in the SNOLAB facility near Sudbury, Ontario in Canada.

In carrying out its charge, the review committee should address the following questions:

1. Science: Does the SuperCDMS-SNOLAB design meet the scientific goals for the DM-G2 initiative as described in the Mission Need Statement?

2. Technical: Is the project's design technically sound and achievable? Are the interfaces with the SNOLAB facility appropriately understood? Furthermore, are the designs of non-DOE in-kind contributions, including their interfaces, sufficiently mature to proceed to early procurement, and are their schedules properly aligned with the remainder of the project?

3. Cost and Schedule: Are the cost and schedule estimates credible? Do they include adequate scope, cost and schedule contingency? Is the cost range assessment appropriate?

4. Management: Is the project being properly managed? Is there a capable team in place to effectively manage risks and ensure quality? Is an adequate Risk Management Plan being developed?

5. ES&H: Are ES&H aspects being properly addressed?

6. Has the project met all the CD-1prerequisites and are they positioned to request CD-1 approval?

7. Are there other issues of note relating to the overall project plans?

Helmut Marsiske, Program Manager for Instrumentation, will serve as the DOE contact for the review. Jim Whitmore, Program Director for Particle Astrophysics – Experiment, will serve as the NSF contact for the review. Both agencies look forward to receiving your report within 45 days of the review's conclusion.

# Appendix B Review Committee

**DOE/SC (CD-1) Review of the**
**SuperCDMS-SNOLAB Project at SLAC**
**November 3-5, 2015**

**Kurt Fisher, DOE/SC, Chairperson**

**SC1**

**Science**

* Jelena Maricic, U of Hawaii

**SC2**

**Detector Towers (WBS 1.1)**

* Harvey Moseley, NASA/GSFC
Dan McCammon, U of Wisconin

**SC3**

**Cryo/Shield, Infrastructure and Installation (WBS 1.2, 1.3, 1.4)**

* Leslie Rosenberg, UW
George Seidel, Brown U
Paul Huffman, NC State

**SC4**

**Electronics, DAQ/Trigger, Computing (WBS 1.5, 1.6, 1.8)**

* Huan Huang, UCLA
Liang Yang, U of Illinois

**SC5**

**Backgrounds, Calibrations, Simulations (WBS 1.7, 1.10)**

* Steve Elliott, LANL
Frank Calaprice, Princeton

**SC6**

**Env, Safety and Health**

* Scott Robinson, LBNL

**SC7**

**Cost and Schedule**

* Dean Hoffer, FNAL
Monty Middlebrook, ORNL
Kelly Hanzel, LBNL

**SC8**

**Project Management**

* John Wilkerson, UNC
Howard Gordon, BNL

**Observers**

Jim Siegrist, DOE/SC
Mike Procario, DOE/SC
Helmut Marsiske, DOE/SC
Michael Salamon, DOE/SC
Kathy Turner, DOE/SC
Paul Golan, DOE/SSO
Hanley Lee, DOE/SSO
Jim Whitmore, NSF

