WISCONSIN ICECUBE PARTICLE ASTROPHYSICS CENTER

# IceCube Upgrade
# Project Year Four
# (FY 2022)
# Annual Work Plan

2021-002.2

**Approval**

| | | |
|---|---|---|
| Principal Investigator | Kael Hanson | Apr 13, 2022 |
| Project Director | Vivian O'Dell Vivian O'Dell (Apr 13, 2022 18:31 CDT) | Apr 13, 2022 |
| Project Manager | Farshid Feyzi | Apr 13, 2022 |

**Change Log**

| Rev | Description: Author | Date |
|---|---|---|
| 0 | PY4 stand-alone plan issued as separate document from Project Execution Plan: Farshid Feyzi | Oct 21, 2021 |
| 1 | Incorporated feedback from NSF received on November 8, 2021 | Nov 11, 2021 |
| 2 | Revised and reissued for second half of project year four per guidance received from NSF on January 31, 2022, milestones statused, financial tables, risk and opportunities updated. | Apr 12, 2022 |

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# Project Year 4 Plan (October 2021 - September 2022)

The following sections describe the IceCube Upgrade project year 4 (PY4) plan starting in October 2021 and ending in September 2022. The stand-alone PY4 plan, as opposed to a plan through completion, was necessitated as a result of the continuing COVID-19 pandemic which led to the cancellation of PY3 and PY4 field seasons and has also caused delays across the project.

## Updates for Second Half of Project Year Four

This document was originally issued for the first half on PY4 (October 2021 – March 2022). In this revision it is issued for the second half of PY4. The main updates are:

- In milestone tables, a new column is inserted where the status of the first-half milestone is reported. The projection against the second-half milestone is also reported.
- Table of risks and opportunities is also updated based on the newly available information of field seasons having been defined. More details of the changes in risks and opportunities are found in that section.

## WBS 1.1: Project Office (UW Madison, WIPAC)

The University of Wisconsin – Madison (UW) headquarters the IceCube Neutrino Observatory Operations and the IceCube Upgrade Project. Upgrade work is divided between the Wisconsin IceCube Particle Astrophysics Center (WIPAC) and the Physical Sciences Laboratory (PSL). WIPAC houses the Upgrade Project Office, including financial controls, technical coordination, system & project engineering, quality control, risk management, polar operation/logistics, and technical tasks spread over all WBS L2 elements. PSL hosts the IceCube Upgrade drill design, engineering, construction, and operation with the ultimate deliverable of holes drilled for science instrumentation at the South Pole.

The overall aim of PY4 workplan is to make as much technical progress as possible under present conditions that restrict work to off-ice tasks not requiring access to the field. This includes replanning the project cost and schedule that incorporates the NSF field support plan. Scheduling of tasks will remain within NSF committed funding to date. The project office and technical leaders are committed to successful project completion and will continue all possible efforts to achieve it.

The project office functionality will remain the same in PY4 and some staffing changes are noted. As of early 2022, most pandemic-related workplace constraints have been lifted. The staff in the project office have been able to meet the needs of the project and interact effectively with level 2 managers, the National Science Foundation Integrated Project Team. The project team and the ASC logistics team will continue close cooperation in advancing project needs.

### Plans to Re-baseline the Project WBS 1.1.1, 1.1.2, 1.1.5.

The IceCube Upgrade project will prepare to re-baseline the entire project during PY4. The reason for the re-baseline is loss of the project management baseline due to:

- Cancellation of the hot water drill System repair that was scheduled for November 2020 to January 2021 and cancellation of hot water drill commissioning that was scheduled for November 2021 to January 2022.
- Stoppage of all cargo shipments to the South Pole which will result in unavailability of key equipment for the start of hot water drill repairs and commissioning.

Both reasons are external to and are beyond the control of the project. They will result in an increase in total project cost and project duration. Project technical scope and configuration will remain the same.

The plan, timeline and principal assumptions for re-baselining are shown in Table 1. Specific milestones and deliverables are listed in Table 2.

Table 1: Overall plan and dates for rebaselining the IceCube Upgrade Project

| **Task** | **Target Date per Rev1** | **Status as of Rev2** |
|---|---|---|
| NSF review of project logistics requirements | November 3-4, 2021 | Completed on time |
| Logistical support plan, schedule and risks ready as input to rebaselining | December 30, 2021 | Received from NSF on January 24, 2022 |
| Revised project schedule | January 31, 2022 | First draft finished on Feb 28, 2022 |
| Revised project cost estimate, risks and contingency | January 31, 2022 | First draft finished on Feb 28, 2022 |
| Revision of Project Execution Plan and associated documents | January 31, 2022 | First draft finished on Feb 28, 2022 |
| Internal review by Upgrade team and by advisory panel | January 15-31, 2022 | PAP and Vice Chancellor review completed March 14-16, 2022 |
| Discussion of plan between WIPAC and NSF-IPT | January 15-31, 2022 | Completed March 14-16, 2022 |
| Draft re-baseline plan submission to NSF-IPT | January 31, 2022 | April 15, 2020 |
| Revisions of plan based on feedback from NSF-IPT | February 1-28, 2022 | April 22, 2022 |
| NSF review of re-baseline plan | March 2022 | Scheduled for April 26-28, 2022 |

Table 2: Milestones and deliverables for WBS grouping

| WBS | Title | First Half PY4 | Status as of Rev2 | Second Half PY4 |
|---|---|---|---|---|
| 1.1.1.3 | Revised project cost and schedule completed | 1/31/2022 | First draft cost and schedule for rebaseline completed on February 28, VC review completed Mar 16, 2020. Delay was due to delayed receipt of support plan | |
| 1.1.1.4 | Revised project risks completed | 1/31/2022 | First draft presented at VC review. Will revise are finish by the time of NSF review | |
| 1.1.1.5 | Rebaseline review: cost, schedule and risk analysis for project completion per NSF review charge completed | 3/31/2022 | Expected on time and will provide to NSF review panel prior to review | |
| 1.1.2.1 | Project Financial and EVMS reporting, monthly reports | monthly | Completed monthly | monthly |
| 1.1.1 | PY4 annual report | | Expected on time | 7/15/2022 |
| 1.1.5.1 | Logistics review documentation made available to review panel | 10/15/2021 | Completed on time | |
| 1.1.5.2 | Logistics review completed | 11/3-5/2021 | Completed on time | |

**WBS 1.1.3 Safety**

Safety functions are integral to all activities and tasks as listed in this plan. The activities in WBS 1.2 in particular have inherent hazards that must be analyzed and mitigated. Many of the hazards experienced on-ice exist off-ice as well. Staff operate, repair, and test the same cable reels, hose reels, drill heads, high-pressure pumps, and heaters that are used at the South Pole and similar injuries and damage are possible.

Safety is responsible for incident reporting at all locations. The lessons learned from off-ice Incident Reports apply directly to actions on-ice. With each incident report, there is a thorough investigation, followed by the creation of a Corrective Action Plan to prevent the chance for the incident to recur. The Corrective Action Plans apply both on-ice and off-ice.

An important element of safety training is the SafeStart Program. This program focusses the individuals to keep themselves safe and trains the staff to look for hazards on the job and mitigate them before they can create an incident. This mindset for safety applies both on-ice and off-ice. In addition to job-specific safety training on various processes and pieces of equipment, safety routinely performs First Aid, CPR, and AED

training for both off-ice and on-ice teams. In PY4, SafeStart training for WIPAC will be recertified and training material will be updated. SafeStart Training will take place in summer of 2022. CPR and AED Training will take place in April 2022, Hazard analyses and mitigation are performed as needed and per schedule of task as listed in milestone tables.

#### WBS 1.1.4 Project Engineering

The Final Design and Production Readiness Reviews for the mDOMs are an important milestone, currently scheduled for March 11-13, 2022. Other PY4 project engineering tasks include managing the D-Egg Final Acceptance Testing results, mitigations, and rework plans, and then applying this scheme to the mDOM production as well. A number of design reviews for special devices and calibration devices are scheduled for PY4. These reviews of subsidiary subsystems are not on the critical path and do not directly impact on-award work. Progress on these reviews, which are within Calibration and Characterization, will be tracked per milestones listed in Table 10.

