IceCube Upgrade Project
Project Year 2 Annual Report

October 1, 2019 – September 30, 2020

This report is submitted in accordance with the reporting requirements set forth in the National Science Foundation award number 1719277 for IceCube Upgrade Project

Foreword

This project year 2 Annual Report is submitted under award number 1719277. The report covers the nine-month period beginning October 1, 2019, and concluding June 30, 2020. Cost performance information is based on available data through June 30, 2020.

Starting with this report, a new section on the impact of COVID-19 pandemic on the project is included. Cost and schedule impact on the project are estimated up to the submission date of the report.

Contents

1 ***Executive Summary***

The following report contains the accomplishments of the IceCube Upgrade in project year two and the present status of the project at the time of submission. Year two accomplishments were highlighted by the start of optical module production, system test of the optical module communication and the start of hot water drill assessment refurbishment and repairs.

The design of the optical modules has advanced ahead of schedule, and the production of the first 50 D-Egg modules was completed. A completely new assembly and production facility was set up and commissioned for this purpose and full production procedures were verified. All the photo multiplier tubes (PMTs) for the D-Egg modules have been procured and other parts are complete or in the procurement stage. This will allow for production of the remainder of the modules as per project schedule. Procurement of the entire quantity of PMTs for the mDOM modules was funded as a contribution-in-kind, and the prototyping has started on schedule. The PMT manufacturer was also contracted to produce and assemble the high voltage bases onto the PMTs allowing for faster assembly at the mDOM production sites. Data communication and calibration device controls were tested and demonstrated through production readout electronics. This step is critical in ensuring proper integration of optical modules in the IceCube detector data systems.

In project year two, a team of 11 systems experts deployed to the South Pole and McMurdo stations to initiate hot water drill component repair and refurbishment. They were able to inspect nearly all critical drill components including heaters, high pressure pumps, main hose reel, drilling and installation towers, generators and the power distribution module. In most cases, the components were found to be in far better condition than anticipated. Many of the deficiencies were repaired on site during the austral summer season. Equipment that required return to the United States for reconditioning was identified, packaged, and shipped. These shipments have arrived at the Physical Sciences Laboratory (PSL) and repair and refurbishment is in process. The main drill hose requiring replacement was procured from the original supplier and production is proceeding on schedule. The data cable path entry and routing into the IceCube Laboratory (ICL) from the tower was inspected and plans for cabling were verified.

During the work on site at South Pole and McMurdo stations, the Upgrade staff were supported and assisted as planned and to the maximum extent possible by the Antarctic Support Contract (ASC) staff. The consistent, knowledgeable, and professional ASC support allowed for work to commence and proceed on schedule and included the critical steps of cargo delivery and handling, work site preparation, skilled labor support, and cargo retrograde operations. Communications and integrated planning between Upgrade and ASC staff were exemplary and will serve the project well in the coming seasons.

Starting in middle of March 2020, the Upgrade project was slowed down by the COVID-19 pandemic and the effects are continuing at the time of this submission. Worldwide restrictions on travel, work environment and manufacturing processes across the globe have reduced project ability to progress on the critical path. Nearly all hands-on work has stopped and all other work has continued remotely. The project management and technical teams closely monitor and actively mitigate issues as they arise and have been very effective in reducing negative impact to the extent possible. This report includes an extensive section containing the effects on the project milestones and an estimate of the COVID-19 cost impact to date.

In summary, the progress in project year two has been very good and would have been much better had it not been for the pandemic. The project staff and technical teams remain fully effective and integrated and are committed to project success.

Figure 1: Cleanroom used in assembly and integration of D-Egg at the Nippon Marine Enterprises (NME) facility in Yokohama, Japan where 50 D-Egg modules were completed.

2 *Technical Progress and Accomplishments*

The following sections list the accomplishments in project year 2 (PY2) organized by WBS item. The project made significant progress in technical and management areas in PY2.

2.1 *Project Management - WBS 1.1*

2.1.1 *Organization Update*

Project organization remained largely unchanged in project year 2. WBS 1.2 which was called Drill has been renamed to Implementation in order to reflect the scope of the work which includes both drilling of holes and installation of instrumentation.

A new Level 2 Manager for WBS 1.2, Ian McEwen, started on June 9, 2020 to replace Thomas Hutchings. Ian brings over 11 years of direct experience at the South Pole in operations and support of projects, including IceCube Upgrade, to the project.

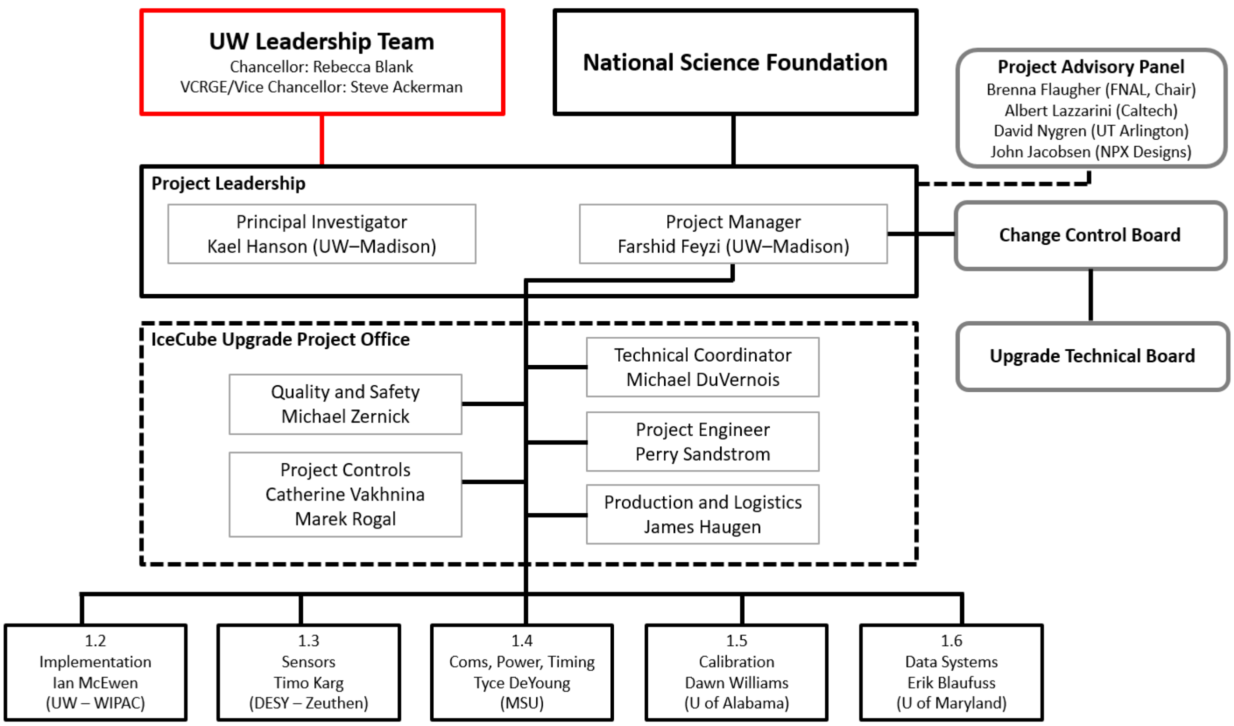


Figure 2: IceCube Upgrade Organization Chart - June 30, 2020

2.1.2 *Project Reviews*

2.1.2.1 *Project Advisory Panel Review*

The IceCube Upgrade Project Advisory Panel meeting was held on February 26-27 to assess progress, ask for advice going forward and seek critical feedback on project deliverables

PAP membership: Brenna Flaugher (Chair), David Nygren, Albert Lazzarini, John Jacobsen

2.1.2.1.1 Executive Summary:

- We compliment the IceCube Upgrade team on the great technical and management progress it has made since the last review.
- We are pleased to see the appointment of a knowledgeable project manager who has a long history of working with IceCube from its early beginnings.
- The plan as presented is aggressive and success-oriented.
- The stakes for success are high: funding prospects for Gen2, plus everyone's safety… not to mention the fundamental science waiting to be done.
- The PAP encourages the Upgrade team to be vigilant against overconfidence driven by the successes of IceCube Gen1.

2.1.2.1.2 Recommendations and Responses:

- Perform a Failure Mode and Effects Analysis
  Response:
  We have adopted an industry-standard FMEA approach, and have begun populating and evaluating the failure modes. We expect to have a completed draft of this by the end of the summer 2020. We are looking at technical issues only in this process, as there are other processes examining the logistics risks (in the risk management strategy) and human safety (in the safety plan, with drill and installation work examined for safe operations).

- The PM should present a comprehensive assessment of the EAC (both the bottoms up and the estimate from EVMS)
  Response:
  This was done at the time of NSF Site Visit and Review in March 2020 and is reported again at the time detail yearly planning which is due on October 1 of every year. The bottom-up EAC is derived from actual costs up to date and estimated cost in the future. The EAC derived from EVMS takes past cost performance index into account and projects an EAC based on the original estimate at the time of project initiation. Both methods are valid and are analyzed by project management to forecast the EAC as accurately as possible.

- The project should develop and implement and communicate to reviewers a comprehensive policy on Milestones as a management tool (down to at least L3)
  Response:
  IceCube Upgrade has implemented milestone tracking tables for each level 2 manager after Project Advisory Panel meeting in February, 2020. Each L2 is responsible for tracking milestones in their area of responsibility and reporting the result monthly. Managers track milestone in such a way as to allow for quick assessment of the critical path and float. Each milestone is evaluated by scheduled finish date, forecast date (which becomes actual date when completed) and resulting float as margin (counted in days). Results are evaluated on a monthly basis within L2 meetings.

- Milestones should be tracked with "baseline date," early finish date (what the L2s are working towards) and actual date completed.

Response:
Level 2 managers are responsible for maintenance and reporting of milestone status data (in uniform way across the project) in the tabulated form stating the scheduled finished date, forecast date (actual if finished) and resulting float as margin (in days). Results from milestone tracking exercise by level 2 managers are reported monthly to the NSF for near-term milestones and are reported in full during annual NSF review meetings.

- Review the risk registry, especially personal injury items, and overall impact. Some items potentially could be combined (e.g., ORG4 and ORG6), and could in some circumstances have a higher cost than stipulated (e.g., if occurring at the beginning of the final season).
  Response:
  The risks have all been reviewed, most recently at the end of the 3rd Quarter of PY 19-20. ORG 4 and ORG 6 actually represent different risks; so, they should not be combined. ORG 6 represents an IceCube Upgrade risk of injury to a driller or installer during the drilling season. ORG 4 represents a risk to M&O personnel. We track those as well. We will continue to review our risks on a quarterly basis, particularly in terms of risk of injury.

- Given the expected schedule pressure before season and on-Ice, continue to be especially vigilant for ways to reduce physical injury risk for deployed personnel. Requiring and providing CPR training for all personnel deploying to the ice is recommended.
  Response:
  As discussed during the PAP, the IceCube Upgrade Project provided first aid/CPR/ and AED training to those drillers and other installers who went to the South Pole this past season. The training occurred during the first week of August, 2019. This training remains in our seasonal training plan to be provided for all of those individuals deploying to the South Pole for the IceCube Upgrade and for IceCube M&O. Our goal is to make it safe for all IceCube staff.

- Add unfinished communications work to risks list, in regard to error detection and correction. Add focus and, potentially, staffing on this item until this risk is retired.
  Response:
  Downhole communications firmware and software development is advancing quickly, with deadlines in mid-2020 for several levels of increasing functionality. In contrast to the IceCube communications design, IceCube Upgrade communications will include error detection and correction in both the firmware and software layers. Firmware error correction is part of the read-only "golden image" installed on each DOM during assembly and will be validated during DOM final acceptance testing prior to shipment to Antarctica. Available bandwidth has been measured with IceCube Upgrade electronics modules communicating over a full-length sample cable, and sufficient headroom is available to accommodate anticipated communications error rates. Possible communications bandwidth limitations, and the potential need for additional staffing, are tracked in the Risk Registry according to project protocols

2.1.2.2 Upgrade National Science Foundation Site Visit and Review

The IceCube Upgrade National Science Foundation site visit and review was conducted on March 16-19. The meeting was conducted remotely due to travel restrictions. The Upgrade team made ten presentations on project management, technical progress, project controls, safety, quality and risks. One Question and one recommendation were generated and answered.

2.1.2.2.1 Recommendation:

COVID-19 Emergency Response Plan: We recommend that you provide a document that describes the risks and projected impact (on the cost, schedule, and budget) on the ICNO M&O & Upgrade/Construction activities due to the COVID-19 outbreak; this should include any respective/potential delays of the procured equipment deliveries, various productions of parts and units (DOMs, etc.), and potential losses or delays of labor and people/positions. Describe the UW & Sub awardees' plans of actions to mitigate the potential risks/events. The plan should include measures that provide for personnel safety and property.

2.1.3 Earned Value Management System (EVMS)

During project year 2, the earned value management system was fully established at the detailed level. All level 2 managers update status monthly in an interactive environment. Earned value, planned value, and actual cost are tracked by the project office and reported at level 1 to NSF on a monthly basis.

Earned value metrics at the level 2 are reported by the project office to all level 2 managers on a monthly basis and analyzed. Corrective actions are discussed and implemented as appropriate.

2.1.4 Technical Baseline Design

The technical baseline design of the IceCube Upgrade project is managed through the Upgrade project office primarily by the technical coordinator and the project engineer. The three primary tools for managing the technical design baseline are the documentation library, the Technical Board conference call discussions and presentations, and the technical review process. The baseline library and the Technical Board were developed from scratch during PY1. Technical reviews began very early in PY1 (as the optical module designs had a history through conceptual design and even to some prototyping activities before the start of the NSF Upgrade funding) and have significantly pushed the finalization of details of the designs, the technical robustness of the designs, and documentation completeness. The design flow from the PEP shows our expectations of the preliminary and final design review levels and the production readiness evaluation. Good progress was made in PY2 achieving broad collaboration participation in the relevant portions of the baseline design. For example, the sensor R&D modules were reviewed in May 2020 for their conceptual design (and how they fit into the mission of the IceCube Upgrade) and each proposed module design team worked through the required documentation and submitted it within the Upgrade SharePoint instance (see below).