**LEGEND**

SC Subcommittee
* Chairperson

**Count: 17 (excluding observers)**

# Appendix C Review Agenda

**DOE/SC (CD-1) Review of the**
**SuperCDMS-SNOLAB Project at SLAC**
**November 3-5, 2015**

**AGENDA**

**Tuesday, November 3, 2015—SLAC Building 048, Redwood Room**

| | | |
|---|---|---|
| 8:00 am | Executive Session | K. Fisher |
| 8:50 am | Welcome | C. Kao/D. MacFarlane |
| 9:00 am | Science Goals | D. Bauer |
| 9:30 am | Technical Overview | B. Cabrera |
| 10:15 am | Break | |
| 10:45 am | Project Management (WBS 1.11) | K. Fouts |
| 11:30 am | Backgrounds (WBS 1.7) | J. Orrell |
| 12:00 pm | Shielding Design (WBS 1.3) | P. Cushman |
| 12:30 pm | Lunch | |
| 1:30 pm | Cryogenics, Mechanical Design, Integration (WBS 1.2, 1.4, 1.9) | R. Schmitt |
| 2:15 pm | Detector Towers and Readout Electronics (WBS 1.1) | R. Partridge |
| 3:00 pm | Break | |
| 3:30 pm | Calibration (WBS 1.10) | L. Hsu |
| 3:50 pm | DAQ and Trigger (WBS 1.6) | S. Oser |
| 4:10 pm | Software and Computing (WBS 1.8) | A. Borgland |
| 4:30 pm | Full Committee Executive Session | K. Fisher |
| 6:00 pm | Adjourn | |

**Wednesday, November 4, 2015**

| | | |
|---|---|---|
| 8:00 am | Subcommittee Breakout Sessions | |
| 12:00 pm | Lunch | |
| 1:00 pm | Subcommittee Breakout Sessions (continued) | |
| 4:00 pm | Full Committee Executive Session | Fisher |
| 6:00 pm | Adjourn | |