## Drilling and Installation (UW Madison, PSL)

## WBS 1.2 Implementation

#### WBS 1.2.1 Management and System Engineering

Drilling and Installation efforts in PY4 will be spread across four fronts; drill control systems, drill mechanical systems, installation processes and hardware, and preparing for the April Rebaseline Review. While good progress was made in PY3, efforts were hampered by the cancellation of field activities as well as pandemic inefficiencies at the University of Wisconsin resulting from site population limits and materials shortages. PY4 activities will benefit from the adjustments made in PY3 to allow work to be accomplished stateside that was originally planned for the field. WBS 1.2.1 is responsible for management and system engineering of all WBS 1.2 tasks.

#### Drill Controls WBS 1.2.4

Efforts in the control area slated for PY4 include development, refurbishment, and testing of control system components including sensors, cabling, I/O (input/output) boxes, E-stop (emergency stop "red buttons") boxes, network boxes, encoders, load cells, pendants, and motor drives. Also in progress is the integration of the aforementioned hardware into the user interface system, or SCADA - Supervisory Control and Data Acquisition, which will provide the interconnect of the myriad of drill subsystems in the Tower Operations Sites (TOS), High Pressure Pump (HPP), Pre-Heat System (PHS), and Main Heating Plants (MHP) to the Drill Control Center. The new design simplifies Input/Output, improves wiring, and adds a Data Acquisition Hardware (DGH)-to-Ethernet gateway/Ethernet switch and interfacing E-stops with network boxes. Networked I/O boxes feed data to motor drives from pendants, encoders, sensors, limit switches. Much of the original Gen1 I/O hardware is not directly compatible with the new motor drives, control devices, and SCADA system. To the extent possible, Generation 1 infrastructure will be reused to minimize the amount of on-ice effort needed to reconstruct a safe and effective drilling system. Specific milestones and deliverables are listed in Table 3 and include a subsystem review.

The following tasks are part of the drill control system work:

- MHP heater display upgrades
- Fuel sled interface definition, probably a new I/O box for this unit
- Return water pump system test with 50 HP motor, cable, new sensors
- Hose heater controller cold testing in a MDFL, and testing with full electrical loads
- TOS pendant I/O box rebuild and testing - (one finished, 7 remaining)
- TOS and DCC PLC box design, build, test (three new boxes)
- New control box for the Return Water Cable Reel (RWCR)
- Network boxes for Main Heating Plants (MHP) and Pre-Heat System
- HPP sensor box testing
- DGH programming, testing, cataloging
- Tower Operations Site (TOS) E-stop controller redesign, build, test
- Plan installations of new motor drives in former Unico locations
- SCADA screen design
- Control Hardware/Software trial in Testbed

Table 3: Milestones and deliverables for WBS grouping

| WBS | Title | First Half PY4 | Status as of Rev2 | Second Half PY4 |
|---|---|---|---|---|
| 1.2.4.1.5 | Control Systems - Final Design Review | | Scheduled for 4-5/2022 | 4/15/2022 |
| 1.2.4.3.3.1 | Control System Software: System Operator Functions - PY4 software/hardware trials completed | | Pending outcome of CS final design review | 8/29/2022 |

**Drill Mechanical WBS 1.2.2, 1.2.3, 1.2.6, 1.2.7**

On the mechanical side, a number of outstanding subsystem design, procurement and fabrication projects will continue in PY4. These efforts will be completed to the extent that they can without access to the actual drill components at the South Pole. During the next field season, the team will perform many of the upgrades and repairs to the individual modules and components that were identified during the 2019/2020 season. The team will also set up the entire Enhanced Hot Water Drill (EHWD) in the actual drill configuration to evaluate the interconnects that create a system out of these individual modules. The work taking place at PSL this year will support these efforts.

Upgrades to the thermal plants, water handling systems, water filtration, condensate management system and integration of existing equipment into the Rodwell system are priorities as well as ensuring that there is a robust inventory of parts, tools, supplies and spares for the project. Engineering will also continue to develop and refine procedural documentation, Plumbing and Instrumentation Diagrams (P&IDs), instrument lists, Process Control Narratives (PCNs), and Integrated Verification and Testing (IV&T) closeout. Preparation for shipment south will continue. Specific milestones and deliverables are listed in Table 4.

Specific drill mechanical efforts:

- Design and construct MHP heater pressure test and flush kit
- Complete heater flowmeter rebuilds and testing
- Design and fabricate plumbing upgrades in Pre-Heat System (PHS)
- Continue refinement of Plumbing and Instrumentation Diagram (P&ID)
- Assemble tower component repair kits
- Complete Main Cable Reel (MCR) and Return Water Cable Reel (RWCR) upgrades
- Order and prepare replacement submersible pumps
- Design and fabricate condensate management system
- Assemble and test water filtration system
- Fabricate heated hoses
- Assess, repair, and replace power feed cables
- Development of ARA Hot Water Drill Subsystem integration plan (Rodwell)
- Main Cable Reel and Drill Supply Hose Reel Load sharing development and testing

Table 4: Milestones and deliverables for WBS grouping

| **WBS** | **Title** | **First Half PY4** | **Status as of Rev2** | **Second Half PY4** |
|---|---|---|---|---|
| 1.2.3.1.5.1 | Tower Operations Structures: Load Cells & Encoders Procured | 3/15/2022 | Complete | |
| 1.2.3.2.9 | Drillheads: Drillheads Updated and Hose Pressure Testing complete | | Complete | |
| 1.2.3.3.8 | Reels & Winches: Reel Load Sharing Testing Complete | | Expected on time | 9/30/2022 |
| 1.2.3.6.3 | Hose Reel Heating System Testing complete | 2/18/2022 | Heating blankets and controller functional testing complete. Cold tests will be done prior to shipping. | |
| 1.2.7.1.6 | Procure Brake Solenoid | 10/26/2021 | Completed on time | |

### Drill Electrical WBS 1.2.5

The generators that were used in IceCube Gen1 will be refurbished and recertified by qualified contractors for use in IceCube Upgrade. In PY4, a statement of work will be developed and solicitation of a qualified contractor will be initiated. Specific milestones and deliverables are listed in Table 5.

Table 5: Milestones and deliverables for WBS grouping

| WBS | Title | First Half PY4 | Status as of Rev2 | Second Half PY4 |
|---|---|---|---|---|
| 1.2.5 | Statement of work for Gen1 refurbishment complete | | Expected on time | 9/1/2022 |

### Installation and Training WBS 1.2.9, 1.2.8

Regarding installation, in PY4, the definition of the sensor flow (including receiving, storing, testing, and staging) will be refined to more detail and part of the equipment needed for these operations will be secured. The sensors will be delivered at Pole on pallets of different sizes and origin. Prior to installation they will be placed (still on pallets, grouped string by string) on UHMW sleds and tested in a dedicated tent. During drilling of the hole, string sensors, still palletized, will be loaded into a sensor staging module. In this module, the sensors will be ordered according to the pre-defined string geometry and passed to the TOS via a roller conveyor as needed. The process is in concept equivalent to what was successfully adopted in IceCube-Gen1, but with necessary modifications related to the higher number of sensors per string, their higher weight, and their different shape and sizes.

The construction of the sensor staging module and the purchase of related equipment will take place in PY4, in order to ensure shipment by vessel 2022-23, and delivery to Pole via traverse in Dec 2023. The module will require assembly at Pole and will need to be ready before the end of the 2023-24 season. The shipment from the point of origin is not in PY4 and, therefore, is not a PY4 milestone.

Since there will be no 2022-23 field season, a team of eight plus two alternates will not be trained and qualified for deployment to carry out drill refurbishment work. The training was a project opportunity for PY4 and has, therefore, been removed.

The string sensor installation hardware will be finalized in PY04 and the installation procedure will be practiced at PSL with the chosen hardware, a section of the main cable assembly and sample sensors. Integration of the deployment connectivity monitor (that will ensure good communication when each sensor is plugged into the main cable during deployment) and of the readout of the bottom pressure sensors with the TOS controls will commence.

Once all the instrumentation is finalized and the installation procedure practiced, the hole diameter at lifetime models will be revisited once more for final tuning.