2.1.5 Design Baseline Documentation

The baseline content is stored in a documentation database instance in SharePoint, which allows for collaboration-wide contributions, editing, and reviewing. This is then moderated with a full available history of edits and a document control system that allows transitioning the uncontrolled documents, held in common by the collaboration, into controlled and approved documents. The transition from uncontrolled to controlled documentation is managed by the quality assurance engineer, with approvals from tech board discussions and internal engineering reviews. All as-built documentation is automatically controlled as well to provide a permanent record of the as-built hardware.

System engineering is handled through the use of multiple defined document types for each baseline configuration item. Configuration items are stored hierarchically from the IceCube Upgrade highest-level down to low-level hardware and software items such as cable assemblies, electronics boards, and glass pressure housings. Each configuration item has the following associated documents:

- Configuration management document (CMD): links the hierarchy of configuration items and bill of materials for bottom-level configuration items, and this typically contains vendor details for purchased items.
- Engineering requirements document (ERD): details the engineering requirements, often including how those requirements hook to science requirements, how the requirements are verified, and how the requirements were set. Some of the ERD content is held in common for multiple subsystems including specifications on shipping requirements, storage and operating environmental requirements, and testability standards.
- Interface definition document (IDD): covers the interfaces (electrical, mechanical, optical, etc.) between this configuration item and any other affected configuration items.
- Design status document (DSN): this presentation-formatted document carries the current status of the design, photos of parts, and links to manufacturers and software repositories, as needed, and generally forms an evolving repository of documentation of the design process of the individual configuration item. Status reports and other presentations can be linked into the DSN to show the evolution and progress of ongoing work.

This configuration management system was developed this first year of the project and is well populated with the systems and subsystems of WBS 1.3, 1.4, 1.5, and 1.6. The drill documentation is handled separately as the requirement of broad, international editing of the documents are not required for the drill. These documents are owned by the respective L3 (or lower) managers until the documents are controlled via successful review and the quality assurance plan.

The engineering requirements have been derived from the higher-level science requirements via the PEP science-engineering requirements flow-down matrix filtered through the hardware experiences from the Gen1 IceCube construction. This is especially important for the extreme environment of the deep, cold glacial ice of South Pole.

2.1.6 Design Reviews

Our core design milestones are defined by engineering reviews run by the project office, with mostly internal reviewers (and some occasional external reviewers) going over the presentations organized by the responsible L2 manager. Summaries of the PY2 reviews are given below. These reviews have generally included site visits to the configuration item host institution, meetings with significant industrial partners, and meetings with the full subsystem team. These full design reviews are typically preceded by discussions on the weekly tech board call and potentially have baseline changes approved through the change control board call as needed.

2.1.6.1 D-Egg Final Design Review

This was held in mid-February in Chiba, Japan with an internal review panel, the Chiba science team, and the NME (Nippon Marine Enterprises) manufacturing team. The outcome of the review was a success, though some low-level noise issues in the Rev3 D-Egg mainboard were noted and a plan to mitigate that noise was recommended.

The Rev4 D-Egg mainboards are now being tested and appear to have resolved the noise issue. Additionally, some electronics parts have new scarcities likely due to COVID-19, and qualified replacement has taken place.

In PY1, we held separate preliminary design reviews for the D-Egg mechanicals (to support early long-lead procurements), the D-Egg DAQ electronics, and the D-Egg high voltage electronics. The high voltage review led to a partial redesign of the High Voltage subsystem with an eye towards more readily understandable reliability and performance specifications.

2.1.6.2 mDOM High Voltage Subsystem Review

The mDOM has 24 separate high-voltage boards, and we held a final design review in January 2020 mostly focused on the manufacturer testing and assembly of the boards. The PMT vendor (Hamamatsu) is having the high-voltage boards manufactured, tested, integrated to tested and quantified tubes, and then quickly tested again. The review was successful and the processes seemed to be in good shape with a test stand manufactured at DESY and shipped to Hamamatsu but the production start was delayed due to COVID-19 and has not yet fully resumed.

2.1.6.3 Precision Optical Calibration Module Review

In October, we conducted an on-site review at Technical University of Munich of the POCAM at the level of a preliminary design review, although some elements were significantly more advanced than that. Prototype POCAMs have been deployed in the deep ocean and in Lake Baikal. The POCAM is a significant part of the Upgrade Calibration system and the review was a success.

2.1.6.4 R&D Sensor Devices Review

We held a conceptual and mission readiness review of potential R&D sensor modules for the Upgrade. Some of these modules are novel communication devices, advanced optical sensor modules for future large detectors, intriguing but untested calibration devices, or modules to do additional types of physics available in the deep, shielded ice surrounded by the IceCube detector. All of the reviewed devices were at least at the conceptual design stage, and most were significantly better documented than one might expect for that stage. The proposed module locations within the Upgrade string geometry was discussed and potential room is available for all requests. These modules are all being delivered as in-kind contributions and common hardware, electronics, and software interfaces guarantee that their inclusion into the detector will come at a minimized cost in complexity on the project.

2.1.6.5 COVID-19 Impact on Reviews

Among the reviews delayed by the COVID-19 Pandemic are the acoustic calibration system review (planned for May 2020 and now rescheduled for July 2020), the pencil beam calibration module (planned for May 2020), the mDOM final design review (planned for July 2020), and the D-Egg Production Readiness Review (planned for July 2020). Right now, these delays are reducing the schedule margin but are not on the critical path. We believe all these reviews (except the D-Egg Production Readiness Review which does need to be in person) can be held remotely, and all can be conducted in the August – November time scale.

2.2 Drilling and Installation - WBS 1.2

2.2.1 Activities Northside

A significant ramp up of activities occurred in the Implementation WBS during PY2. Key staff recruitments were made to bolster the drilling team in the areas of leadership, experience, and control system development. An Upgrade implementation manager, two full-time drill leads, one full-time control systems engineer, two experienced seasonal drillers, one contributed driller, and one part-time contributed electronics engineer joined our team. Project requirements, activities, on-ice support needs, and population plans were developed and coordinated with the Antarctic Support Contractor (ASC) resulting in a successful and productive 2019-2020 season. Bi-weekly coordination meetings with ASC continue planning the next and out-year field seasons. WIPAC and ASC are actively engaged in improving communication and planning strategies to facilitate coordination, thorough schedule development, and resource requests. The first annual meeting with the newly formed Drill Advisory Panel (DAP) was also convened in March ‘20.

Complete subsystem evaluation is well underway at the component level, new control system architecture is in progressing and hardware choices have been established. Major procurements were initiated and all cargo was moved southbound as planned. PY2 northside Upgrade activities include:

- Shipping generator 1 to McMurdo after complete rebuild in CONUS and successful acceptance testing.
- Completing refurbishment and testing of the Independent Firn Drill System and shipped to McMurdo.
- Procurement of main drill hose completed early to take advantage of a 10% discount. On-site pre-production acceptance testing in Italy performed by drill engineers. Delivery

of the entire procurement expected in July, as planned. Strain relief fabrication and assembly was completed and delivered to hose manufacturer. The winter hose heating system is currently in development.

- Purchasing of two Polaris snowmobiles and a Caterpillar 287B tracked loader, per ASC's recommendation, was completed. The snowmobiles were received at the South Pole and commissioned. The 287B, a vessel shipment, is currently staged in McMurdo for future year shipment to the Pole.
- Initiating main drill cable Request for Proposal (RFP) process.
- Launching overhaul of main drill cable reel and return water cable reel. Return water cable reel loaded with new combo cable planned to ship in November 2020.
- Building and shipping control system and motor drive evaluation kits to support on-ice testing and evaluation.
- Completing motor drive selection and procured first of two motor drive orders.
- Finalizing control system architecture and hardware. Integration activities and evaluation of SCADA user interface software ongoing at the PSL drill testbed.
- Completing overhaul of all three drillheads. Testing is in progress. The pressure vessel for final tests, secured through an agreement with the Ice Drilling Program (IDP), was received on-site and commissioned. Drillhead testing will be completed in July 2020.
- Developing installation procedures, identifying additional hardware requirements, and planning on-site evaluation of instrumentation.

2.2.2 South Pole Field Season

The focus of the 2019-2020 South Pole field season was a comprehensive assessment of each drill subsystem and full inventory of the drill equipment, tools, and materials stored on-site. A team of 4 drillers was sustained all season with a peak of 12 with one manager providing oversite. The majority of evaluative operations were conducted out of a temporary camp, consisting of a workshop and an office/warming building, established outside the South Pole Cryogen facility. Building modules, drill components, and cargo was cycled through this area over the course of the austral summer, inspected, and returned to its overwinter storage location. Key reconnaissance tasks also included evaluation of IceCube Laboratory cable tray real estate and conducting a GPR survey of the Upgrade drill pad footprint. The Cold Regions Research and Engineering Laboratory (CRREL) analysis of GPR scan data is to be completed by mid-August. The technical details of drill component inspection are as follows:

- Performed complete evaluation of each drill module. Multiple drill modules were pulled from the berm to the work area in groups, powered up, and assessed.
- Performed water heater rebuild and preliminary testing. All heater control functions were tested and verified. Sampling of components retrieved for further testing in the North.
- Performed preliminary low-pressure pneumatic testing of all plumbing to identify major leaks. Shipped deficient components to PSL for repair.
- Performed electrical testing of heated hoses and began identifying inventory that will need to be restocked. Analysis of data is ongoing.
- Sizing information gathered for new motor drive retrofit kits. Network, e-stop, and I/O boxes removed and shipped north for rebuild.

- Performed suite of testing on all motors using new motor drive test cart with new Allen Bradley motor drive. There were no deficiencies found.
- Reinstalled high-pressure pump 4.
- Examined and inspected water tanks and liners. No major issues identified, however, plumbing assemblies and shelters will need to be rebuilt.
- Performed visual inspection of structural elements of drill towers. Reinstalled hose crescents onto tower.
- Inspected and exercised main hose reel. Removed plumbing manifold and hydraulic rotary union for rebuild in the North.
- Inspected all reels and winches and performed repairs.
- Inspected ARA hot water drill system, which has been transferred to Upgrade and will replace the Rodwell System (RWS) module which no longer exists.
- Verification of schematics with as-built configuration.

ASC provided timely support keeping our tasking moving along. Essential buildings at the Cryogen facility (Cryo) site were in place prior to drill team arrival at Pole. This included the addition of four 480vac 3-phase power outlets installed to simulate the drill camp power feeders. Excavation of the drill train storage and cargo berm was well underway. Coordination with equipment operations for building and material movements was easy and reliable. ASC staff readily offered suggestions to improve our operational efficiency. One example was the colocation of all crated materials with the heated buildings at Cryo rather than processing them at their storage location. While this took many cargo sleds loads to accomplish, it drastically reduced commute times and improved working conditions and processing speed greatly. Crane support was excellent for the installation of the crescents on the drill towers. By seasons end, equipment operations had established the relocated ICL road and compacted and groomed the drill pad. Both will need additional work next season to complete the hardening process. The overwinter storage site grade was raised, hardened, and groomed. A new material berm was constructed to elevate crates roughly five feet to minimize snow accumulation. Testing and evaluation of a back-up generator (formerly used to power tunneling equipment) was completed by ASC for project use in following seasons.

2.2.3 <u>McMurdo Field Season</u>

The focus of the 2019-2020 McMurdo field season was the upgrade and testing of two of the three generators and to demonstrate load sharing via the Power Distribution Module (PDM). A team of 3 drillers, a contracted electrician, and a contracted generator technician deployed to McMurdo to support this work. Scheduled repairs and upgrades to generators 2 and 3 were completed. The power distribution module was repaired and achieved syncing and load sharing of both generators. Additional repairs are required before generator 2 can be put into service. The PDM was delivered to the South Pole and placed on skis.

Coordinating the consolidation of equipment transferred from the University of Nebraska – Lincoln (UNL) and preparing this equipment for traverse shipment to the South Pole was also accomplished. Identified UNL equipment including two Heating Plant Units (HPU), one Reel Container Unit (RCU) and a fuel day tank were loaded onto flat racks for traverse. The Independent Firn Drill, generator 1, and a CAT 287B loader purchased for South Pole operations were received. These items are stored over-winter in McMurdo and are scheduled to ship on the next available traverse. The hose crimper was shipped to PSL for repair and calibration.

2.2.4 COVID-19 Impacts

Development of the drill control system is two months behind schedule, to date. PLC, motor drive, and software testing in the PSL drill testbed is progressing slowly due to social distancing induced staffing limitations. As a result, evaluation of SCADA user interface options, PLC hardware selection, and programming has been pushed back. Delays in South Pole retrograde cargo deliveries to PSL curtailed testing and evaluation efforts in key control and electrical subsystem areas, namely heater controls and system cabling. Procurements, integration, and testing will likely see follow-on delays.

Main Drill Cable Reel repairs are estimated at ten weeks behind schedule. The reel requires a major mechanical overhaul, and limited on-site access has prevented this hands-on work from beginning. Parts orders for this work are occurring, but at a much slower pace. These delays will push out downstream tasks such as control system integration, winding on the new drill cable, and development and testing of updated hose and cable syncing algorithms. The main drill cable reel will not be able to ship on schedule (end of 2020). Instead it will need to ship from Wisconsin in the fall of 2021.

Main Drill Cable procurement is approximately 6 weeks behind. Purchasing services suffers from widespread inefficiencies in procurement processing, this as well as reduced vendor response has greatly slowed the RFP and procurement of the main drill cable. Retrograde cargo from the South Pole arrived at PSL 2 months later in than planned. This delayed evaluation of components and subsystems to be used to initiate and inform near-term off-ice plans (i.e. heater controls and pump instrumentation that need to be rebuilt, and cabling for operating the main drill cable reel). PSL site access limitations has also slowed the unpacking this cargo.