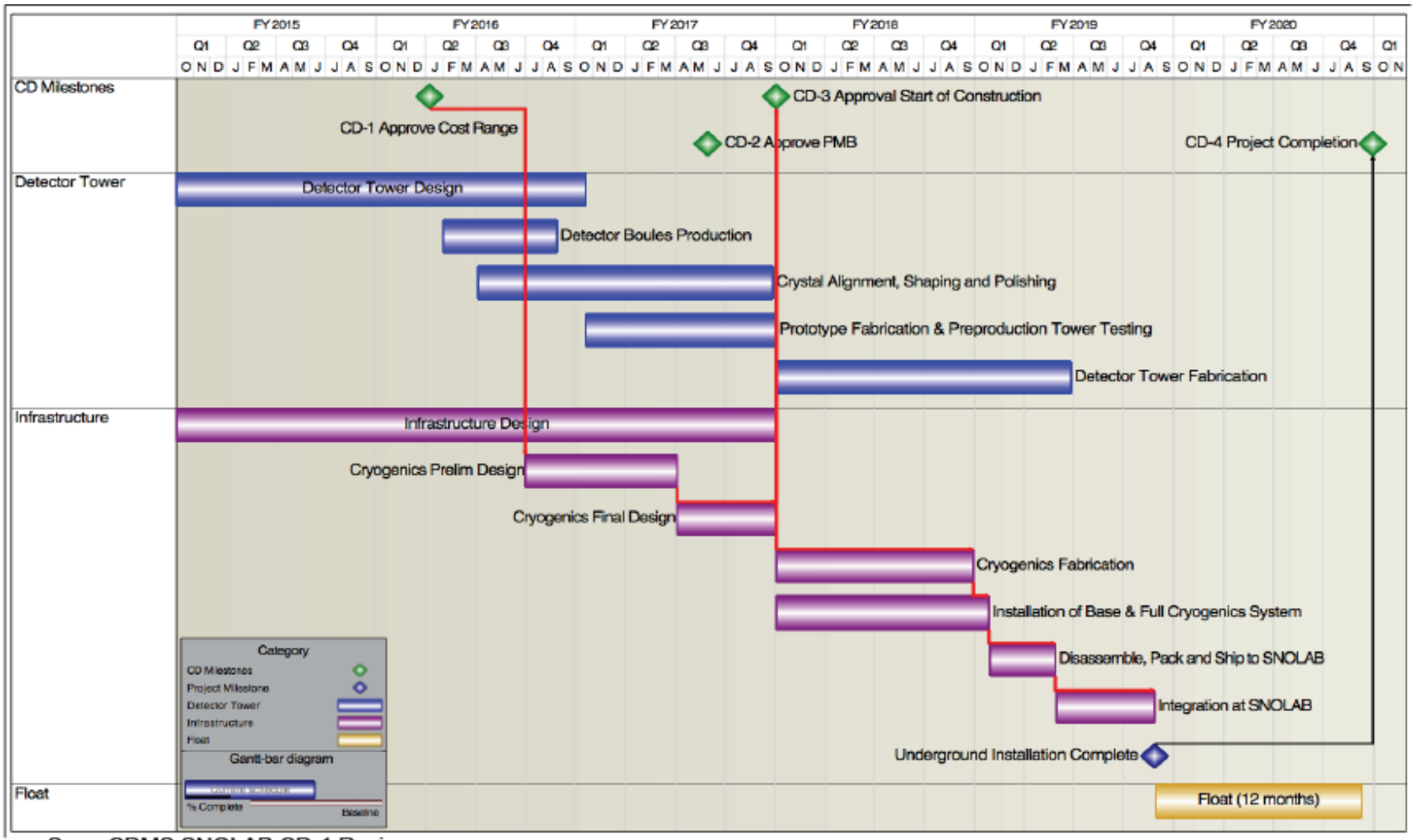
**Thursday, November 5, 2015**

| | | |
|---|---|---|
| 8:00 am | Executive Session—Closeout Dry Run | Fisher |
| 10:00 am | Closeout Presentation | Fisher |
| 11:00 am | Adjourn | |

# Appendix D SuperCDMS-SNOLAB Cost Table

| WBS | WBS Title | DOE Cost ($M) | NSF Cost ($M) | CFI Cost ($M) | Total Cost ($M) |
|---|---|---|---|---|---|
| 1.1 | Detector Towers | 0.01 | 5.72 | | 5.73 |
| 1.2 | Cryogenics | 3.12 | | 0.94 | 4.06 |
| 1.3 | Shielding | 0.39 | | 1.36 | 1.75 |
| 1.4 | SNOLAB Infrastructure | 0.42 | | 0.35 | 0.77 |
| 1.5 | Readout Electronics | 1.50 | | | 1.50 |
| 1.6 | Data Acquisition and Triggering | 0.57 | 0.06 | | 0.63 |
| 1.7 | Material Selection | 0.97 | | | 0.97 |
| 1.8 | Software and Computing | 0.07 | 0.23 | | 0.30 |
| 1.9 | Integration and Test | 0.95 | | | 0.95 |
| 1.10 | Calibration | 0.24 | | | 0.24 |
| 1.11 | Management | 1.70 | 1.22 | | 2.92 |
| **Total TEC (Midscale)** | | **9.95** | **7.22** | **2.65** | **19.82** |
| Total OPC (Base) | | 2.76 | 1.79 | 0.00 | 4.55 |
| Contingency | | 4.89 | 2.99 | 0.15 | 8.03 |
| Contingency % of TEC | | 49% | 41% | 6% | 41% |
| **TPC** | | **17.60** | **12.00** | **2.80** | **32.40** |