Table 6: Milestones and deliverables for WBS grouping

| WBS | Title | First Half PY4 | Status as of Rev2 | Second Half PY4 |
|---|---|---|---|---|
| 1.2.8.1.2 | 2022-23 Off-Ice EHWD & Safety Training completed - 10 Drillers (8-primary 2-alternates) - if needed | | This will not take place due to no possibility for a field season in 2022-23 | |
| 1.2.8.1.8 | 2022-23 Field Season Readiness Review completed | | This will not take place due to no possibility for a field season in 2022-23 | |
| 1.2.9.3.2 | Sensor Handling Process definition completed | 11/15/2021 | Logistics Review preparation took priority. Final Design Review to be rescheduled | |
| 1.2.9.3.5 | Procedures for Installation Document Completed | | Expected on time | 8/15/2022 |
| 1.2.9.3.6 | Procedure and Hardware Review completed | | Expected on time | 9/15/2022 |

## FY2022 Shipping

A list of cargo that will enable on-ice work in field season 2022-23 to begin as expeditiously as possible has been supplied to NSF. Specific milestones and deliverables are listed in Table 7. The list contains the dates needed on ice. The project has requested the items to be transported, pre-staged at McMurdo station and transported to the South Pole per needed date. If this shipping plan is not realized in FY22, or is partially realized, on-ice work plan in field season 2022-23 will be adjusted accordingly. Since on-ice work in field season 2022-23 is not part of PY4 workplan, the cost estimates for PY4 do not change. However, the risks for future years will increase by possibly one year. At a very minimum, the containers with refit material for thermal plant and water handling systems would allow for productive on-ice work in field season 2022-23, given adequate local support for snow removal, power and staging of drill containers.

Table 7: Milestones and deliverables for WBS grouping

| WBS | Title | First Half PY4 | Status as of Rev2 | Second Half PY4 |
|---|---|---|---|---|
| 1.2.1.5 | Shipments for prestaging in McMurdo Station: | 11/15/2021 | Completed on time | |
| 1.2.1.5.2.1 | MHP Replacements & Spares to PTH (Vessel) | 11/15/2021 | Completed on time | |
| 1.2.1.5.2.2 | PHS Replacements & Spares to PTH (Vessel) | 11/15/2021 | Completed on time | |
| 1.2.1.5.2.3 | Fuel Systems & Tower Components to PTH (Vessel) | 11/15/2021 | Completed on time | |
| 1.2.1.5.2.4 | TOS Components & Spares to PTH (Vessel) | 11/15/2021 | Completed on time | |
| 1.2.1.5.2.5 | GEN-2, 3, PDM - Ship Components, Repair Parts to PTH (Vessel) | 11/15/2021 | Completed on time | |
| 1.2.1.5.2.12 | Drill Filtration Equipment to PTH (Vessel) | 11/15/2021 | Completed on time | |
| 1.2.1.5.2.13 | Shop Parts - Crimper, Spares, etc. to PTH (Vessel) | 11/15/2021 | Completed on time | |
| 1.2.1.5.2.14 | Cable Reels Main and RWCR to PTH (Vessel) | 11/15/2021 | Completed on time | |
| 1.2.1.5.2.6 | Ship Control Systems Components to PTH (Comsur) | | In discussion with AIL | 11/15/2022 |

| | | | | |
|---|---|---|---|---|
| 1.2.1.5.2.12 | Ship ARA Drill Subsystem Parts to PTH (Comsur) | | In discussion with AIL | 11/15/2022 |
| 1.2.1.5.2.21 | Ship Repair/Replacement Components to PTH (Comsur) | | In discussion with AIL | 11/15/2022 |

## WBS 1.3: Deep Ice Sensor Modules

### On-Award work WBS 1.1.4, 1.3.1, 1.3.3

More than 100 IceCube Gen1 DOM spares wholly qualified for deployment were returned to PSL following the last deployment over a decade ago. A small number of these Gen1 DOMs may be retrofitted into PDOMs with modern data acquisition electronics "mainboards" nearly identical to the D-Egg mainboards, and deployed in the Upgrade for purposes of cross-calibration of the existing IceCube modules. The electronics design work is part of the UW-Madison NSF project technical scope. Firmware support for all optical modules, mDOMs, D-Eggs, and PDOMs is supported by the PSU sub-award and will continue. This task has been moved to WBS 1.6. Specific milestones and deliverables are listed in Table 8.

The development of the Ice Comms Module (ICM) firmware was completed in PY3 by a WIPAC-based firmware development team. Only support during testing of DOMs is planned for PY4.

Special Devices are contributed in-kind by collaborating institutions and this element is responsible for coordination and reviews of these Special Devices. Preliminary design reviews have been scheduled for all proposed Special Devices.

Purchase of parts and materials for refurbishment of 10 PDOMs in PY4 is a project opportunity and may be added as a change request.

Table 8: Milestones and deliverables for WBS grouping

| WBS | Title | First Half PY4 | Status as of Rev2 | Second Half PY4 |
|---|---|---|---|---|
| 1.3.1 | mDOM Final Design Review | 2/1/2022 | Scheduled 4/11-13/2022 at DESY | 4/13/2022 |
| 1.3.1.9.2.1.4 | mDOM Production Readiness Review complete (in US at MSU) | | Delayed due to procurement issues for Mainboard parts (expected Oct. 2022 in re-baselined schedule) | October 2022 |
| 1.3.3.4.4.2 | DOM Refurbishment Facilities Ready | | On track | 5/1/2022 |

### Off-award Work (included for context)

In PY3 the first Integrated mDOMs for design verification testing (DVT) have been built by DESY-Zeuthen. During DVT an issue has been identified with bubbles developing in the optical gel of the

integrated module. This issue, together with severe procurement problems for electronics components has led to a delay of about nine months compared to the PY3 work plan. We expect the mDOM Final Design Review to be conducted in February 2022. Tenders for series production have been completed for all mDOM subsystems that have passed previous reviews, but due to COVID-19 several electronics components (ICs and connectors) have very long and partially unknown lead times. We expect the series production of mDOMs to commence earliest in spring 2022 depending on the availability of electronics components.

The production of D-Eggs (Chiba University) was completed November 2021 at Nippon Marine Enterprises, Japan, the contract manufacturer. PY4 will be dominated by the final acceptance testing of the D-Eggs in the dark freezer lab at Chiba University, Japan. Production and testing of D-Egg modules do not depend on any on- award tasks other than routine support for data collection during testing.

## WBS 1.4: Communications, Power and Timing

### WBS 1.4.1, 1.4.2

The primary effort in Communications, Power and Timing Systems in PY4 is the procurement of the main (downhole) cables to connect the in-ice instrumentation to the surface cables and junction boxes. Engineering support for the design and procurement of the cables and junction boxes is paid from NSF award funds, along with capital expenditures for the surface cables and junction boxes, while the capital expenditures for the main cables are an in-kind contribution by Michigan State University from institutional resources. Following the withdrawal of a key cable supplier in PY3, two alternatives are being explored: a novel cable design that could be fabricated by Hexatronic, the cable supplier for the original IceCube project; and a more traditional cable design from a new supplier, which may or may not meet communications quality requirements. Prototypes for both approaches will be procured and evaluated in the first half of PY4, with a final design review and procurement of the production cables to follow in the second half of PY4. Final design of the breakout connections and mechanical attachments will follow finalization of the cable design in late PY4 and early PY5.

In addition, the surface cable assemblies will be completed (connector installation and testing at MSU) and shipped to Pt. Hueneme, and the surface junction boxes will undergo final design review and enter production, with delivery to follow in early PY5. MSU provides engineering and procurement support for the junction boxes, while management and planning for installation are UW responsibilities.

Penetrator cable assembly production will be completed (MSU) and preliminary design and prototyping of breakout cable assemblies will be done (MSU).