Due to the cancellation of the 2020-2021 field season, all planned integration and testing that was to occur in the field will not be executed. Major installs of control system hardware and commissioning of the system connected together as a whole were part of the 2020/21 plan. In response, we will expand the scope of our test program in the north to any extent possible. This will incur additional costs for test planning and development.

Major cargo movements are planned as work of opportunity in the 2020-2021 field season. IceCube Upgrade vessel and overland cargo priorities have been supplied to ASC for planning purposes. Collaboration will continue between WIPAC and ASC as vessel and South Pole Traverse capacities are clarified. While we are working to maintain the planned tempo of cargo movements, some delays in procurement, packaging, and shipment to Port Hueneme will likely be encountered. USAP transportation and logistics delays will compound the downstream outyear impact on integration and testing prior to production drilling operations.

Figure 3. Barb Birrittella and Jake Nesbit working on high pressure pumps. The HPPs are used to pressurize the water that is sent through the main hose downhole to the drillhead.

Figure 4. Lexi Oxborough working the Main Drill Hose Reel which is used for reeling and paying out the hose that carries hot pressurized water to the drillhead

Figure 5. McMurdo team working on generators and power distribution module. The generators and PDM are used to power all the drilling and installation equipment.

Figure 6. James Roth testing main heater control system elements. The main heaters are used to increase the water temperature to near boing point before it is delivered to the hose reel and drillhead.

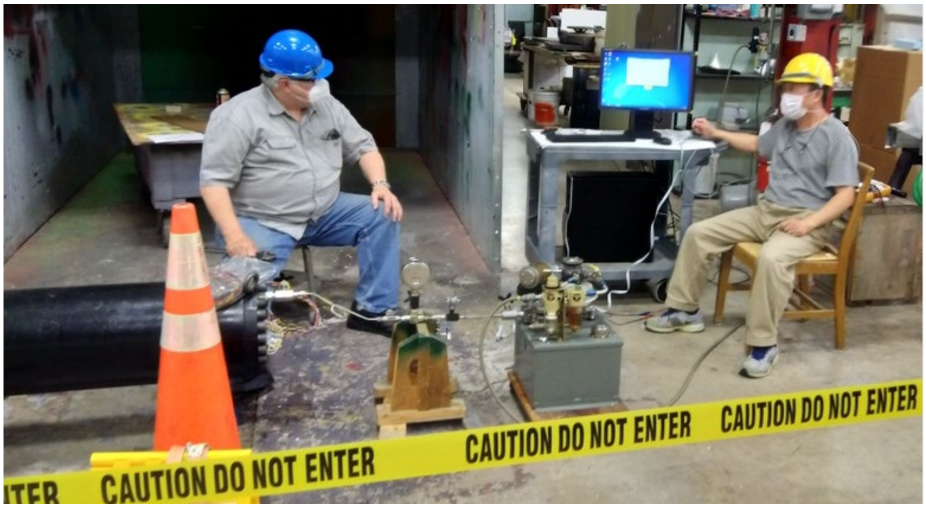


Figure 7. Ron Smith and Qiang Xiao pressure testing a drillhead during PSL limited operations. All three drillheads are tested with high pressure water to simulate the conditions during drilling and to ensure proper operation.

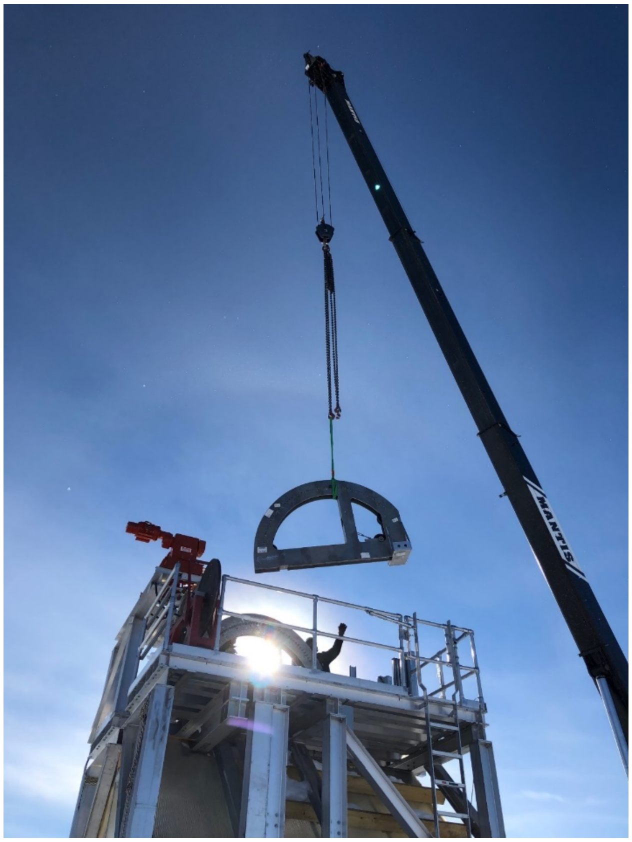


Figure 8. Graham Roberts marshalling during hose crescent installation. The hose crescent guides the main hose over the drill tower as it points downward into the hole.

Figure 9. Team laying out heated hoses used to carry unheated water from water tanks to heater modules. Heated hoses ensure against water freezing between the modules.

2.3 Sensors - WBS 1.3

2.3.1 mDOM

All mDOM subsystems are now close to final design. The integration of 10 mDOMs for integrated mDOM design verification testing and the subsequent final design review had to be postponed until Fall 2020 due to COVID-19-related sourcing problems for various subsystems, most notably the PMT and high voltage-base assembly. A contract was made with Hamamatsu Photonics K.K. for the production and acceptance testing of PMTs with integrated high-voltage base for the mDOM. A purchase order for 10,000 units (2.3 MEuro) was placed by KIT in Germany in December 2019. The ramp-up of the production is ongoing but currently delayed due to sourcing problems for electronics parts for the high-voltage base. A pre-production batch of 320 units needed for the integration of the 10 design-verification mDOMs is not expected to be delivered before September 2020.

The tooling for the mDOM integration lines at DESY, Germany and Michigan State University has been developed and tested. DESY has rented an industrial hall close to its campus for the integration that will be shared with the pre-assembly of telescopes for the Cherenkov Telescope Array (CTA). The installation of the integration and final acceptance testing facilities at DESY and MSU is ongoing as planned but delays due to COVID-19 cannot be excluded at this point.

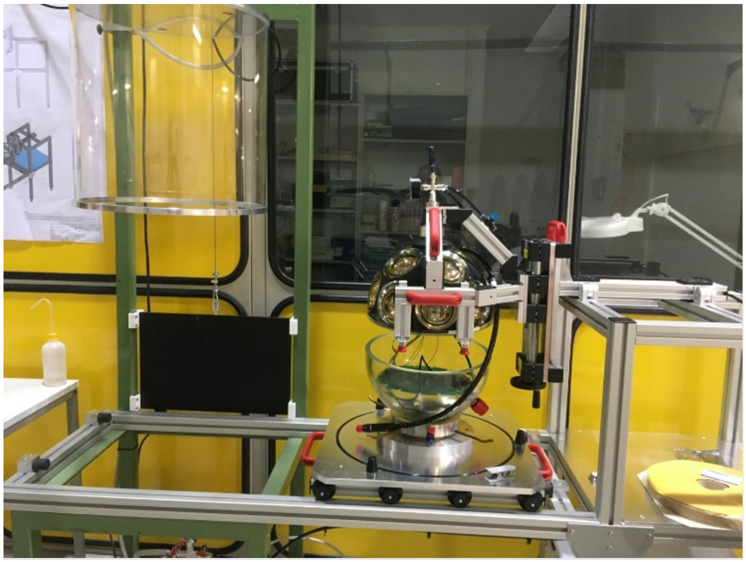


Figure 10: mDOM assembly and sealing station with partial prototype mDOM. The upper half with PMTs can be seen above the lower half. Lower half will also have the same number of PMTs.

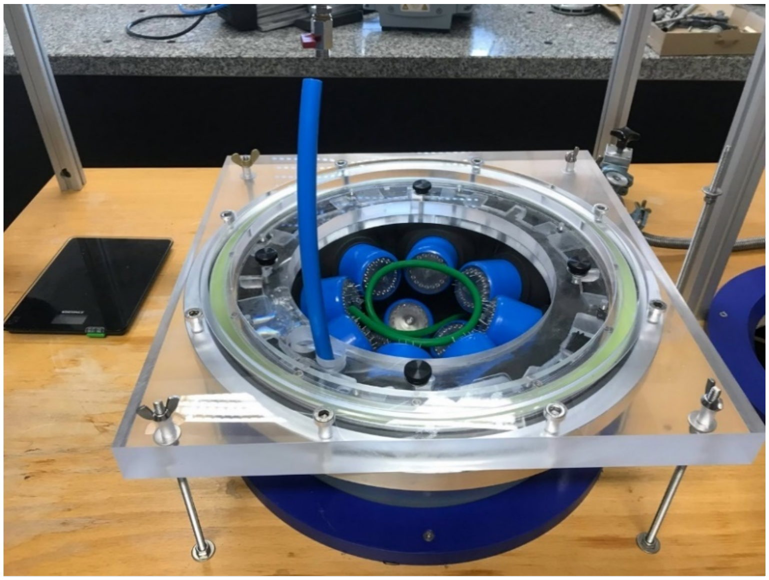


Figure 11: Gel pouring fixture for mDOM. The gel is used to support the PMTs and improve optical coupling from the glass sphere to the PMT.

Figure 12: Prototype of mDOM PMT and HV-base assembly manufactured by Hamamatsu on the left and HV-base acceptance test setup to be delivered to Hamamatsu on the right

2.3.2 D-Egg

In December 2019 ten D-Eggs have been integrated and design verification testing has been successfully carried out. The Integrated D-Egg Final Design Review was passed in February 2020 with the exception of minor necessary modifications to the Mainboard. The D-Egg integration lab at Nippon Marine Enterprises, Ltd near Yokohama, JP was damaged in a typhoon in September 2019 but could be refurbished and relocated to a more secure facility without any time loss for the project. A pre-production of 100 half-D-Eggs was completed on schedule in March 2020. The sealing of these D-Eggs is delayed due to the open issues with the Mainboard and delays in the ICM firmware development (cf. below). The Mainboards for the 50 pre-production D-Eggs have been delivered and tested in June 2020. The sealing and final acceptance testing for these modules is expected for October 2020.

Figure 13: First of the D-Egg Design Verification Testing units, Chiba, January 2020. Ten modules were built and tested to verify the design met requirements before production was allowed to start.

Figure 14: Cleanroom used in assembly and integration of D-Egg at the Nippon Marine Enterprises (NME) facility in Yokohama, Japan. Half D-Eggs here are being inspected and cleaned at this assembly step along the production line.

Figure 15: Integrated D-Egg design verification: industrial standard shock testing setup on the left and hydrostatic pressure testing to 10,000 psi (700 bar) on the right

2.3.3 PDOM

The PDOM is an IceCube Gen1 DOM refurbished with new readout electronics and a new high-voltage subsystem. After additional mDOM funding became available in 2018, the number of deployed PDOMs has been reduced to 14, mainly for cross-calibration purposes with the existing IceCube detector. The PDOM Mainboard is identical to the D-Egg Mainboard on the schematic level and after finalization of the D-Egg Mainboard, layout and production of PDOM prototype mainboards has commenced. No issues are expected with the on-schedule delivery of the PDOMs.

2.3.4 Ice Communications Module (ICM)

The ICM is the unified communications and timing module used by all in-ice sensors and calibration devices. A total of 900 ICMs will be produced for the IceCube Upgrade. Batch #1 (120 ICMs) has been completed and delivered to the Chiba group for the pre-production D-Eggs and to other module developers. Batch #2 (200 ICMs) for D-Egg Batch #2 integration is currently in production.

The firmware necessary to operate the ICMs has been added to this WBS element late (Change Request 15). This firmware is permanent on the ICM, cannot be updated later and is critical for operating all devices and ensures that other firmware and software on all devices can always be accessed and updated. The development of this firmware is currently delayed due to COVID-19-related shifts in responsibilities of the lead developer. The project has identified and allocated additional firmware developer resources from WIPAC engineering pool to address this issue. The final firmware image required for sealing the pre-production D-Eggs is expected in September 2020.

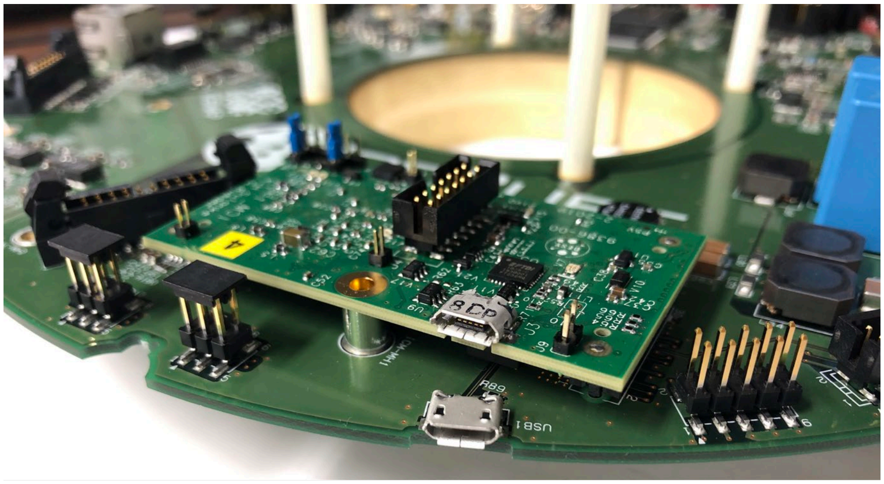


Figure 16: Ice communication module (ICM, small PC board in the foreground) mounted on D-Egg Mainboard. All sensors in the Upgrade project use the same ICM for communications through the downhole cables.

2.3.5 Special Devices

The special devices work package is responsible for the coordination and review of in-ice R&D devices developed and contributed as in-kind by members of the IceCube Collaboration. A mission review and conceptual design review for proposed devices was held in May 2020 and 8 types of special devices (56 modules in total) have been fixed in the Upgrade detector geometry (Change Request 17).