# Appendix E SuperCDMS-SNOLAB Schedule Chart

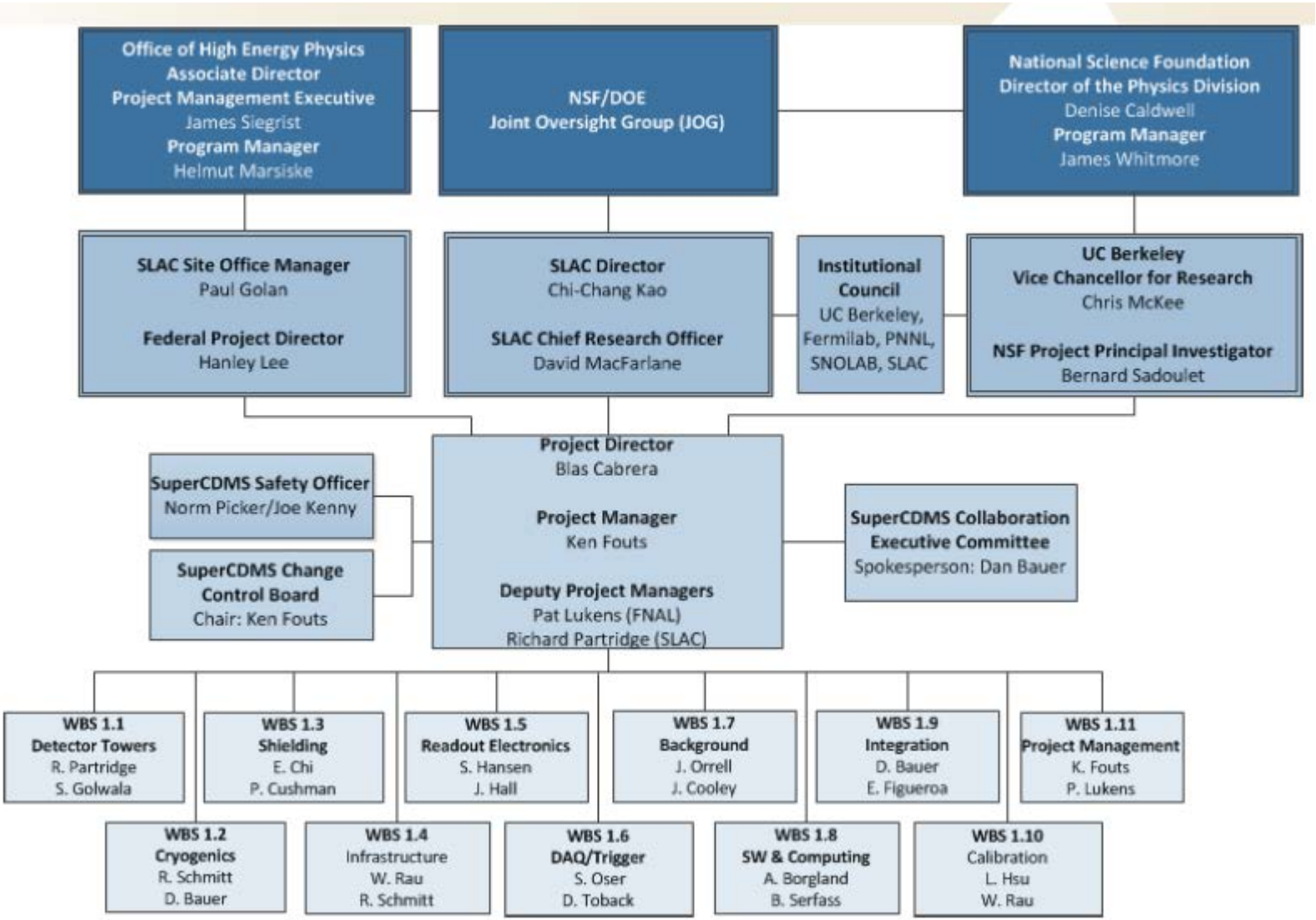



SuperCDMS SNOLAB CD-1 Review

# Appendix F SuperCDMS-SNOLAB Funding Table

| Fiscal Year | FY15 | FY16 | FY17 | FY18 | FY19 | Total ($M) |
|---|---|---|---|---|---|---|
| DOE OPC* | 2.6 | 0.2 | | | | 2.8 |
| DOE TEC** | | 2.3 | 5.0 | 5.3 | 2.2 | 14.8 |
| NSF Base | 1.0 | 1.0 | | | | 2.0 |
| NSF Midscale | | 3.0 | 2.0 | 4.0 | 1.0 | 10.0 |
| CFI | 2.8 | | | | | 2.8 |
| **Total Cost** | **6.4** | **6.5** | **7.0** | **9.0** | **3.2** | **32.4** |

* *DOE Other Project Costs (OPC) includes Conceptual Design, R&D, prototypes and Pre-Operations project management.*

** *DOE Total Estimated Cost (TEC) includes Preliminary and Final Designs, fabrications, project management, other cost not captured in OPC.*

# Appendix G SuperCDMS-SNOLAB Management Chart