### WBS 1.4.1. 1.4.2, 1.4.3, 1.4.4, 1.4.5

The first prototypes of the FieldHub surface readout electronics will be produced and tested at DESY, evolving from the design of the mini-FieldHubs used for development and DOM acceptance testing. And design of the DOM power supply and distribution system will be finalized at UW, pending input from ASC regarding ICL power supply constraints. Final design and procurement of patch cables and panels for the ICL will also be done (UW),

Other PY4 activities under CPT include design and production of cables for DOM South Pole Acceptance Testing (MSU), design of cable emulator boxes for lab development use (MSU), and expansion of the Northern Test System integration facility at MSU as additional DOMs become available for use at NTS. Specific milestones and deliverables are listed in Table 9

Table 9: Milestones and deliverables for WBS grouping

| WBS | Title | First Half PY4 | Status as of Rev2 | Second Half PY4 |
|---|---|---|---|---|
| 1.4.1.1.2.2.4 | Main Cable Breakout preliminary design review complete | | Expected on time | 8/1/2022 |
| 1.4.1.2.1.2 | Breakout Cable Assembly preliminary design review complete | | Expected on time | 6/1/2022 |
| 1.4.2.1.8 | Surface Cable Assembly delivery to PTH complete | 11/30/2021 | Delayed due to delay in delivery of connectors. Shipping date will be determined after connectors arrive – current estimate is April 2022. This will not affect overall schedule as these items are expected to ship on vessel in FY23 | |
| 1.4.2.3.3.3 | ICL patch panel and patch cable preliminary design review complete | | Expected on time | 8/1/2022 |
| 1.4.4.2.1.3 | Power system final design review complete | | Likely to be delayed due to required revision of preliminary design to accommodate available ICL power outlets | 6/30/2022 |
| 1.4.4.2.2.5 | Power system delivery to NTS for testing complete | | Expected to be delayed due to delayed power system FDR | 9/15/2022 |
| 1.4.4.2.1.4 | Power Systems: procurement of commercial rack-mount power supplies completed | | Rescheduled due to delayed field season for installation | 9/22/2022 |
| 1.4.4.2.2.4 | Power Systems: production of the control and monitoring systems for NTS complete | | Rescheduled due to delayed field season for installation | 9/1/2022 |

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|---|---|---|---|---|
| 1.4.5.2.2 | Installation of NTS quads complete | | Likely to be delayed due to late delivery of SCA connectors (the SCA work is being performed in the room that will house NTS in the long term). | 5/26/2022 |

## WBS 1.5: Characterization and Calibration Systems

PY4 tasks under this WBS element are almost entirely contributed in-kind with the exception of 2 weeks' faculty support (D. Williams – U Alabama). The remainder of the tasks described in this section are not on NSF award. Specific milestones and deliverables are listed in Table 10.

Calibration instruments in mDOMs and D-Eggs (cameras and LED flashers): Design is complete on these devices. Final Acceptance Testing (FAT) of D-Eggs will include tests on flashers and cameras, with test results being included in a central database. Production of cameras for mDOMs at DESY is expected to be complete in PY4, in plenty of time for integration into the mDOMs. Production of cameras for mDOMs at MSU will continue into PY5, again in plenty of time for production.

Standalone calibration instruments: The mini-mainboard, an electronics motherboard for standalone calibration devices and special photosensors, will undergo final design review and production of first articles in PY4 following input from all stakeholders. The standalone calibration module: Precision Optical Calibration Module (POCAM) is anticipated to undergo Final Design Review (FDR) in PY4, with remaining devices undergoing FDR in PY5.

Dust Logger: A plan is in place to use an existing winch from the Ice Drilling Program for the Upgrade Dust Logger. In PY4, we expect to have greater certainty about when the winch will be used and will make a request for its use to the program officer.

Table 10: Milestones and deliverables for WBS grouping

| **WBS** | **Title** | **First Half PY4** | **Status as of Rev2** | **Second Half PY4** |
|---|---|---|---|---|
| 1.5.2.2.1.4 | POCAM Final Design Review | | Rescheduled to September 2022 due to COVID-related delays and electronics components availability | 9/15/22 |
| 1.5.2.3.1.2.19 | Delivery of cameras for mDOMs (DESY production) complete | | Rescheduled to May 2022 due to delays in camera production during mDOM testing | 5/18/22 |

| | | | | |
|---|---|---|---|---|
| 1.5.2.6.1 | Delivery of first articles of V3 mini-mainboards | | Rescheduled to July 2022 due to electronics components shortage | 7/18/22 |

## WBS 1.6: Data Systems Integration

The majority of the PY4 tasks in WBS 1.6 are not on NSF award and mostly supported under the IceCube Management and Operations award. Tasks funded by this award are approximately 1 month overall WBS 1.6 management by a UMD senior scientist and, at UW, 3 months labor (software development and cluster management) and 0.5 FTE of a software developer to support embedded software development and test system development. Specific milestones and deliverables are listed in Table 11.

**Rationale for Supporting WBS 1.6 Using IceCube M&O Funding**

IceCube M&O is a mature organization with a well-defined WBS structure, and institutional management structures to support the deliverables of the program. Among these deliverables are specific tasks to support the IceCube data acquisition system (M&O WBS 2.2.2), online processing and filtering systems (M&O WBS 2.2.3), and offline software (M&O WBS 2.5.1, 2.5.2, and 2.5.3). Within the scope of responsibilities of these areas is the support of integration of new detector subsystems, including IceCube Upgrade. The integration of Upgrade instrumentation utilizes these existing infrastructure, labor resources and expertise which ensure full functionality for both the Upgrade hardware and the existing IceCube instrumentation.

Guidance for management planning activities on whether to use M&O or Upgrade project resources for a particular task or task group is as follows: software or firmware development targeting existing IceCube detector systems (e.g. DAQ/Online systems) should be supported by M&O resources. Software or firmware development targeting new detector instrumentation such as D-Egg or mDOM modules or the production and testing systems to support these should be supported by Upgrade project resources.

### WBS 1.6.1, 1.6.4

For PY4, the focus in WBS 1.6 will shift from development of optical module testing software to wider operational support of new hardware. Software systems to support FAT testing are mature and will continue to be supported through the testing program. Furthermore, this project year sees the start of mDOM production, as well as the design of special calibration devices that use the mini-mainboard. These new hardware systems will require modification of verification and testing software suites developed with the D-Egg testing effort.

A major task this year is preparing the existing software systems with the IceCube operations structure for the additional Upgrade hardware. These include extensions to the data acquisition (UW), experiment control (UW) and online filtering systems (UMD) to handle data from the newly expanded detector array. These changes are planned to use some ongoing refactoring of our current online systems (UMD) to make them less specialized to IceCube Gen1 DOMs. One major review was completed to support this effort in PY4:

- WBS 1.6.1.4 – OM on-board operational software and firmware review

A further review of all online systems and their readiness for Upgrade activities:

- WBS 1.6.1.1 – IceCube DAQ and online systems review of Upgrade integration plans

Has been moved to May 2023 to avoid conflicts with planned M&O activities with the 2022/3 pole season. Both reviews are focused on ensuring the planned hardware and software systems delivered will seamlessly integrate into the current IceCube operational program.

Additionally, work continues in this project year toward readiness of higher-level IceCube analysis and simulation software systems to include the upgrade modules in data analysis (UMD). This work targets the inclusion of D-Egg, mDOM, pDOM, and calibration devices into high fidelity as-designed simulations samples. This work prepares the IceCube data flow to be ready to include readouts from the newly deployed instrumentation at project completion.

Due to COVID-19 delays, items tied to the string deployments have been pushed back from PY4. Most notable are some hardware purchases for the South Pole System (SPS) computing system, where these purchases will be made just ahead of system need. Additionally, preparation and planning for post-deployment string commissioning is also delayed, as processes there will be informed by the conclusion of FAT testing in the North prior to shipment to pole. None of these delayed items significantly impact other work packages in the project.