2.4 Communications, Power, Timing - WBS 1.4

Communications, power, and timing systems efforts in PY2 were focused on development of the main cables, FieldHub surface readout electronics, and power distribution system.

2.4.1 Penetrator Assemblies

The penetrator cable assemblies are integrated into individual DOMs and calibration devices to carry the power and communications cable through the device's pressure housing. Procurement of the penetrator cable assemblies was completed and production and shipment is underway, with the D-Egg production line at Chiba University prioritized for initial deliveries. The start of penetrator cable production was delayed by slightly over one month due to coronavirus-related disruption of Taiwan-based supply chains for PEEK (polyether ether ketone) and other materials.

Figure 17: Production penetrator cable assembly. The PCA carries the power and communications cable through the pressure vessel surrounding the optical module or other sensor.

2.4.2 Main Downhole Cables and Surface Cables

The main cable supplier for IceCube Gen1, Hexatronic, produced a new design based on subassemblies of bundled high-quality copper twisted quads that could be incorporated into a full downhole cable by a third-party supplier. A short first prototype based on this design was produced by Hexatronic and is now undergoing mechanical and electrical testing in Sweden. Discussions are ongoing with several possible suppliers for cable layup and breakout connector installation with a request for proposals planned for the end of PY2 or early PY3. These discussions have been delayed by coronavirus-related illness of project engineering personnel and disruptions of the operations of cable manufacturers.

Figure 18: Downhole cable prototype ready for electrical testing. The downhole cable connects the optical modules, calibration devices and other devices in the ice to the surface cable at the surface junction box. There is one downhole cable for each hole.

Planning for surface cables and junction boxes is well advanced, pending the results of the GPR survey conducted at Pole in 2019-2020. We are interfacing with ASC regarding the routing and planning for installation of the surface cables in the ICL the season prior to drilling and deployment.

2.4.3 Readout Electronics

A production run of the first development version of the surface readout electronics, the "mini-FieldHubs," was distributed by DESY to collaborating institutions to support software and firmware development and for use in D-Egg DVT and FAT. The software and firmware interfaces between the FieldHub systems and those of the on-board Communications Module (developed by WBS 1.3) and the IceCube software systems (WBS 1.6) were clarified and are being documented in formal interface specifications. Design iterations based on experience with the mini-FieldHubs are being collected for implementation in the production FieldHubs to be deployed at Pole.

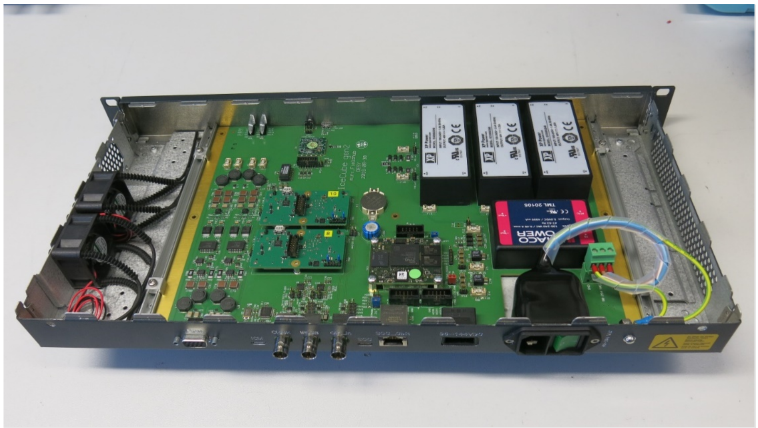


Figure 19: Mini-FieldHub (first version of readout electronics module). Mini-FieldHubs are used to communicate with DOMs and other sensors during sensor design verification testing, final acceptance testing of production sensors, and for software and firmware development. The mini-FieldHub design will evolve into the FieldHubs used to read out the deployed sensors from the ICL.

2.4.4 Power Distribution

Development of the power distribution system is underway, with hardware interfaces to the FieldHubs being specified. Power distribution board prototyping is underway with candidate power supply modules identified.

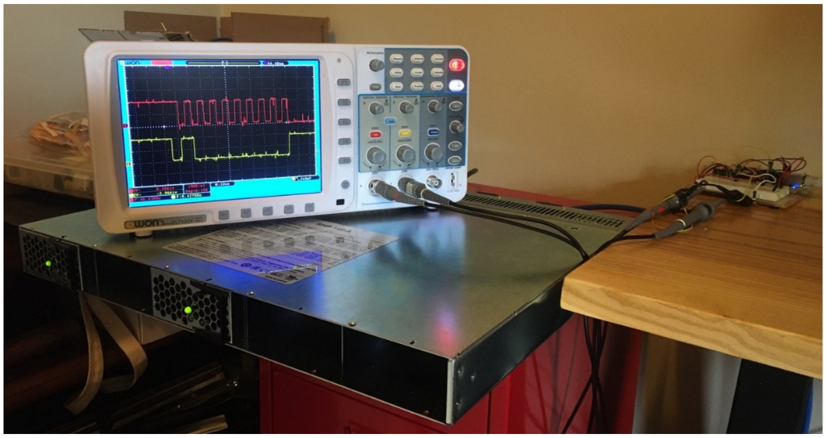


Figure 20: Power distribution system prototyping underway, oscilloscope traces showing the serial communications signals between the power supply modules and the prototype power control and monitoring system.

2.4.5 Northern Test System

Renovations for the Northern Test system were completed and network hardware for the dedicated connection to South Pole Testing System (SPTS) was installed. Installation of DOMs and electronics were delayed due to the D-Egg development timeline and by the coronavirus-related shutdown of the MSU campus, but are planned for the end of PY2.

2.5 Calibration - WBS 1.5

During PY2, we have finalized the mechanical and electrical design of the calibration devices (cameras and LED flashers) which are located onboard the D-Egg. The cameras and LED flashers were successfully integrated into the first batch of D-Egg production (L2 milestone). We have demonstrated control of these devices through the mainboard.

2.5.1 LED Flashers and Cameras

The next stage of LED flasher and camera development will be to finalize integration into the mDOMs which will have their first production batch in PY3. The LED flashers and cameras use the same control software and circuits but will require different opto-mechanical interface. Camera production will be handled by Sungkyunkwan University; the mDOM camera production at SKKU is now fully funded by the National Research Foundation of Korea. Flasher production for the mDOM will be handled by the University of Mainz. Additionally, Mainz has developed a testing rig for the LED flasher boards which is also being ported to the D-Egg flasher board for future production runs. Both cameras and LED flashers have passed initial tests of quality and consistency. Testing of the cameras and LEDs will be part of the FAT testing of the production D-Eggs and mDOMs.

Figure 21: SKKU camera module (rev G) for use in both D-Eggs and mDOMs. The camera is common for both types of modules but a different mounting system is used for each type.

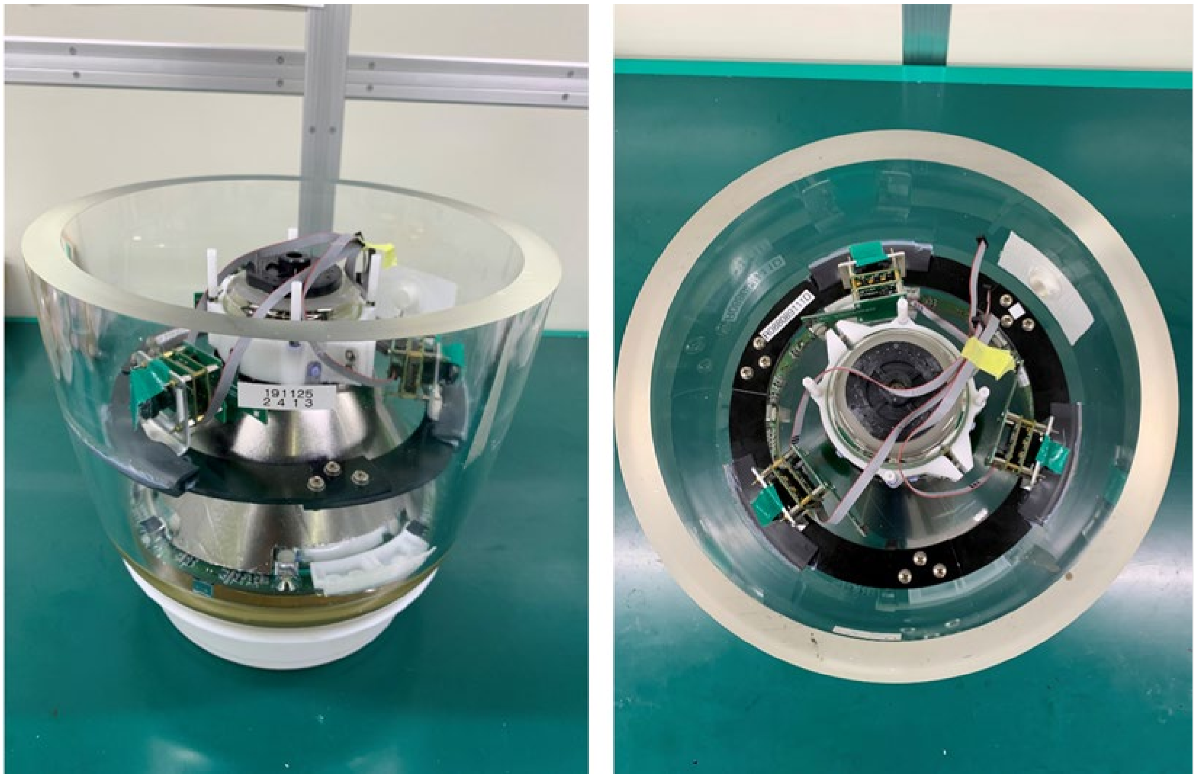


Figure 22: First cameras installed in D-Eggs. Cameras images will be analyzed to understand the hole ice (the refrozen column of water in the drilled hole) detailed absorption and scattering properties. Additional camera measurements will be used to improve understanding of the bulk ice surrounding the hole ice (looking sideways).

2.5.2 *Standalone Calibration Modules*

The standalone calibration modules will be the precision optical calibration module (POCAM) and the PencilBeam and acoustic module transmitter/receiver assembly. An additional standalone calibration device was proposed in PY2, the Swedish camera, which is an updated version of a camera which was deployed in IceCube Gen1 and was very successful in delivering information on the re-frozen hole ice. The POCAM passed preliminary design review in October 2019 (L2 milestone). The acoustic modules are scheduled for preliminary design review in July 2020. The PencilBeam preliminary design review is tentatively planned for fall 2020. In PY2, a common mainboard design was proposed for all standalone calibration devices. This "mini-mainboard" is being designed by RWTH Aachen. A prototype should be available before the end of PY2.

2.5.3 *COVID-19 Impacts*

Worldwide restrictions on in-person work and travel due to COVID-19 have impacted the development of the standalone calibration devices and the mini-mainboard, and have restricted the ability of personnel from SKKU to assist with D-Egg camera integration in Chiba. The most likely impacts to the schedule are inability to ship standalone modules to Pole in 2021. This means that all modules would need to be shipped in 2022, in the same season as deployment, which increases risk that modules would not arrive at Pole in time for deployment.

2.6 Data Systems - WBS 1.6

Within the IceCube Upgrade, WBS area 1.6 is focused on data systems integration, with the overall goal of ensuring that all new optical modules and calibration devices produced and deployed operate as seamless additions to the existing IceCube Neutrino Observatory. This work covers all data systems including the online systems, responsible for system control, triggering, acquisition and processing of data at South Pole; offline systems, including the data processing framework simulation and reconstruction; and the computing infrastructure to host these processes at the Pole and in the north. In PY2 of the Upgrade project, major progress has been made in all areas, from low-level software that resides within the new hardware to advances in simulating and reconstructing events from the planned Upgrade instrumentation.

2.6.1 Online Software

The start of production of D-Egg modules has required a complete testing infrastructure be put together that tests all components and functionality of the D-Egg. This test suite, called the Simple Testing Framework (STF), checks the functionality of all hardware devices, ensures correction operation of hardware and characterizes electronic performance for each D-Egg. A software development test stand, shown in Figure 23, has been assembled at UW Madison to allow remote, concurrent development of software across multiple generations of shared D-Egg hardware, including fully instrumented half-modules in light-tight enclosures.

The STF has clearly defined pass/fail criteria and is run on newly produced mainboards at the electronics manufacture, at multiple stages during D-Egg production, and as a critical component of the Final Acceptance Testing (FAT) that is planned for all modules prior to shipment to Antarctica. To help team members understand the large amount of test data produced, visualization tools based on the IceCube detector monitoring suite IceCube Live, have been created. Example test results from recent mainboard testing on newly produced hardware are shown in Figure 24. FAT testing, planned to start in Fall 2020 for the initial batch of D-Egg modules, will utilize the STF, as well as operating newly produced D-Egg modules in cold (-40C) conditions and collecting key calibration information using well-characterized light sources. Software and visualization tools for FAT results are also nearing maturity ahead of these tests. Additional work over the next year will include extension of these tools to support the mDOM and calibration device mini-mainboard systems.

Seamless integration of these new modules into the IceCube data stream requires they are configured, controlled and read out by the IceCube DAQ. The design work for this version of the IceCube DAQ is well along, based on prototype scintillator hardware deployed at South Pole and D-Egg and mDOM designs. This DAQ will read data from existing IceCube DOMs and Upgrade OMs simultaneously. To support this development effort, the Northern Test System (NTS), shown in Figure 25, will host Upgrade test hardware, seamlessly linked to IceCube test hardware to provide testing infrastructure for DAQ and experiment control development.

2.6.2 Offline and Simulation Software

For the broader software support, work has focused on updating the existing IceCube software analysis framework (IceTray) to support the broad array of new instrumentation. This work involves generalizing the software to support a wide array of multiple-PMT devices compared to the homogenous array of IceCube DOMs. Early work has produced simulated neutrino samples used in design verification tasks and improved reconstruction tools that take advantage of the multiple-PMT nature of the new hardware. On-going software development will include a complete simulation of the as-designed hardware to allow refinement of analysis tools to prepare for Upgrade deployment.