Table 11: Milestones and deliverables for WBS grouping

| WBS | Title | First Half PY4 | Status as of Rev2 | Second Half PY4 |
|---|---|---|---|---|
| 1.6.1.1.2.4 | NTS minimal DAQ ready for calibration device testing at NTS | 3/16/2022 | Hardware delays from MMB prototyping delayed tasks | 9/14/22 |
| 1.6.1.1.2.5 | IceCube DAQ and online systems review of Upgrade integration plans complete | | Delayed until May 2023 | |
| 1.6.1.2.1.10 | Review Experiment Control - Upgrade plans for new modules complete | | Delayed until May 2023 | |
| 1.6.1.2.2.2 | ExpControl- Calibration Devices software Interface Documented complete | 12/15/2021 | Delays due to late arrival of mini-main boards, expected May 2022 | |
| 1.6.1.2.2.4 | NTS Minimal ExpControl ready for NTS calibration devices testing complete | | As planned | 9/15/2022 |
| 1.6.1.4.5.2 | OM on-board operational software and firmware review complete | 10/31/2021 | Review completed Dec 16-17, 2021 | |
| 1.6.1.4.5.5 | Review OM data collection app in detector operations complete | | Delayed until May 2023 | |
| 1.6.1.4.6.2 | Review MMB xDOMapp design complete | 10/31/2021 | Review completed Dec 16-17, 2021 | |
| 1.6.1.4.6.4 | MMB support in xDOMapp ready for calibration device testing at NTS | | As planned | 9/15/2022 |
| 1.6.1.5.4 | review Field Hub software in Upgrade detector operations complete | | Delayed until May 2023 | |
| 1.6.2.1.4 | Core Software Released Supporting Upgrade | 11/1/2021 | Released 12/22/2021 | |
| 1.6.2.2.4 | Reconstruction tools Released Supporting Upgrade | 11/1/2021 | Released 12/22/2021 | |
| 1.6.3.1.3.2 | Release v1 simulation tools complete | 11/1/2021 | Released 12/22/2021 | |
| 1.6.3.2.3.2 | Release v1 calibration device simulation tools complete | | Delayed until after device Final designs: November 2023 | |

| | | | | |
|---|---|---|---|---|
| 1.6.3.3.4 | “As designed” simulation sample ready | 1/24/2022 | Early test samples are being tested | April 2022 |
| 1.6.4.1.2.4 | SPTS computing system complete | 10/4/2021 | complete | |

## Project Year Four Estimated Cost by Month and Priorities

The estimated costs for on-award activities in PY4 are listed in Table 12. The cost estimates are represented by WBS level 2 and 3. They are broken down further into categories of:

- Labor-LoE: The labor in this category is for level of effort
- Labor-Task: The labor in this category is for performing specific tasks
- M&S: This is the estimate for materials and supplies and is not capitalized
- CapEx: This is the estimate for procuring new capital items or adding to existing capital items
- Travel; This is the cost estimate for travel to collaborations and design review meetings. Travel cost estimates are added to the months when the expected travel will take place and are reflected in the totals for those months.

Table 12: Cost estimate for PY4 on-award activities broken down by month and by half-year as well as by WBS categories. All cost estimates are fully burdened. Also listed are task priorities.

| L2/L3 | Oct | Nov | Dec | Jan | Feb | Mar | Total First 6 months | Apr | May | Jun | Jul | Aug | Sep | Total Last 6 months |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.1 Project Office** | **$95,248** | **$95,535** | **$95,535** | **$95,535** | **$95,535** | **$95,535** | **$572,921** | **$95,535** | **$127,665** | **$105,327** | **$112,977** | **$95,535** | **$95,535** | **$632,572** |
| **1.1.1 Project Management** | **$40,663** | **$40,950** | **$40,950** | **$40,950** | **$40,950** | **$40,950** | **$245,412** | **$40,950** | **$48,600** | **$40,950** | **$43,704** | **$40,950** | **$40,950** | **$256,103** |
| Labor - LoE | $38,794 | $39,081 | $39,081 | $39,081 | $39,081 | $39,081 | $234,199 | $39,081 | $39,081 | $39,081 | $39,081 | $39,081 | $39,081 | $234,486 |
| M & S | $1,869 | $1,869 | $1,869 | $1,869 | $1,869 | $1,869 | $11,214 | $1,869 | $1,869 | $1,869 | $1,869 | $1,869 | $1,869 | $11,214 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $7,650 | $0 | $2,754 | $0 | $0 | $10,404 |
| **1.1.2 Project Controls** | **$18,553** | **$18,553** | **$18,553** | **$18,553** | **$18,553** | **$18,553** | **$111,315** | **$18,553** | **$23,449** | **$18,553** | **$18,553** | **$18,553** | **$18,553** | **$116,211** |
| Labor - LoE | $18,553 | $18,553 | $18,553 | $18,553 | $18,553 | $18,553 | $111,315 | $18,553 | $18,553 | $18,553 | $18,553 | $18,553 | $18,553 | $111,315 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $4,896 | $0 | $0 | $0 | $0 | $4,896 |
| **1.1.3 Quality and Safety** | **$13,729** | **$13,729** | **$13,729** | **$13,729** | **$13,729** | **$13,729** | **$82,374** | **$13,729** | **$18,625** | **$13,729** | **$13,729** | **$13,729** | **$13,729** | **$87,270** |
| Labor - LoE | $13,729 | $13,729 | $13,729 | $13,729 | $13,729 | $13,729 | $82,374 | $13,729 | $13,729 | $13,729 | $13,729 | $13,729 | $13,729 | $82,374 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $4,896 | $0 | $0 | $0 | $0 | $4,896 |
| **1.1.4 Project Engineering** | **$18,766** | **$18,766** | **$18,766** | **$18,766** | **$18,766** | **$18,766** | **$112,597** | **$18,766** | **$28,558** | **$28,558** | **$33,454** | **$18,766** | **$18,766** | **$146,869** |
| Labor - LoE | $18,751 | $18,751 | $18,751 | $18,751 | $18,751 | $18,751 | $112,505 | $18,751 | $18,751 | $18,751 | $18,751 | $18,751 | $18,751 | $112,505 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M & S | $15 | $15 | $15 | $15 | $15 | $15 | $92 | $15 | $15 | $15 | $15 | $15 | $15 | $92 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $9,792 | $9,792 | $14,688 | $0 | $0 | $34,272 |
| **1.1.5 Polar Operations** | **$3,537** | **$3,537** | **$3,537** | **$3,537** | **$3,537** | **$3,537** | **$21,222** | **$3,537** | **$8,433** | **$3,537** | **$3,537** | **$3,537** | **$3,537** | **$26,118** |
| Labor - LoE | $3,522 | $3,522 | $3,522 | $3,522 | $3,522 | $3,522 | $21,130 | $3,522 | $3,522 | $3,522 | $3,522 | $3,522 | $3,522 | $21,130 |
| M & S | $15 | $15 | $15 | $15 | $15 | $15 | $92 | $15 | $15 | $15 | $15 | $15 | $15 | $92 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $4,896 | $0 | $0 | $0 | $0 | $4,896 |
| **1.2 Implementation** | **$148,440** | **$181,003** | **$166,961** | **$176,191** | **$179,295** | **$135,276** | **$987,166** | **$200,286** | **$196,076** | **$179,434** | **$200,012** | **$175,493** | **$127,691** | **$1,078,991** |
| **1.2.1 Drill Management & Systems Engineering** | **$46,718** | **$52,096** | **$40,843** | **$40,843** | **$40,843** | **$42,283** | **$263,625** | **$46,243** | **$42,268** | **$38,443** | **$56,927** | **$60,752** | **$60,432** | **$305,064** |
| Labor - LoE | $38,443 | $38,443 | $38,443 | $38,443 | $38,443 | $38,443 | $230,657 | $46,243 | $38,443 | $38,443 | $38,443 | $38,443 | $38,443 | $238,457 |
| Labor - Task | $3,686 | $4,320 | $2,400 | $2,400 | $2,400 | $3,840 | $19,045 | $0 | $0 | $0 | $14,342 | $14,342 | $0 | $28,685 |
| M & S | $4,590 | $9,333 | $0 | $0 | $0 | $0 | $13,923 | $0 | $3,825 | $0 | $4,142 | $7,967 | $21,989 | $37,923 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **1.2.2 Thermal Plant** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$39,565** | **$35,907** | **$18,147** | **$10,123** | **$10,680** | **$6,000** | **$120,421** |
| CapEx | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $32,082 | $26,500 | $5,500 | $0 | $3,000 | $0 | $67,082 |
| Labor - Task | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $7,483 | $9,407 | $12,647 | $10,123 | $7,680 | $6,000 | $53,339 |
| **1.2.3 Tower Operations Site** | **$960** | **$960** | **$27,147** | **$32,007** | **$35,607** | **$20,614** | **$117,295** | **$22,934** | **$17,014** | **$22,943** | **$17,014** | **$17,014** | **$17,014** | **$113,934** |
| CapEx | $0 | $0 | $10,133 | $10,133 | $10,133 | $0 | $30,399 | $4,000 | $0 | $3,700 | $0 | $0 | $0 | $7,700 |
| Labor - Task | $960 | $960 | $17,014 | $21,874 | $25,474 | $20,614 | $86,896 | $18,934 | $17,014 | $19,243 | $17,014 | $17,014 | $17,014 | $106,234 |
| **1.2.4 Computing and Control System** | **$57,264** | **$62,099** | **$63,899** | **$52,439** | **$59,484** | **$48,133** | **$343,319** | **$53,399** | **$66,368** | **$48,839** | **$32,529** | **$23,100** | **$25,880** | **$250,115** |
| CapEx | $16,585 | $10,500 | $9,900 | $0 | $1,885 | $14,054 | $52,923 | $7,800 | $18,369 | $7,800 | $6,369 | $4,500 | $2,000 | $46,838 |
| Labor - Task | $40,679 | $51,599 | $53,999 | $52,439 | $57,599 | $34,079 | $290,396 | $45,599 | $47,999 | $41,039 | $26,160 | $18,600 | $23,880 | $203,277 |
| **1.2.5 Electrical Generation and Distribution System** | **$0** | **$0** | **$0** | **$0** | **$0** | **$3,000** | **$3,000** | **$1,800** | **$0** | **$0** | **$0** | **$0** | **$0** | **$1,800** |
| CapEx | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Labor - Task | $0 | $0 | $0 | $0 | $0 | $3,000 | $3,000 | $1,800 | $0 | $0 | $0 | $0 | $0 | $1,800 |
| M & S | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** |
| **1.2.6 Water Handling Systems** | **$31,612** | **$12,005** | **$3,600** | **$16,070** | **$14,275** | **$3,725** | **$81,288** | **$17,660** | **$10,760** | **$17,300** | **$6,280** | **$0** | **$0** | **$52,000** |
| CapEx | $18,500 | $6,500 | $0 | $11,750 | $11,750 | $0 | $48,500 | $12,850 | $5,000 | $11,300 | $1,000 | $0 | $0 | $30,150 |
| Labor - Task | $13,112 | $5,505 | $3,600 | $4,320 | $2,525 | $3,725 | $32,788 | $4,810 | $5,760 | $6,000 | $5,280 | $0 | $0 | $21,850 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.2.7 Support Equipment** | **$5,334** | **$8,331** | **$6,920** | **$960** | **$18,360** | **$5,835** | **$45,740** | **$8,679** | **$960** | **$2,844** | **$960** | **$2,844** | **$1,920** | **$18,207** |
| CapEx | $1,168 | $5,768 | $5,000 | $0 | $15,000 | $0 | **$26,937** | $924 | $0 | $924 | $0 | $924 | $0 | $2,772 |
| Labor - Task | $4,166 | $2,563 | $1,920 | $960 | $3,360 | $480 | **$13,448** | $2,400 | $960 | $1,920 | $960 | $1,920 | $1,920 | $10,080 |
| M & S | $0 | $0 | $0 | $0 | $0 | $5,355 | **$5,355** | $5,355 | $0 | $0 | $0 | $0 | $0 | $5,355 |
| **1.2.9 String/Cable Installation** | **$6,552** | **$45,512** | **$24,552** | **$33,872** | **$10,726** | **$11,686** | **$132,900** | **$10,006** | **$22,799** | **$26,073** | **$23,032** | **$7,956** | **$16,445** | **$106,311** |
| CapEx | $0 | $38,000 | $18,000 | $21,946 | $0 | $0 | $77,946 | $0 | $12,000 | $10,000 | $10,000 | $0 | $0 | $32,000 |
| Labor - LoE | $6,552 | $6,552 | $6,552 | $6,552 | $6,552 | $6,552 | $39,312 | $6,552 | $6,552 | $6,552 | $6,552 | $6,552 | $6,552 | $39,312 |
| Labor - Task | $0 | $960 | $0 | $5,374 | $4,174 | $5,134 | $15,641 | $3,454 | $4,247 | $9,521 | $6,480 | $1,404 | $4,538 | $29,643 |
| M & S | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $5,355 | $5,355 |
| **1.3 Sensors** | **$8,517** | **$44,527** | **$10,025** | **$6,465** | **$3,232** | **$24,687** | **$97,453** | **$3,232** | **$17,404** | **$30,783** | **$4,762** | **$57,500** | **$31,253** | **$144,935** |
| **1.3.1 mDOM** | **$5,284** | **$9,735** | **$3,232** | **$3,232** | **$0** | **$0** | **$21,484** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** |
| Labor - Task | $3,448 | $9,735 | $3,232 | $3,232 | $0 | $0 | $19,648 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** |
| M & S | $1,836 | $0 | $0 | $0 | $0 | $0 | $1,836 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** |
| **1.4 CPT** | **$86,493** | **$33,722** | **$14,168** | **$25,417** | **$26,485** | **$104,920** | **$291,204** | **$83,218** | **$59,224** | **$80,025** | **$278,143** | **$63,662** | **$31,441** | **$595,715** |
| **1.4 CPT management** | **$2,984** | **$0** | **$0** | **$194** | **$0** | **$0** | **$3,178** | **$2,984** | **$5,659** | **$11,319** | **$11,513** | **$5,659** | **$0** | $37,134 |
| Labor - LoE | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $5,659 | $11,319 | $11,319 | $5,659 | $0 | $33,957 |
| M & S | $194 | $0 | $0 | $194 | $0 | $0 | $388 | $194 | $0 | $0 | $194 | $0 | $0 | $388 |
| Travel | $2,790 | $0 | $0 | $0 | $0 | $0 | $2,790 | $2,790 | $0 | $0 | $0 | $0 | $0 | $2,790 |
| **1.4.1 Downhole Cables** | **$20,904** | **$27,560** | **$13,974** | **$18,825** | **$15,416** | **$62,817** | **$159,497** | **$50,731** | **$43,979** | **$29,113** | **$223,981** | **$39,351** | **$13,353** | **$400,507** |
| CapEx | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $178,000 | $0 | $0 | $178,000 |
| Labor - Task | $17,246 | $27,560 | $13,974 | $18,050 | $15,416 | $43,752 | $135,999 | $49,297 | $34,741 | $29,113 | $35,906 | $33,771 | $13,198 | $196,025 |
| M & S | $3,658 | $0 | $0 | $775 | $0 | $2,325 | $6,758 | $1,434 | $9,238 | $0 | $1,705 | $0 | $155 | $12,532 |
| Travel | $0 | $0 | $0 | $0 | $0 | $16,740 | $16,740 | $0 | $0 | $0 | $8,370 | $5,580 | $0 | $13,950 |
| **1.4.2 Surface Cables** | **$59,232** | **$5,970** | **$194** | **$191** | **$1,722** | **$1,725** | **$69,034** | **$1,722** | **$1,722** | **$12,544** | **$2,132** | **$676** | **$679** | **$19,476** |
| CapEx | $0 | $5,000 | $0 | $0 | $0 | $0 | $5,000 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Labor - Task | $21,435 | $970 | $0 | $0 | $1,531 | $1,531 | $25,467 | $1,531 | $1,531 | $12,350 | $1,941 | $485 | $485 | $18,323 |
| M & S | $37,797 | $0 | $194 | $191 | $191 | $194 | $38,567 | $191 | $191 | $194 | $191 | $191 | $194 | $1,153 |
| **1.4.3 FieldHub** | **$0** | **$0** | **$0** | **$828** | **$414** | **$414** | **$1,655** | **$414** | **$0** | **$0** | **$0** | **$0** | **$0** | **$414** |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Labor - Task | $0 | $0 | $0 | $828 | $414 | $414 | $1,655 | $414 | $0 | $0 | $0 | $0 | $0 | $414 |
| **1.4.4 CPT Central Infrastructure** | **$0** | **$191** | **$0** | **$5,380** | **$8,933** | **$33,820** | **$48,324** | **$17,407** | **$5,795** | **$27,050** | **$40,518** | **$17,976** | **$17,410** | **$126,155** |
| CapEx | $0 | $0 | $0 | $0 | $0 | $750 | $750 | $200 | $0 | $4,635 | $32,000 | $12,405 | $12,030 | $61,270 |
| Labor - Task | $0 | $0 | $0 | $5,380 | $8,742 | $33,070 | $47,191 | $17,207 | $5,604 | $22,415 | $8,518 | $5,380 | $5,380 | $64,503 |
| M & S | $0 | $191 | $0 | $0 | $191 | $0 | $383 | $0 | $191 | $0 | $0 | $191 | $0 | $383 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **1.4.5 Northern Test System** | **$3,373** | **$0** | **$0** | **$0** | **$0** | **$6,144** | **$9,517** | **$9,960** | **$2,069** | **$0** | **$0** | **$0** | **$0** | **$12,029** |
| Labor - Task | $3,179 | $0 | $0 | $0 | $0 | $5,951 | $9,130 | $9,960 | $2,069 | $0 | $0 | $0 | $0 | $12,029 |
| M & S | $194 | $0 | $0 | $0 | $0 | $194 | $388 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **1.5 Characterization and Calibration System** | **$373** | **$373** | **$373** | **$373** | **$3,055** | **$373** | **$4,917** | **$1,373** | **$5,141** | **$26,231** | **$15,040** | **$5,141** | **$373** | **$53,297** |
| **1.5.3 Array Calibration** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$1,000** | **$0** | **$25,859** | **$0** | **$0** | **$0** | **$26,859** |
| CapEx | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $1,000 | $0 | $0 | $0 | $0 | $0 | $1,000 |
| Labor - Task | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $0 | $23,105 | $0 | $0 | $0 | $23,105 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $0 | $2,754 | $0 | $0 | $0 | $2,754 |
| **1.5.4 Calibration Management and Organization** | **$373** | **$373** | **$373** | **$373** | **$3,055** | **$373** | **$4,917** | **$373** | **$5,141** | **$373** | **$15,040** | **$5,141** | **$373** | **$26,438** |
| Labor - LoE | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $0 | $0 | $11,985 | $0 | $0 | $11,985 |
| M & S | $373 | $373 | $373 | $373 | $373 | $373 | $2,235 | $373 | $373 | $373 | $373 | $373 | $373 | $2,235 |
| Travel | $0 | $0 | $0 | $0 | $2,682 | $0 | $2,682 | $0 | $4,768 | $0 | $2,682 | $4,768 | $0 | $12,218 |
| **1.6 IceCube Data Systems Integration** | **$18,053** | **$18,053** | **$18,053** | **$18,053** | **$18,053** | **$19,507** | **$109,774** | **$29,888** | **$18,053** | **$20,807** | **$18,053** | **$18,053** | **$20,834** | **$125,691** |
| **1.6.0 L2 Task Management** | **$6,081** | **$6,081** | **$6,081** | **$6,081** | **$6,081** | **$6,081** | **$36,486** | **$14,397** | **$6,081** | **$6,081** | **$6,081** | **$6,081** | **$8,862** | **$47,583** |
| Labor - LoE | $6,081 | $6,081 | $6,081 | $6,081 | $6,081 | $6,081 | $36,486 | $6,081 | $6,081 | $6,081 | $6,081 | $6,081 | $6,081 | $36,486 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $8,316 | $0 | $0 | $0 | $0 | $2,781 | $11,097 |
| **1.6.1 Online Systems Software** | **$10,960** | **$10,960** | **$10,960** | **$10,960** | **$10,960** | **$12,413** | **$67,211** | **$13,714** | **$10,960** | **$13,714** | **$10,960** | **$10,960** | **$10,960** | **$71,265** |
| Labor - LoE | $884 | $884 | $884 | $884 | $884 | $884 | $5,302 | $884 | $884 | $884 | $884 | $884 | $884 | $5,302 |
| Labor - Task | $10,076 | $10,076 | $10,076 | $10,076 | $10,076 | $10,076 | $60,455 | $10,076 | $10,076 | $10,076 | $10,076 | $10,076 | $10,076 | $60,455 |
| M & S | $0 | $0 | $0 | $0 | $0 | $1,454 | $1,454 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $2,754 | $0 | $2,754 | $0 | $0 | $0 | $5,508 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.6.4 Computing Infrastructure** | **$1,013** | **$1,013** | **$1,013** | **$1,013** | **$1,013** | **$1,013** | **$6,078** | **$1,778** | **$1,013** | **$1,013** | **$1,013** | **$1,013** | **$1,013** | **$6,843** |
| CapEx | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $0 | $0 | $0 | $0 | $0 | **$0** |
| Labor - LoE | $1,013 | $1,013 | $1,013 | $1,013 | $1,013 | $1,013 | $6,078 | $1,013 | $1,013 | $1,013 | $1,013 | $1,013 | $1,013 | $6,078 |
| Labor - Task | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| M & S | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $765 | $0 | $0 | $0 | $0 | $0 | $765 |
| Travel | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | $0 | $0 | $0 | $0 | $0 | $0 | **$0** |
| **Grand Total** | **$353,892** | **$338,421** | **$298,322** | **$318,801** | **$322,422** | **$355,610** | **$1,987,467** | **$410,300** | **$406,159** | **$406,979** | **$571,077** | **$304,737** | **$275,874** | **$2,375,126** |