In WBS 1.6, as much of the work focused on software development, the impact of COVID-19 on the project is limited. The previously established remote hardware testing platforms has allowed development to continue remotely. However, delays in arrival of new hardware prototypes and needed communication interfaces has translated in schedule delays in some areas. Work priorities have been shifted from these tasks to other areas, such as software for FAT testing, allowing progress to continue. However, software development and testing tasks will still require time on the schedule once hardware components are available before software packages are ready for general use.

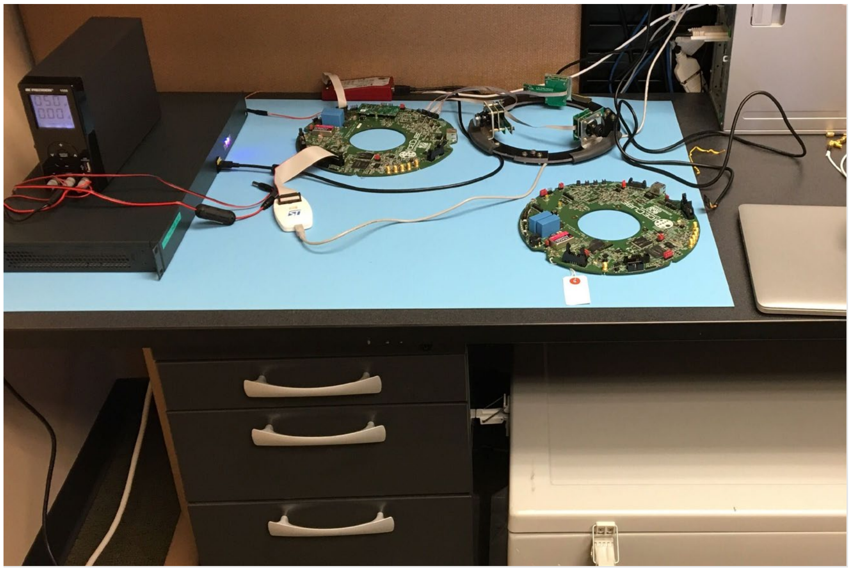


Figure 23: DRTS development test stand located at UW, used for shared, remote development of mainboard-resident and testing software. Several D-Egg mainboards are under test including cameras and LED flashers, as well as a fully instrumented half D-Egg module in the dark box below desk. This setup has been invaluable during the COVID work-at-home period, allowing for remote access to the hardware demonstrator.

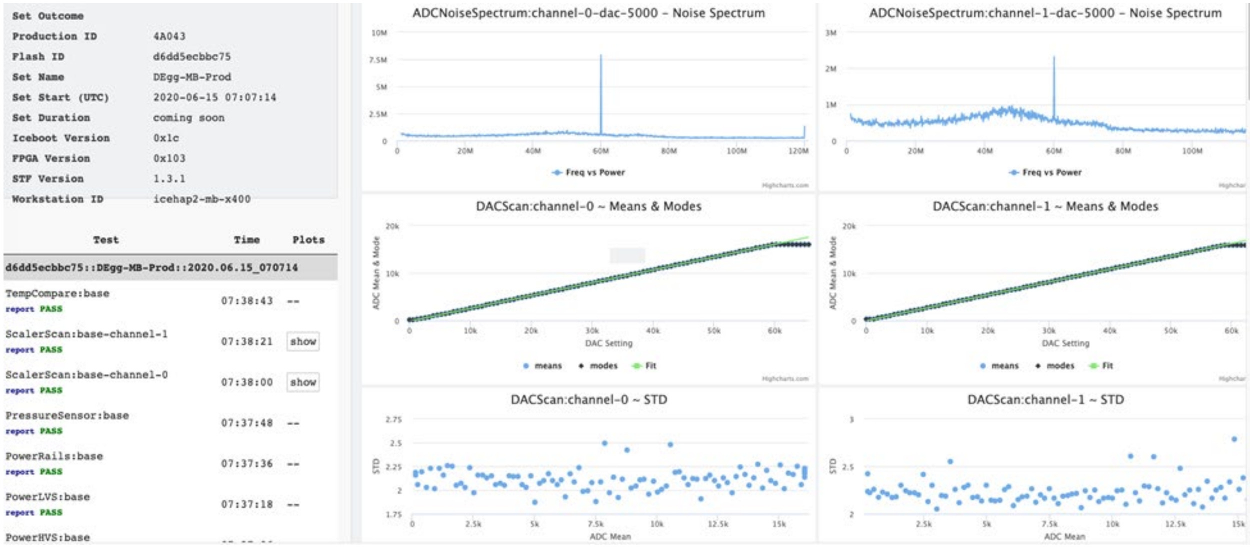


Figure 24: VeriCal visualization interface to STF testing results, showing test results for a new revision of D-Egg mainboard.

Figure 25: Northern Test System (NTS) infrastructure to allow seamless testing between Upgrade testing hardware, located at MSU and the existing IceCube testing hardware located at UW.

3 ***Last Month Achievements***

This annual report also fulfills the requirement for the last monthly report of project year 2, which is June 2020. The table below lists achievements for this month.

WBS 1.1. Project Management
• Level 2 manager for drilling and installation started and integrated seamlessly into project • Developed risk due to COVID-19 and mitigations plans, developed tracking of cost impact to date • Conducted review of and fixed the IceCube Upgrade strings configuration • Developed cargo shipping plan and priority for 2020-2021 season
WBS 1.2. Drilling and Deployment
• Strain reliefs completed and sent to IVG for installation onto production hose • MDCR and RWCR brake hydraulics rebuilt • Completed pressure testing the X, Y, and R drillheads • Rebuilt "black box" controllers for TU10, RWCR, and IFD • First motor drive and DGH orders received • Testbed heater/MHP controls integrated into new control system testing platform • 2020-2021 logistics plan under revision • Bullwheel tensioner rebuilt
WBS 1.3. Sensors
• Development of mDOM Mainboard schematics completed • European-wide tender for mDOM pressure vessels published • Pressure testing to 700 bar as part of the design verification of the mDOM Harness performed • Incoming acceptance testing for 50 D-Egg Mainboards Rev 4a completed • Production of D-Egg Mainboards Rev 4.1 and acceptance testing at the manufacturer started • Change request for higher-elasticity D-Egg optical gel initiated (CR #18) • Additional engineering resources secured for the time-critical ICM firmware development
WBS 1.4. Communication, Power, and Timing
• Mechanical load test of initial main cable prototype completed with satisfactory results • Detailed main cable assembly RFI including statements of work for both main cable fabrication and connectorization issued to potential suppliers in advance of design review and RFP issuance • Firmware / software interface between FieldHub and ICM has been settled and documentation of the interface is in production • First version of the DOM power control board schematics complete, interfaces to FieldHub specified

• Preliminary design of the power supply modules is also complete • NTS remains on hold pending DEgg delivery and MSU campus reopening
WBS 1.5. Calibration
• Flashers: The flasher testing module developed by Mainz for the mDOM flasher boards is being duplicated in Chiba for the D-eggs. Some technical issues with the setup are being resolved over Slack. A JavaScript Object Notion (JSON) data format is being developed in order to load flasher testing results into the common database. • Camera: During testing it was discovered that in very rare cases communication errors can occur during the image data transfer from the camera to the mainboard. Detailed characterization is on-going. The errors are not critical as corrupted data can be repaired offline and individual images can be fully recovered. A new diagnostics function has been added to the camera firmware which will also help streamline error handling during calibration runs. • Mini-mainboard: testing of the first prototype revealed that the power supply layer (1V8, 3V3, 5V) and GND layer of the PCB are missing. A new prototype board might take up to a month to produce. The faulty boards are available as mechanical dummies for integration testing. • POCAM: The POCAM is now fully financed at TU Munich. • Acoustic Modules: The preliminary design review of the Acoustic Modules is set for July 13-14. The review will be held remotely via Zoom due to travel restrictions with COVID-19.
WBS 1.6. Data Systems
• Continued DEgg software development for MB resident software and external software to support DVT testing of mainboards and coming FAT testing • Improved visualization tools for DVT test results • ICM interface and schedule refinement • Simulation design work started for "as designed" simulation samples.

4 Cost Performance and Earned Value Report

4.1 Brief Narrative

The University of Wisconsin–Madison is maintaining two separate accounts with supporting charge numbers for collecting IceCube Upgrade funding and reporting related costs: 1) IceCube Upgrade Core account, 2) IceCube Upgrade Contingency account.

A total amount of $10,436,927 was released to UW–Madison to cover the costs of IceCube Upgrade in PY1 and PY2 (FY2019-FY2020): $9,196,946 was directed to the IceCube Upgrade Core account, and the remaining $1,239,981 was directed to the IceCube Upgrade Contingency account.

Of the PY1-PY2 Core funds, $1,291,976 were committed to the U.S. subawardee institutions based on their statement of work and budget plan. The institutions submit invoices to receive reimbursement against their actual IceCube Upgrade costs on monthly or quarterly basis.

4.2 *Funding Profile*

This table lists the budget profile per the cooperative agreement with funded amount for PY1 and PY2 and projected funding for future years.

Table 1: Project funding profile per cooperative agreement

	PY1 FY19 (Funded)	PY2 FY20 (Funded)	PY3 FY21 (Pending)	PY4 FY22 (Pending)	PY5 FY23 (Pending)
Readiness Preparation & Design Stage					
NSF Approved Budget (R&RA)	$4,066,527				
Allocated Budget (R&RA)	$4,066,527				
Development & Design (Other)					
Total	$4,066,527				
Construction Stage					
NSF Approved PMB Budget		$5,130,419	$3,641,504	$3,604,047	$3,985,016
NSF Approved Contingency Budget	$664,979	$575,002	$362,229	$464,748	$788,853
Total	$664,979	$5,705,421	$4,003,733	$4,068,795	$4,473,869
NSF Allocated PMB Budget		$5,130,419	$3,641,504	$3,604,047	$3,985,016
NSF Allocated Contingency Budget		$575,002	$362,229	$464,748	$788,853
Total		$5,705,421	$4,003,733	$4,068,795	$4,473,869

4.3 *Cost Performance – NSF-Funded*

4.3.1 *Top Level EVM Data Table*

This table compares actual cost and earned value with planned value using Earned Value Management System methodology.

Table 2: Overall project EVMS metrics

EVM Metrics		**$M**	**Description**
EVM Reporting Date		June 2020	Budget and schedule reporting date
Total Project Cost (TPC)		$22,983,324	PMB + approved contingency budget
NSF Funding To-Date		$10,436,927	Cumulative funding received to date
NSF Approved Contingency budget		$2,855,811	Total contingency budget approved
NSF Allocated Contingency to date		$1,239,981	Amount of contingency budget
Budget at Completion (BAC)		$21,206,537	Sum of all budgets established for the work to be performed
Planned Value ($M)		$7,799,262	
Earned Value ($M)		$6,871,009	
Actual Costs ($M)		$7,133,386	
% Complete (Planned)		37.10%	Based on schedule

% Complete (Actual)		32.42%	EV/BAC*100%
% Complete (Spent)		33.64%	AC/BAC*100%
Cost Variance (CV)		-$262,378	EV-AC
Cost Performance Index (CPI)		0.96	EV/AC
Schedule Variance (SV)		-$928,254	EV-PV
Schedule Performance Index (SPI)		0.88	EV/PV
Estimate at Completion (EAC) EAC		$22,016,334	BAC/CPI
Estimate to Complete (ETC) ETC_1		$14,882,948	EAC-AC
ETC_2		$14,073,151	Bottom-up estimate to complete
Date of last ETC_2 update		06-2020	Date of last bottom-up ETC
Contingency balance against NSF Approved Contingency budget		$2,855,811	
Contingency balance against NSF Approved Contingency budget as % of ETC_1		19.1%	
Contingency balance against NSF Allocated Contingency to-date		$1,227,548	
Schedule Contingency (calendar days)		In evaluation	
Monte Carlo simulation confidence level		70%	N/A
PMB completion date		In evaluation	Forecast project end date is uncertain due to cancellation of 2020-21 field season
Award completion date		09/30/2023	As specified in CSA
Risk exposure		$1310K	See Section 5.2.1

4.3.2 ***S Curve Report***

4.3.2.1 ***Stage Timeline of Total Construction Schedule***

This S curve shows data to compare the Actual Cost of Work Performed (ACWP) with the Budgeted Cost of Work Performed (BCWP) up until the present time. Added to this is data for the Budgeted Cost of Work Scheduled (BCWS) extending to the end of the construction phase of the project. BCWP and BCWS are combined into Planned Value (PV) and plotted as one curve. The planned value is plotted as a monthly value for the current and upcoming years and as yearly value for PY4 and PY5 years. The apparent sharp increase in planned values for PY4 to PY5 is merely an artifact of the change of scale along the horizontal time axis, from monthly, for the period of October 2018 to September 2021, to yearly beyond September 2021.