Cost justifications for expenses in PY4 above $200k are detailed in the tables Table 13, Table 14 and Table 15. All cost estimates listed are fully burdened.

Table 13: Cost justification for expenses over $200k for the Project Office WBS 1.1

| **WBS** | **Total Cost** | **FTE** | **Justification of cost for PY4** |
|---|---|---|---|
| **1.1.1 Project Management** | **$501,516** | 1.22 | |
| Labor - LoE | $468,684 | 1.22 | PI is responsible for entire project, PI is assisted by CoPIs for integration of IceCube Upgrade into IceCube Observatory as well as coordination of collaborating institutions. Project manager is responsible for managing the project scope, adherence to project objectives, and managing the NSF award. |
| M & S | $22,428 | | Software licenses and IT hardware. |
| Travel | $10,404 | | Travel to collaborating institutions for project level meetings and communication |
| **1.1.2 Project Controls** | **$227,527** | 1.40 | |
| Labor - LoE | $222,631 | 1.40 | Project Controls Manager is responsible for managing (0.4 FTE) all financial aspects of the project and is the liaison between UW system, NSF, WIPAC and subawardees on all financial matters. Project controls specialist 91 FTE) is responsible for project tracking in coordination with level 2 managers and project cost and schedule analysis. |
| Travel | $4,896 | | Travel to collaboration board meetings |
| **1.1.4 Project Engineering** | **$259,466** | **0.90** | |

| | | | |
|---|---|---|---|
| Labor - LoE | $225,010 | 0.90 | Responsible for coordination of all technical aspect of the instrumentation, cables, data systems and software, in order to ensure adherence to project scientific, engineering, and quality requirements, manage the technical board, direct project design reviews. Oversee preparation of systems documents, manage technical changes, |
| M & S | $184 | | Supplies |
| Travel | $34,272 | | Travel for technical reviews and travel cost for guest reviewers |

Table 14: Cost justification for expenses over $200k for the Implementation WBS 1.2.

| **WBS** | **Total Cost** | **FTE** | **Justification of cost for PY4** |
|---|---|---|---|
| **1.2.1 Drill Management & Systems Engineering** | **$568,689** | **2.38** | |
| Labor - LoE | $469,113 | 2.13 | Manage the refurbishment activities of the drilling systems in accordance with technical requirements. Develop shipping and logistics requirements and plans. Develop work plans for catching up to delayed work due to the pandemic. Labor consist of one full time L2 manager, one full time systems engineer, 0.3 assistant systems engineer. System engineering hours added to support logistics review and rebaselining efforts. PSL supplies required subject matter expertise in both of these areas. Engineering support has also been added to address needs that have emerged from a better understanding of control system development and system support documentation requirements; compiling parameters documentation, development of P&ID (Plumbing and Instrumentation Diagrams) and Instrumentation lists, closing out IV&T (Integrated Verification & Testing), reviewing and editing Drill Procedures, and developing a Process Control Narrative. See 1.2.1 detail |
| Labor - Task | $47,730 | 0.25 | See 1.2.1 detail |
| M & S | $51,846 | | See 1.2.1 detail |
| Travel | $0 | | |

| | | | |
|---|---|---|---|
| **1.2.3 Tower Operations Site** | **$231,229** | **0.97** | |
| CapEx | $38,099 | | See 1.2.3 details |
| Labor - Task | $193,130 | 0.97 | Conduct planned work in PY4 for upgrades to reels and winches, drillheads, conduct hose and cable reel load share testing, prepare tower repair kits. Hose heating system procurements and testing added in PY4. The Gen 1 hose heating system stored at the South Pole was found to be beyond repair in the PY2 field season. Procurements and testing are required to complete the replacement Hose Reel Heating System. Main Drill Cable Reel and Drill Supply Hose Reel motion control development extended into and increased in PY4. This effort was underestimated in the baseline plan, and field season delays have required adjustments to shift more integration and testing activities off-ice. See 1.2.3 details |
| **1.2.4 Computing and Control System** | **$593,433** | **2.27** | |
| CapEx | $99,761 | | See 1.2.4 details |
| Labor - Task | $493,672 | 2.27 | Conduct PY4 planned work for design, procurement and testing of control system components including sensors, cabling, I/O boxes, emergency stop, network, encoders, load cells, pendants, and motor drives. Labor consist of 2.27 FTE in PSL engineering and technical labor.<br>See 1.2.4 details |
| **1.2.9 String/Cable Installation** | **$239,210** | **0.71** | Procedures for installation document complete |
| CapEx | $109,946 | | See 1.2.9 detail |
| Labor - LoE | $78,624 | 0.46 | Design and build sensor handling and infrastructure needed for sensor testing and installation, build sensor handling structure, labor is 0,.46 FTE PSL engineering. See 1.2.9 detail |
| Labor - Task | $45,285 | 0.25 | 0.25 PSL technician for above. See 1.2.9 detail |
| M & S | $5,355 | | |

Table 15: Cost justification for expenses over $200k for the Instrumentation WBS 1.3 and Communications, Power and Timing WBS 1.4

| **WBS** | **Total Cost** | **FTE** | **Justification of cost for PY4** |
|---|---|---|---|
| **1.3.3 PDOM** | **$220,903** | **0.48** | Refurbish 10 PDOM units. This was postponed from previous years in order to get a head start on D-Egg modules (same mainboard). Now, that D-Eggs are done, we use that experience to finish the PDOMs. |
| CapEx | $82,600 | | |
| Labor - Task | $79,245 | 0.48 | |
| M & S | $50,796 | | |
| Travel | $8,262 | | |
| | | | |
| **WBS** | **Total Cost** | **FTE** | **Justification of cost for PY4** |
| **1.4.1 Downhole Cables** | **$560,003** | **1.66** | |
| CapEx | $178,000 | | |
| Labor - Task | $332,023 | 1.66 | Conduct engineering and design, procurement of prototypes and support for procurement of downhole cables and breakout cables.<br>The CapEx increase is a combination of updated costs for Yale Grips and break out cable assembly (BCA) prototype costs moved forward from early PY5 to late PY4.<br>The primary contributors to the labor costs are:<br>Cable emulator box work rescheduled from PY3 to PY4 due to labor unavailability<br>BCA design and prototype work rescheduled from PY3 to PY4 due to labor unavailability, and revised estimate of work required<br>Additional labor required for mechanical design of main cable load member, under new main cable design<br>Addition of scope in penetrator cable assembly retesting after rework, production of South Pole acceptance test cables |
| M & S | $19,290 | | |
| Travel | $30,690 | | |

## Justification for Size of Project Office

A list of personnel, the WBS area they contribute to, and their duties and fraction of support are listed in Table 16. The Project Office totals to 4.51 FTE which provides project financial and technical (science, engineering, quality and safety, and logistics) management of the total project scope with a cost in excess of $37M which includes the scope funded by the NSF award and the contributions in kind.

Table 16: Project Office size and duties

| Person | Title | WBS | Duties | FTE |
|---|---|---|---|---|
| Kael Hanson | Principal Investigator | 1.1.1 | Overall responsible for project scientific and technical scope. | 0.15 |
| Farshid Feyzi | Project Manager | 1.1.1 | Manage project scope and budget, award management. | 1.00 |
| Greg Sullivan | UMD Inst. Lead | 1.1.1 | Oversee UMD subaward. | 0.04 |
| Doug Cowen | Co-PI / PSU Inst. Lead | 1.1.1 | Oversee PSU subaward. | 0.04 |
| Marek Rogal | PMCS | 1.1.2 | Project cost, schedule and controls. | 1.00 |
| Catherine Vakhnina | PMCS | 1.1.2 | EVMS reporting; subaward management; award compliance. | 0.4 |
| Mike Zernick | Quality & Safety Manager | 1.1.3 | On-ice and off-ice safety lead. Quality lead, change control. | 0.75 |
| Mike DuVernois | Technical Coordinator | 1.1.4 | Project scientific and technical management; Technical Board chair. | 0.5 |
| Perry Sandstrom | Project Engineer | 1.1.4 | Project system engineering; owner of engineering configuration management | 0.5 |
| Delia Tosi | Installation Manager | 1.1.5 | Responsible for installation of optical modules and associated instrumentation. | 0.25 |

## Current Project Financial Status and Projections for Project Year 4

Table 17 shows the project financial status through February 28, 2022 and projection of finances for PY4 second half. The effects of Cooperative Agreement amendment 11 are also included.

Table 17: PY4 plan expenditure, prior year financial status and PY4 status

| Line # | PY4 Plan | |
|---|---|---|
| 1 | Projected expenditures for on-award activities (total from Table 12) | $4,362,593 |
| | | |
| | **Baseline Funding** | |
| 2 | Total baseline funding allocated for PY1, PY2 and PY3 | $12,838,450 |
| 3 | Baseline funding allocated for PY4 first half | $1,987,467 |
| 4 | Actual baseline funds spent through February 28, 2022 | $(14,008,626) |
| 5 | Available balance as of March 1, 2022 (line 2 plus 3 less 4) | $817,291 |
| 6 | Requested increment to baseline funds PY4 second half (line 1 minus 3) | $2,375,126 |
| | | |
| | **Contingency Funding** | |
| 7 | Contingency funding allocated to date for PY1, PY2 and PY3 | $ 1,117,210 |
| 8 | Contingency funding allocated for PY4 first half | $0 |
| 9 | Actual contingency funds spent through February 28, 2022 | $(686,746) |
| 10 | Available balance as of March 1, 2022 (line 7 plus 8 less 9) | $430,464 |
| 11 | Requested increment to contingency funds PY4 second half | $0 |

## Project Year Four Risks

Table 18 shows the risks and opportunities for PY4 standalone plan as submitted with rev 1 of this document.
Table 19 shows the risks and opportunities for PY4 standalone plan as submitted with rev 2 of this document. The risks are composed of cost uncertainty on activities planned for PY4 and additional discrete risks and opportunities. The total represents the possible take on contingency funds for PY4.

The differences are summarized below:

- Cost uncertainty risks are retired because the stand-alone PY4 project is being managed to stay within the estimated amounts.
- Opportunity for training has been removed because there will be no field season in 2022-23
- Due to shortage of electronic pars, a risk for purchasing of electronics parts as they are available has been added. These parts are necessary to expedite board production.

Table 18: Risk and opportunities for PY4 standalone plan – as envisioned in rev1 of this document.

| | | |
|---|---|---|
| Cost uncertainty risk | $553,237 | Calculated per procedure in cost estimating plan for activates planned in PY4 |
| Main cable prototype risk | $80,000 | Additional main cable prototyping may be required to qualify vendor |
| Training for 2022-23 deployment opportunity | $111,140 | Training has been removed from plan, will be done only if 2022-23 season takes place |
| Materials for PDOMS opportunity | $133,396 | PDOM refurbishment has been removed from plan, buying material reduces future risk allowing PDOM refurbishment to start expeditiously in future years |
| Total risks and opportunities | $877,774 | |

Table 19: Risk and opportunities for PY4 standalone plan – as envisioned in rev2 of this document.

| | | |
|---|---|---|
| Main cable prototype risk | $80,000 | Additional main cable prototyping is required to qualify a backup vendor |
| Materials for PDOMS opportunity | $133,396 | PDOM refurbishment has been removed from plan for PY4. Buying material in PY4 reduces future risk allowing PDOM refurbishment to start expeditiously in future years |
| Expedited procurement of parts for mDOM main boards | $80,000 | The production of main boards for mDOM is being delayed due to shortage or electronic parts. The project office is actively searching and buying parts for expediting production in Germany. |
| Total risks and opportunities | $293,396 | |

# IceCube Upgrade PY4 Annual Plan 2021-002.2

Final Audit Report 2022-04-13

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