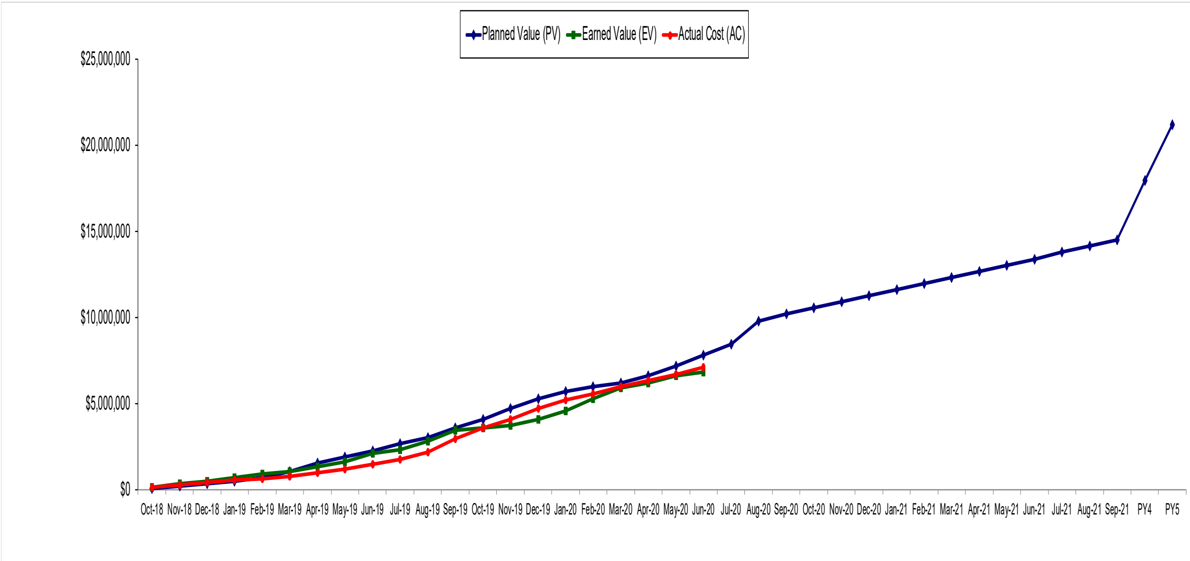
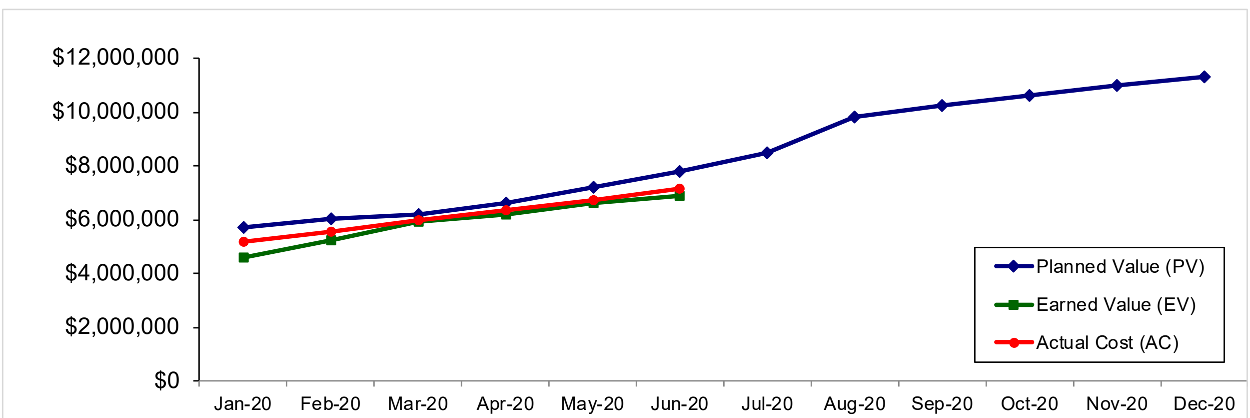


Figure 26: Overall project cost and schedule performance plot

4.3.2.2 Rolling Twelve-Month Window, Centered on Current Month

This S-curve reflects the Upgrade project to date in a twelve-month snapshot centered on the month of the report. The project office performed the process of preliminary detail planning for PY3 based on an average monthly planned value. This planning is expected to change when detail planning of PY 3 is done. Detail planning for PY4 to PY5 are not available at this time.



	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20
Planned Value (PV)	5,696,238	6,031,520	6,206,887	6,615,715	7,192,024	7,799,262	8,477,845	9,797,131	10,258,301	10,610,887	10,963,473	11,316,058
Earned Value (EV)	4,617,411	5,262,338	5,908,530	6,211,074	6,604,296	6,871,009						
Actual Cost (AC)	5,201,217	5,546,560	5,991,988	6,369,062	6,733,105	7,133,386						

Figure 27: 12-monthn rolling cost and schedule performance plot

Table 3: WBS sub-system level EVM table by period and cumulative from October 1, 2018 through June 30, 2020

	WBS Earned Value Variance Report as of June 30, 2020												
	CURRENT PERIOD					CUMULATIVE TO DATE					AT COMPLETION		
WBS L1/L2	PLANNED	EARNED	ACTUAL	SV	CV	PLANNED	EARNED	ACTUAL	SV	CV	BAC	EAC	VAC
1.0	607,239	266,713	400,281	-340,526	-133,569	7,799,262	6,871,009	7,133,386	-928,254	-262,378	21,206,537	22,016,334	-809,797
1.1	111,765	95,730	119,633	-16,035	-23,903	1,715,742	1,854,178	1,950,069	138,436	-95,891	5,983,150	6,292,576	-309,426
1.2	363,258	112,001	191,908	-251,257	-79,907	3,877,694	3,403,957	3,640,028	-473,737	-236,071	10,980,507	11,742,026	-761,519
1.3	47,866	14,744	8,235	-33,122	6,509	775,892	605,812	406,540	-170,080	199,273	1,076,235	722,223	354,011
1.4	51,103	25,730	60,552	-25,372	-34,821	932,093	662,052	685,645	-270,040	-23,592	1,824,841	1,889,870	-65,028
1.5	5,417	5,205	-7,366	-212	12,571	60,278	57,784	112,354	-2,493	-54,570	356,473	693,116	-336,643
1.6	27,830	13,302	27,320	-14,528	-14,018	437,563	287,224	338,751	-150,339	-51,527	985,331	1,162,095	-176,763

4.3.3 SV and CV Trend Graph

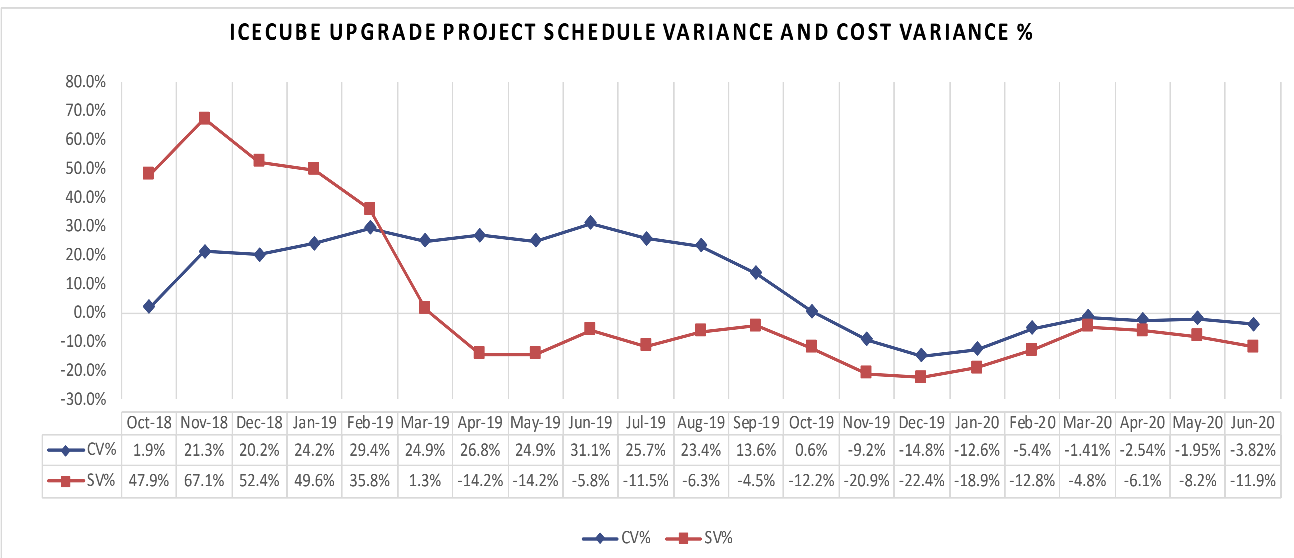


Figure 28: Cost and schedule variance relative to 100% as the target and change per period

Project cost and schedule performance data are shown above as indices.
The project schedule variance and project cost variance show that the project showed an increase in negative schedule variance. This is attributable to COVID-19 impact on the project. (Note that prior to project baseline date of March 2019, the indices are inaccurate because they are based on divisions of relatively small numbers.)

4.4 Discussion of Variance and Corrective Actions at the WBS Level

Earned Value Measurement (EVM) data as of end of June 2020 are presented in the tables and charts above. Actual costs are available from the UW accounting system through the end of May, while June costs are estimated based on planned values and on partial actual values as available.

The EVM is based on the baseline budget plan from March 14, 2019 covering the entire project. The measured Cost Variance (CV) = 0.96 and Schedule Variance (SV) = 0.88 indicates the project work is costing roughly 4% more than the estimated cost of the work completed. The work completed is about 12% less than planned and therefore behind schedule. We have taken steps in PY2 to reverse the downward trend by adding staff to project office and by improving our earned value metrics. The corrective action had resulted in improving performance in PY2 leading up to the onset of work stoppage in delay due to COVID-19 pandemic starting in March of 2020. The CV and SV indices have decreased for the last three months and are likely to continue in this trend in the coming months.

The current estimate to completion is $14.9M based on cost performance index. This value is derived from estimated cost at completion, based on past cost performance, less actual cost. It is higher than the bottom up estimate to complete of $14.1M and is partially due to the negative impact of the COVID-19 pandemic.

5 Risk Management

5.1 Narrative

The IceCube Upgrade Risk Management Plan is a controlled document in the IceCube Upgrade SharePoint document management system. It describes the methodology used in maintaining the Risk Register including quarterly review and derivation of the project contingency from this source. Major risk items, those at or above $1 million, are risks associated with the drilling and installation season in PY5 and include partial or total loss of the season due to injury or other mishap.
Risk identification and treatment is an agenda topic for the weekly L2/CCB meetings and the L2/CCB members review the risk registry quarterly. All risks have been reviewed for Q1 2020. The IceCube Upgrade Risk Registry has been revised, accordingly.

5.2 Project Risk Exposure

The risk exposure of the project represents the effect of uncertainty on the entire project and thus is more than the sum of individual risks on a project. The table below defines the elements which, when summed together, represent the current level of project risk exposure.

Table 4: Project risk exposure

	Value ($k)	Notes
Risk Register Probability Weighted Cost Estimate	$495	The value for this item should not include risks that have a pending Change Request (CR) for contingency budget.
Project Liens List	$815	Pending CRs including cost variances determined to be unrecoverable
Cumulative Cost Variance	$0	Cost Variance that has not been converted to either a risk register entry or an LCR
Project Manager Watch List	$0	Items of concern that have the potential to be converted into risk register entries.
Risk Exposure	$1310	Sum of all entries

5.2.1 ***Risk Change Table (June 2020)***

Table 5: risk change table

New	Risk ID	Risk Title
0		No new risks
Modified	Risk ID	Risk Title
0		No modified risks
Retired	Risk ID	Risk Title
0		No retired risks

Table 6: Risk categorization table

Red & Orange Risks			
WBS Element	Risk Title	Probability Weighted Cost Exposure ($k)	Mitigation
1.1	Crew Deployment Risk ORG8 Red	832.5	Expedite Travel Qualification Procedures, Reduce capacity and scope.
1.1	Season 2021-2022 Installations Risk ORG9 Orange	499.5	Expedite the production and delivery of the surface cables, surface junction boxes, and related fieldwork and work in the ICL. Plan and coordinate as much of the field work as possible during the 2022-2023 season.
1.2.8	Season Delay/Logistics ORG3 Orange	199.8	See 4, 5, 6, 8, and 9 above
1.2.4	Delay in Drill Control Systems Development TECH36 Orange	832.5	Motor drive procurement progress through remote communication. Work on delivery as partial delivery options or expedite. Focus on documentation and developing procedures during the working-at-home period of time. Expedite travel when resumed.
1.6.1.1	DAQ software interface delays TECH37 Orange	499.5	Prioritize remote development efforts. Prioritize remote development efforts, such as FAT software readiness using networked
Yellow Risks ID List			
Risk ID #TECH23, Risk ID #TECH2, Risk ID #ORG4, Risk ID# TECH31, Risk ID #TECH1, Risk ID #ORG #2, Risk ID #PM2, Risk ID #TECH27			

The risks in the yellow/green category are:

1. TECH 23: Fire/Major Equipment Damage
2. TECH 2: Bad Optical Module Glass Sphere/ Excessive Radioactive Material
3. ORG 4: Driller Injury during Drilling
4. TECH 31: Insufficient Communication Cable Bandwidth for Optical Modules (Green)
5. TECH 1: Old Enhanced Hot Water Drill Failure
6. ORG 2: Inexperienced Drillers
7. PM 2: In-kind Financial tracking Issues experienced by Project Management Office
8. TECH 27: Main Supply Hose Reel Failure

Table 7: Project risk heat map table

		Performance Impact				
		Minimal	Low	Medium	High	Very High
		Cost Impact (% of Budget Contingency) Schedule Impact (% of Schedule Contingency)				
		<0.1%	0.1%<1.0%	1.0%<2.0%	2.0%<5.0%	>5.0%
Probability	50%-75%				1	
	25%-50%				4	
	10%-25%		1	7		
	5%-10%					
	<5%					

6 COVID-19 Impact on Project Cost and Schedule

Starting in Mid-March 2020, the ICNO, collaborating institutions, and subawardees, initiated an assessment of technical, cost, and schedule risks associated with the COVID-19 outbreak, including mitigation plans. In addition, organizational plans have been enacted to ensure safety of personnel and protection of property. Nearly all work for the IceCube Upgrade has been conducted remotely. On-site work has been carried out at the Physical Sciences Laboratory as much as allowable in order to advance the drilling equipment. In this section of the report the present status of the project is presented.

6.1 Present Status of Level 1 and Level 2 Milestones

Project milestones and status of near-term project milestones are summarized in the following tables for Level 1 and Level 2. The status of tasks as of February 2020 are shown for completed tasks, or as planned in detailed planning of project year 2. The impact of COVID-19, which resulted in work slow-down starting in March 2020, is shown as of June 2020 to the extent known.

Table 8: IceCube Upgrade project – Level 1 milestones

ID	Milestones	Target Dates	Status Feb 2020	Status June 2020
1	NSF Upgrade readiness review	Mar 2019	Done on time	
1	Deploy drill team (8) for recon and fire/life safety upgrades	Nov 2019	Done on time	
1	D-Egg final design and production readiness review exit	Nov 2019	FDR done Feb 2020 PR in May 2020	PR in October 2020
1	Start of D-Egg production	Dec 2019	Feb 2020 start pre-production	
1	mDOM final design review exit	Apr 2020	July 2020	Delayed due to Covid-19
1	Upgrade string design complete	May 2020	Pending definition	Review done May 2020. CR to be completed June 2020
1	South Pole 2020 shipment complete	Oct 2020		Drill hose may be on time, drill cable reel delayed, drill controls may be on time.
1	Start of mDOM production	Jan 2021	Preproduction start Oct 2020	
1	Standalone calibration devices final design review exit (There is preliminary but no final – 1.5.2.2.1)	Jul 2021		
1	South Pole readiness review	Aug 2021		
1	South Pole 2021 shipment complete	Oct 2021		May be delayed by one year
1	EHWD wet test and commissioning and firn drilling complete	Jan 2022		May be delayed by one year
1	Special devices readiness review	Feb 2022		
1	CPT infrastructure systems commissioned in ICL	Feb 2022		
1	Drill readiness review - PSL	Apr 2022		May be delayed by one year
1	South Pole readiness review	Sep 2022		May be delayed by one year
1	South Pole 2022 shipment complete	Oct 2022		May be delayed by one year
1	Online software ready for deployment in 2022/23 season	Nov 2022 (01/16/23 1.6.1.1.1.9)		
1	SJBs and ICL ready for Upgrade string commissioning	Dec 2022	Will be ready Feb 2022	May be delayed by one year
1	On-Ice drilling readiness assessment and start of drilling (1.2.8.6.6.13)	Dec 2022		May be delayed by one year
1	7 Upgrade strings commissioned (1.2.9.5.3.6)	Jan 2023	March 2023	May be delayed by one year
1	Decommission, retro and store drill equipment (1.2.8.6.9.9)	Feb 2023		May be delayed by one year
1	Upgrade project completion report	Sep 2023		May be delayed by one year

Table 9: IceCube Upgrade project – Level 2 milestones

ID	Milestones	Target Dates	Status Feb 2020	Status June 2020
Project Office				
1.1	Start EV reporting	Mar 2019	Done	
1.1	NSF Upgrade readiness review	Mar 2019	Done	
1.1	Quarterly risk registry update	Mar Jun Sep Dec	Ongoing	
1.1	Instrumentation and online systems pre-ship review	Sep 2021	Was intended for traverse, not needed until Sept 2022	May be delayed by one year
1.1	Upgrade project completion report	Sep 2023		May be delayed by one year
Enhanced Hot-Water Drill				
1.2	Generator 1 overhaul complete	Sep 2019	Done	
1.2	Procure main drill hose	Nov 2019	Ahead of schedule	On schedule
1.2	Deploy drill team (8) for recon and fire/life safety	Nov 2019	Done	
1.2	Procure drill cables (1.2.3.5.9 shipment)	Mar 2020	Start Mar 2020	PO in June/July
1.2	Fuel day tank rebuild complete	Oct 2020		Deferred until next available field season
1.2	Winches and reels complete	Oct 2020		Delayed, ship Oct 2021
1.2	Deploy drill team (8) to start replacement/repairs	Nov 2020		Cancelled/Delayed
1.2	Complete drill head rebuild	Nov 2020		On track
1.2	Deploy drill team (15) for commission, wet test, firn drilling	Nov 2021		
1.2	EHWD wet test and commissioning	Jan 2022		
1.2	Drill all 7 firn holes	Jan 2022		
1.2	Drill readiness review	Apr 2022		
1.2	Deploy drill team (30) for drilling and installation	Nov 2022		
1.2	Drilling start	Dec 2022		May be delayed by one year
1.2	Drilling/installation ends	Jan 2023		May be delayed by one year
1.2	Decommission and store drill	Feb 2023		May be delayed by one year
1.2	Final drill completion report	May 2023		May be delayed by one year
Deep Ice Sensor Modules				
1.3	Ice comms module and DOMs interface defined	Feb 2019	Done on time	
1.3	Decision on mDOM baseline PMT model	Feb 2019	Done April 2019	
1.3	D-Egg production test complete	Feb 2019	March 2019	
1.3	Start of mass production of ice comms modules (NOT a milestone, 1.3.4.12.1)	Oct 2019	Started Nov 2019	

1.3	D-Egg final design review and production readiness review	Nov 2019	See above	
1.3	Start of D-Egg mass production (bundled with 1.3.2.8.6)	Dec 2019	See above	
1.3	mDOM final design review	Apr 2020	See above	
1.3	mDOM production readiness review (1.3.1.9.1.1.4)	Jul 2020		Delayed due to Covid-19
1.3	Start of refurbishment of IceCube DOMs	Aug 2020	Delayed due to reduced number, start Feb 2021	
1.3	Start of mDOM mass production	Jan 2021	See above	
1.3	Special devices mission review	Jan 2021	May 2020	Completed May 2020
1.3	All DOMs ready to ship to Pt. Hueneme (Production ready, 1.3.1.10.1.2.23)	Sep 2021	First 2 strings Sep 2021, next 5 Sep 2022	
1.3	Special devices deployment readiness review	Jan 2022		
Communications Power and Timing				
1.4	Penetrators shipped to DOM assembly facilities (not a milestone, bundled into 1.4.1.3.5)	Sep 2019	Prototypes Dec 2019, Prod. Mar 2020	Shipments ongoing since April 2020
1.4	First-run main cable delivered for evaluation	Dec 2019	Feb 2021 Moved from traverse to airlift	
1.4	NTS dark facility ready for operations	Dec 2019	March 2020	Delayed due to COVID-19, current estimate fall 2020
1.4	FAT driver units (early FieldHubs) for DOM production testing (1.4.3.1.1.5)	Dec 2019	Done on time	
1.4	Main cable assembly production complete	Oct 2020	Sep 2021 Replanned for air shipment	
1.4	Breakout cable assembly production complete	Oct 2021		
1.4	FieldHub final design review	Dec 2021		
1.4	CPT infrastructure systems commissioned in ICL	Feb 2022		
1.4	FieldHub production complete	Oct 2022		
Calibration and Characterization				
1.5	Module production calibration review August 30	Aug 2019	Not done	
1.5	Onboard device PDR, determine scope of non-flasher devices	Apr 2019	Done on time	
1.5	Final design reviews for onboard devices	Sep 2019	Done on time	
1.5	Onboard devices ready for integration into DOMs	Nov 2019	Done Jan 2020	
1.5	Preliminary design reviews for standalone devices (15.2.2.1.2)	Nov 2019	Broken into individual devices, started on Oct 2019	
1.5	Final design review for standalone devices	Jul 2021		

1.5	Standalone devices delivered (shipping to SP)	Sep 2022		
1.5	Delivery of timing, geometry calibration	Mar 2023		
1.5	Array calibration (NOT MILESTONE)	Sep 2023		
Data Systems and M&O Integration				
1.6	Provide design verification simulation samples	Feb 2019	Done on time	
1.6	DAQ/experiment control/OM software interfaces defined	Jun 2019	Done Oct 2019	
1.6	NTS Upgrade computing infrastructure ready	Oct 2019	Done on time	
1.6	Provide software development tool support for Upgrade	Aug 2019	Done on time	
1.6	Minimal DAQ/experiment control ready for OM testing	Oct 2019	Done Jan 2020	
1.6	Testing DAQ/experiment control ready for FAT testing	Jan 2020	May 2020	Planned Aug2020 ahead of D-Egg FAT
1.6	Core software (IceTray) upgraded to support new sensors	Jul 2020	Oct 2020	Still planned for Oct 2020
1.6	Provide full as-designed simulation samples	Jan 2021		
1.6	Online software ready for deployment in 2022/23 season	Nov 2022		
1.6	SPS Upgrade computing infrastructure ready for use	Jan 2023		
1.6	Provide full as-built simulation samples	Jul 2023		

6.2 COVID-19 Related Technical Impact March 2020-June 2020

In this section details of COVID-19 related impact to date are documented and explained by WBS area.

6.2.1 WBS 1.1

Project office functional remotely and cost and schedule impact are minimal

6.2.2 WBS 1.2

6.2.2.1 Drill Control System

3 months behind (as of June 30)
PLC, motor drive, and software testing in the drill testbed at PSL has only been able to progress at a limited rate. This has delayed PLC hardware selection and programming, and evaluation of SCADA user interface options. Delays in retrograde cargo deliveries to PSL have prevented efforts in some key control and electrical subsystem areas, namely heater controls and system cabling. Most of this hardware was supposed to be procured, integrated, and tested in the North and shipped to Pole for installation during the 2020-2021 field season.

6.2.2.2 Main Drill Cable Reel

6 weeks behind (as of June 30)

The reel requires a major mechanical overhaul, and limited on-site access has prevented this hands-on work from beginning. Parts orders for this work are occurring, but at a much slower pace. This delay will push out downstream tasks such as control system integration, winding on the new drill cable, and development/testing of updated hose/cable syncing algorithms. At this stage, May, it is unlikely the main drill cable reel will be able to ship on schedule (end of 2020). Instead it will need to ship from Wisconsin fall of 2021 and will need to be delivered to Pole in that same 2021-2022 season.

6.2.2.3 Main Drill Cable

2 weeks behind (as of mid-May)
Purchasing services suffers from widespread inefficiencies in procurement processes, this has greatly slowed the RFP and procurement of the main drill cable. Retrograde Cargo Delivery - 2 months late (this will have an effect on several downstream activities, as mentioned below) PSL has been unable to receive retro cargo. There are several areas where this has prevented tasks from continuing, including Main Heat Plant plumbing and controls rework, pump evaluation, sensor testing, control system and network box rework and integration.

6.2.2.4 Logistics

Major cargo deliveries are planned for the 2020-2021 field season. COMSUR, VESSEL, SPOT, and C17 and LC130 are all utilized to some extent to move this cargo. Delays in the North in preparing the cargo in time, compounded by potential delays in the logistics chain itself is likely to have downstream consequences in terms of getting all the equipment (and people) to Pole in time for required integration and testing prior to production drilling operations.

6.2.3 WBS 1.3

6.2.3.1 D-Egg

Mainboard testing: This was slowed a fair amount by our testing being homebound. Chiba probably incurred some costs due to this. We may have also spent a month or so of Jim Braun and Perry Sandstrom time that would have been otherwise spent on other efforts.
Mainboard production: There are non-NSF costs incurred by Chiba on expediting, and also on the partial order followed by a separate completion of the order. If we had all hands in the lab, we might have avoided some of this. Additionally, there is now another two-week delay at the board house due to COVID restrictions in Japan. This is not yet pushing on the schedule.
Testing programs: The students and postdocs at Chiba have not been able to work on the test plans. We've been holding internal deadlines for pulling those plans together, so it's likely Erik B. and others may end taking on some of this work.

6.2.3.2 mDOM

Development of the full production schedule has been slowed by vendors which are largely closed down. Not sure of the exact impacts here. The pre-production of the µBase+PMT assemblies for the design verification mDOMs is delayed by currently three months due to problems at Hamamatsu to procure electronics components.

mDOM electronics: On hold right now, probably a month or so lost effort. At home efforts have been focused on the ICM firmware work instead, that was planned later in the schedule. Non-NSF.

6.2.3.3 R&D Sensor Modules

A lot of this work just didn't happen. Not being in the lab is probably close to a 100% reduction in effort since COVID began. These modules are not in the NSF budget. We might need to consider resources for them if the schedules slip on the more important R&D modules such as the LOM.

6.2.4 WBS 1.4

6.2.4.1 Main Cables

Mechanical testing of the initial main cable prototype in Sweden has been delayed by approximately one month due to disruption of supplier production schedules. Final main cable design efforts have been slowed due to unavailability of project and supplier personnel. This delay is reducing the schedule margin and may necessitate air shipment of main cables to Antarctica.

6.2.4.2 Penetrator Cable Assemblies

PCA production was delayed by approximately 4 weeks due to supply chain disruptions. The PCAs required for the initial D-Egg production batch and the prototypes required for mDOM testing are being shipped, and this delay will not have broader impact on the project schedule. Production of mating cables has been delayed due to supply chain disruptions. Cables will not be available for active readout of D-Eggs during DEgg pressure tests. We are working with suppliers to avoid impact on the D-Egg FAT schedule.

6.2.4.3 FieldHubs

Development of FieldHub firmware and driver interfaces has been slowed due to reduced efficiency of personnel working from home. Increased coordination between FieldHub, DOM, and DAQ developers is being instituted to ensure readiness for FAT testing.

6.2.4.4 Power Supply and Distribution System

Development of the power distribution system has been slowed due to reduced efficiency of personnel working from home. This may delay preliminary design review of this subsystem, but is not expected to have broader impacts on the project schedule.

6.2.4.5 Northern Test System

Commissioning of NTS has been delayed due to closure of the MSU campus. This delay has not had a broader impact as DOM, FieldHub, and DAQ software and firmware development is proceeding independently and does not yet require integration testing of the full system.

6.2.5 WBS 1.5

Calibration Modules:
Pencil Beam: Work has been slowed somewhat in this area here at UW. I would say we're probably at 50% efficiency on using Jack Nuckles's time.
Flasher testing: Martin R. has just moved to Mainz and is working from home. He is estimating that he is about 75% efficient. Probably a couple of weeks of lost effort so far on his front. Non-NSF supported.
POCAM; Does not seem to have been affected.

6.2.6 WBS 1.6

Previously established remote hardware testing platforms has allowed D-Egg software development to continue remotely. However, delays in arrival of new prototype hardware and needed communication interfaces and firmware has translated in schedule delays in some areas. Work priorities have been shifted from these tasks to other areas, such as software for FAT testing, allowing progress to continue. However, software development and testing tasks will still require time and effort once hardware components are available before software packages are ready for general use

6.3 Summary of Cost Impact to Date by Period and Cumulative

The impact of the COVID-19 is mainly due to delays in completion of tasks which have been scheduled starting in March of 2020, or were in progress at that time. As schedules task make progress per project plans, the value of the completed portions are added to the total earned value of the project. This is done by the earned value management system (EVMS) which has been in operation since July 2019 and is used by the project office to track project performance.

When tasks are delayed and completion is not per project plans, the earned value will lag behind the planned value which will result in a negative schedule variance. The schedule variance represents tasks, or portions of tasks, for which the project has incurred cost but not earned the associated value. Such tasks will need to be completed at a later time at additional cost. Therefore, negative schedule variance is a good predictor of COVID-19 cost impact.

The following table shows the potential cost impact by period, and the cumulative impact, starting in April of 2020 when we started the COVID-19 cost impact tracking. The impact shown is for the total project at WBS level 1. The tracking is done and analyzed down to WBS level 5 (not reported here for brevity).

Table 10: COVID-19 cost impact per period and cumulative to date

Period	Cost Impact (schedule variance per period)	Cumulative Cost Impact (cumulative schedule variance)
April 2020	-$106,284	-$106,284
May 2020	-$183,087	-$289,371
June 2020	-$340,526	-$629,897

Additionally, the project has incurred direct costs due to work conditions and restrictions. The following table lists the accumulated cost to date.

Table 11: Direct expenses related to COVID-19 induced work conditions

WBS	Cost Incurred	Justification	Notes
1.1.4.1.1	$15,280	Oscilloscope for remote technical work	Need for the oscilloscope to enable remote, in-home work on mainboard integration.
1.2.1	$30,000	Dynamometer for drill testing	Due to delay in access to equipment at the South Pole, this system is needed for testing control system synchronization
Total	$45,280		

6.4 Anticipated Schedule Impact

This section is a listing of schedule impacts foreseen at the time of this report. The principal assumption at this time is that there is a three-month total, or near total, stoppage of technical work, followed by a three-month period of gradual return to normal operations, resulting in a total of a six-month schedule impact.
As operating procedures were developed, IceCube Upgrade project was able to resume operations almost immediately with some restrictions. As a result, technical progress has been very good and nearly on schedule as reported.

However, due to the lack of a field season for IceCube Upgrade in 2020-2021, and delay in procurement and installation of critical components, a one year delay in the project is anticipated at this time. The Upgrade project will review the status at the time of detail planning for PY3, which is scheduled to start on July 1, 2020, and provide a revised project plan on October 1, 2020.

6.4.1 Drill Control System

Description of risk: Unable to procure motor drives on time. Unable to make timely progress with hands-on integration and test activities in the drill testbed; unable to add staff due to travel or hiring restrictions. Delay in development of user interfaces and control algorithms.
Impact: The control system is scheduled to be implemented and tested during 2021-2022 season in order for the drill to be ready for drilling seven holes in 2022-2023 season. This delay will result in all testing postponed to 2022-2023 season, with the possibility that main drilling may not be completed on time.
Mitigation: Motor drive procurement progress through remote communication. Work on delivery as partial delivery options or expedite. Focus on documentation and developing procedures during the working-at-home period of time. Expedite travel when resumed.

6.4.2 ***Crew Deployment***

Description of risk: Inability to deploy full crew to the South Pole for the 2020-2021 field season.
Impact: A large majority of hot water drill repair work is scheduled for the 2020-2021 season. If we are unable to complete this work on time, it may not be ready for full system testing in the 2021-2022 season and for drilling of seven holes in the 2022-2023 season.
Mitigation: Work with ASC to expedite travel and qualification procedures. Work with smaller crew if needed at reduced capacity and scope.

6.4.3 ***ICM Firmware Development***

Description of risk: Working remotely is possible for a short time without access to hardware. Testing and commissioning likely delayed due to limited hardware access.
Impact: A setback will result in delay in testing of production optical modules.
Mitigation: Prioritize remote development efforts.

6.4.4 ***Drill Cable***

Description of risk: Delay in procurement of main drill cable.
Impact: Drill cable likely to miss ship date (on reel) of Nov 2020.
Mitigation: Delay shipment of the main drill cable reel to fall of 2021: put on C17, and ship all the way to the Pole in the 2021-2022 season, rather than shipping by vessel and wintering in McMurdo. This will mitigate drill cable procurement lead time, cable reel refurbishment, control system integration of reel, and weathering considerations.

6.4.5 ***Season 2021-2022 Shipments***

Description of risk: During 2021, several systems are scheduled to be finished and shipped. They will winter-over in 2022 in order to be at the South Pole for a timely start of installation. They include main cables and optical modules for the first two holes. Delays in production will lead to all or some of the above not being ready for shipment in the 2021-2022 season.
Impact: The result will be that all equipment mentioned above must be shipped via air in order to be ready at the South Pole in early 2022-2023 season. Otherwise, full installation may be delayed.
Mitigation: Complete design reviews (remotely) as quickly as possible. Assuming production facilities will be available in fall-winter 2020 (Sweden) and spring-summer 2021 (US), this can succeed.

6.4.6 ***Season 2021-2022 Installations***

Description of risk: During 2021-2022, several systems are scheduled to be installed in preparation for 2022-2023 main installation season. They include surface cables, surface junction boxes, and related fieldwork and work in the IceCube Lab. Delays in production or shipping will lead to some or all of the above not being ready for installation on time.
Impact: The result will be that some or all above equipment must be installed on site in early 2022-2023 season, putting pressure on the final installation season.

Mitigation: Expedite production and delivery of above items. Plan and conduct as much field work as possible during the 2021-2022 season.

6.4.7 DOM and Cable Delivery for 2022-2023 Season

Description of risk: Delivery of DOMS and cables for 2022-2023 deployment is delayed.
Impact: The 2022-2023 season is the main drilling and installation season. Cables and DOMs for five strings are scheduled to be completed and shipped in order to be ready for installation. Delay in shipment may result in the project not being finished on schedule at the end of the 2022-2023 season.
Mitigation: The main cables and DOMs have sufficient float in the schedule to absorb a six-month delay. Continue on the present pace with D-Egg and mDOM activities at production sites. Continue with main cable engineering tasks during the work stoppage in order to ensure timely main cable production.

6.4.8 Calibration and Special Devices

Description of risk: The standalone calibration and special devices are scheduled to be all ready at the South Pole for the 2022-2023 installation season.
Impact: Delay in on-time delivery may result in some of the calibration and special devices not being ready for installation. This will result in reduced calibration capability of the IceCube Upgrade project or a reduction in the R&D efforts.
Mitigation: Finalize documentation and firmware work as much as possible. Finalize design of prototype boards. Hardware design work can continue remotely for several weeks, including set up of orders for components. Mitigate effect of delays by working on design aspects that were originally planned for after the prototypes.

6.4.9 DOM Software Development

Description of risk: Lack of access to hardware may result in delay in software development.
Impact: Any development work that requires hands-on access to hardware may be delayed until physical access is allowed, including testing new mDOM hardware and ICM firmware images.
Mitigation: Prioritize remote development efforts, such as FAT software readiness using networked mainboards.

7 Safety

There were zero OSHA Reportable and Lost Time Injuries at Pole during October 2019 through June 2020 period.

A Test Bed Hazards Analysis has been completed at PSL, in April. Mitigation plans have been conceived for any uncovered hazards as necessary. Safe operations must be kept on everyone's minds.

PSL is in limited operation mode due to COVID-19. The activities at the Test Bed are limited to those that can be done with two people. They are working at recommended separation distance and in accordance with institutional guidelines.

Draft Electrical Hazards Training Presentation is available and will be used to teach electrical hazards and their mitigations to all IceCube staff who that work at PSL. We will customize this training to our own applications. The training includes Lock-Out/Tag-Out and Arc Flash Training.

Supplementing project electrical training program, the latest versions of the NFPA 70E standard, along with the NFPA 70E Handbook will be incorporated.

Even though the IceCube Upgrade personnel will not be deploying to Pole this season, most of applicable safety training will be conducted this summer. The Training will include: SafeStart; Ladder Safety; Fall Protection, Electrical Safety; Rigging Training; some form of First Aid/CPR/AED training, and possibly other training.

Seasonal Debrief and Lessons Learned Meetings took place in February. The valuable lessons learned will contribute to this season's Driller and Installer Safety Training this summer.

ASC and the IceCube Upgrade Project are working with the NSF in establishing an IceCube Upgrade EHWD Fire Safety Plan. This plan establishes a methodology for fighting and preventing fires at the drill camp without any automatic fire suppression system. A draft of the plan has been reviewed by ASC, the IceCube Upgrade Project, and by the NSF. Comments are now being considered with the plan being revised accordingly. This plan has the scope of the IceCube Upgrade Project only. Currently, all CO_2 Fire Suppression systems have been deactivated in all MDS structures at the IceCube Upgrade Drill Camp.

8 Quality Assurance and Change Control

Issue Trackers have been established for the Tech Board and the L2/CCB Calls. Issues will be defined, assigned, and resolved with follow-up during each call. This process continues.

The IceCube Upgrade Automated Change Request Approval Process was completed in April, 2020. Its use by the Upgrade Project continues.

Work has begun in developing a Non-Conforming Material Program for the IceCube Upgrade. This program will track any production/ field failures in OM components or supporting equipment. A pilot program has started at the Test Bed at PSL.

During project year 2, eleven change requests as listed below were approved by the CCB (Change Control Board) and enacted.

Table 12: Project year two change log

ID	Title	Initiator	Approvals	Notes
CR8	Upgrade Project Salary Allocation	Feyzi	Submitted and approved by NSF	Assign staff cost to contingency funds due to increased effort in project management, technical coordination, safety and system engineering as a result of PY2 detail planning. Assign travel cost for project office personnel for project reviews to contingency funds.
CR2	IDF Removal	Kelley	Complete	Remove IDF, cables route into ICL
CR9	Contingency from PY2 will be used to	Feyzi	Complete	The main reason for the shortfall is the larger expected cost of the holding

	make up funding shortfall at SKKUensure continuity of funding for camera production for D-egg mass production batch 1 and mDOM DVT			structures. It should be noted that the holding structures are still under discussion to try and find better or cheaper options. The cost of mDOM DVT and D-egg mass production batch 1 is $32,199 (USD) and the current Korean funding period is funded for $22,000, with a shortfall of $10,200. Therefore $10,200 is requested from contingency for PY2.
CR10	CMS "Penetrator Cable Assembly" documents for a second PCA type added	DeYoung	Complete	Due to varying schedule and internal space constraints, the Penetrator Cable Assemblies (PCAs) used for DEgg-type DOMs will feature different internal cables and main-board connectors than the PCAs used for mDOM and pDOM-type DOMs. Funds are required for engineering and to purchase prototypes for a second type of PCA. Additional activities are added to the schedule at WBS 1.4.1.3.3. The schedule of previously planned activities is not affected.
CR11	Additional Engineering effort for Main Cable.	DeYoung	Submitted and approved by NSF	Original IceCube main cable supplier no longer has capability of producing fully assembled main cables (only subcomponents), so a second level cable assembly partner is required. Relocation of surface electronics to ICL and addition of surface cables and surface junction boxes necessitates additional engineering effort for design and procurement.
CR12	Additional software development effort for embedded micro-controller programming	Blaufuss	Submitted and approved by NSF	Need additional software development effort for embedded micro-controller programming to support D-Egg, mDOM, pDOM and mini-mainboard applications in the IceCube Upgrade effort Added additional manpower in the 1.6 development effort, as the effort needed to develop the embedded software was greater than the M&O manpower available are able to provide. A dedicated embedded programmer with expertise in this area has been identified

				and hired to provide needed software development effort.
CR13	Risk retirement, contingency increase. At the time of PY2 detail planning and project review, cost estimates for PY2 were done with better accuracy. In addition costs for PY1 are known, and is less than the budgeted amount. Therefore, surplus amount from PY1 is transferred to contingency and cost uncertainty risks for PY2 are reduced.	Feyzi	Complete	Retire non capital cost uncertainty risk for PY2. Risk reduction $597,420. Retire cost uncertainty risk for capital purchases of drill hose (PM9) and movers (PM14) form PY2 because they were purchased in PY1 and actual costs are known. Risk reduction $195,918. Total risk retirement with this CR is $793,338.
CR14	Add WBS item to reflect consolidation of electronics development for standalone calibration devices	Williams	Complete	All standalone calibration devices (including 1.5.2.2.1 POCAM, 1.5.2.2.2 PencilBeam and 1.5.2.4 Acoustic Sensors are required to communicate through the Ice Comms Module, as are all photosensors. We have consolidated effort to create one common “mini-mainboard” for standalone calibration devices, which performs the same interface and control functions as the mainboards for the photosensors, but without unnecessary items such as digitizing electronics. The mini-mainboard has the following functionality: • Provide Power for ICM and host system • Provide MCU for control of host system • Provide signal and power interface to host system • Provide interface to penetrator This change will retire risk associated with multiple design efforts for the same required functionality.

				Retire WBS 1.5.2.6 Muon Tagger that is not needed to reach Upgrade project objectives. Cost is zero, all effort is in-kind.
CR15	Administrative changes were made to the WBS Dictionary.	Feyzi	Accepted by the NSF	Reference CR#15 for all of the details.
CR16R	Purchase and oscilloscope cope for remote COVID-19 related work	Meures	Reviewed by the NSF	$15,280 taken from Project Engineering Funds for COVID-19 related purchase.
CR17	IceCube Upgrade String Design Complete	DuVernois	In-Process	The IceCube Upgrade Strings Design is finalized. The CMD (Configuration Management Document) is going through final approval.
CR18	D-Egg Gel formulation change	Ishihara	Sent to NSF as requested	The IceCube Upgrade Project made a process change to incude a superiorly performing gel in the assembly of the D-Eggs.

9 ***Environmental Evaluation***

The NSF has signed the IEE (Initial Environmental Evaluation), submitted by the ASC Contractor to the NSF for review in November, as of 11/26/19. As part of the evaluation, the IceCube Upgrade project is required to submit additional detail regarding the Retrograde Plan prior to the end of the project.