IceCube Upgrade Project
Project Year 1 Annual Report

October 1, 2018 – September 30, 2019

Submittal Date: October 23, 2019

This report is submitted in accordance with the reporting requirements set forth in the IceCube Upgrade Project Cooperative Agreement 161202122

Foreword

This Project Year 1 Annual Report is submitted under Cooperative Agreement Number: 161202122 and award number 1719277. This report covers the twelve-month period beginning October 1, 2018, and concluding September 30, 2019. Cost performance information is based on available data through September 30, 2019. Some of the actual costs in the latter part of September are based on information not fully verified and are therefore estimated actuals.

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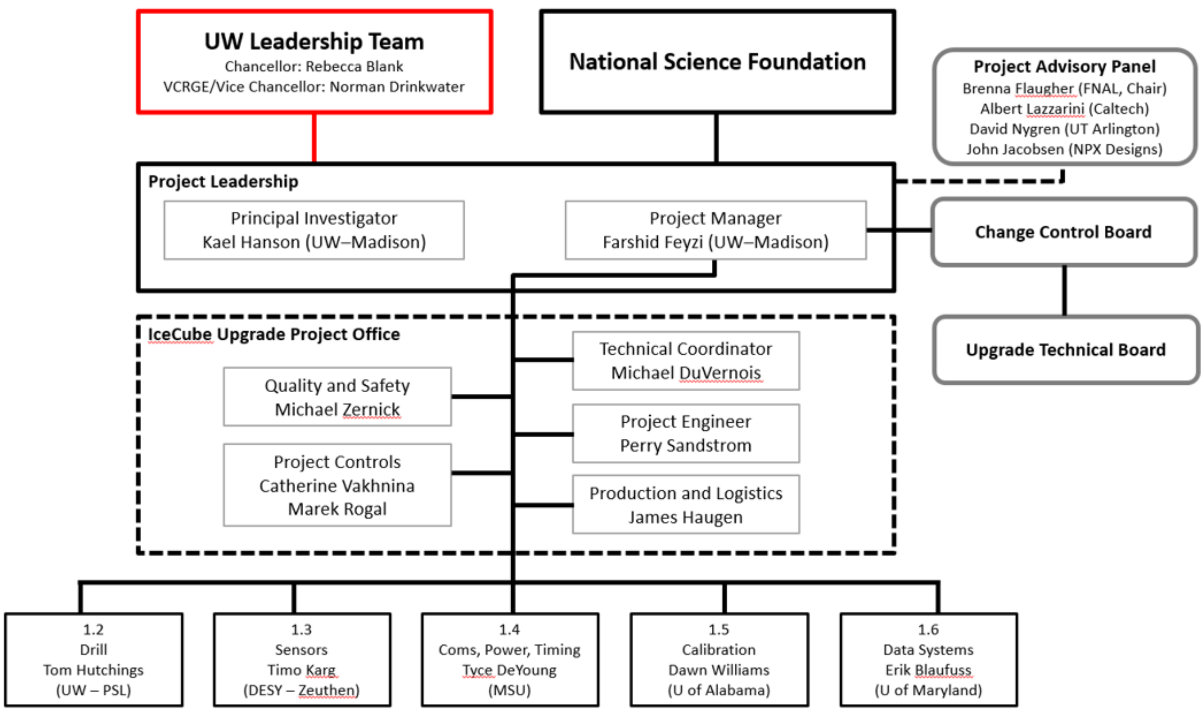
1. ***Summary of Accomplishments***

The following sections list the accomplishments in project year 1 organized by WBS item. The project made significant progress in technical and management areas in PY1. In the technical areas, project definition advanced to the level necessary for final design of items to proceed on schedule. As a result, long-lead procurement items, such as the drill hose and photomultiplier tubes, commenced on or ahead of schedule. The project office also advanced to the level necessary for project management and tracking as required by the cooperative agreement.

1.1. ***Project Management - WBS 1.1***

1.1.1. ***Organization***

Project organization was established with the hiring of a full-time project manager and project controls specialist. Level 2 management, technical coordination, safety and quality, system engineering, and production and logistics remain the same. Technical board and change control board memberships are also unchanged from last review.



1.1.2. ***Milestones***

Project year 1 milestones and status of near-term project year 2 milestones are summarized in the following table. The status of tasks marked as re-planned results from detailed planning of project year 2.

ID	Level 1 Milestones	Completion Date	Status	WBS
1	NSF Upgrade Readiness Review	Mar 2019	**Completed**	1.1.2.4.1.1
1	Deploy Drill Team (8) for Recon and Fire/Life Safety Upgrades	Nov 2019	**In progress**	1.2.8.3.2
1	D-Egg Final Design and Production Readiness Review exit	Nov 2019	**In progress**	1.3.2.9/ 1.3.2.7.5
1	Start of D-Egg Production	Dec 2019	**In progress**	1.3.2.9.1.2

ID	Level 2 Milestones	Completion Dates	Status	WBS
	Project Office			
1.1	Start EV Reporting	Mar 2019	**Completed**	1.1.2.1.2.6
1.1	NSF Upgrade Readiness Review	Mar 2019	**Completed**	1.1.2.4.1.1
1.1	Quarterly Risk Registry Update	Mar Jun Sep Dec	**In progress**	1.1.3.1/ 1.1.4.3
1.1	Instrumentation and Online Systems Pre-Ship Review	Sep 2021	**In progress**	1.1.2.4.2
	Enhanced Hot Water Drill			
1.2	Generator 1 Overhaul	Sep 2019	**Completed**	1.2.5.1.4
1.2	Procure Main Drill Hose	Nov 2019	**In progress**	1.2.3.4.4
1.2	Deploy Drill Team (8) for Recon and Fire/Life Safety	Nov 2019	**In progress**	1.2.8.3.2
	Deep Ice Sensor Modules			
1.3	Ice Comms Module and DOMs Interface Defined	Feb 2019	**Completed**	1.3.4.1
1.3	Decision on mDOM Baseline PMT Model	Feb 2019	**Completed**	1.3.1.2.2.3
1.3	D-Egg Production Test Complete	Feb 2019	**Completed**	1.3.2.1.1.2
1.3	Start of Mass Production of Ice Comms Modules	Oct 2019		1.3.4.12.1
1.3	D-Egg Final Design Review + Production Readiness Review DVT	Nov 2019	**Re-planned**	1.3.2.7.6
1.3	Start of D-Egg Mass Production	Dec 2019	**Re-planned**	1.3.2.9.1.2
	Communications, Power, and Timing			
1.4	~~IDF Requirements Defined (Final)~~ ***per CR 2***	~~Aug 2019~~	**Cancelled**	~~1.4.2.1.2~~
1.4	Penetrators Shipped to DOM Assembly Facilities	Sep 2019		1.4.1.3.5
1.4	First-run Main Cable Delivered for Evaluation	Dec 2019	**Re-planned**	1.4.1.1.3.2.2
1.4	NTS Dark Facility Ready for Operations	Dec 2019	**In progress**	1.4.5.3.3
1.4	FAT Driver Units (early FieldHubs) for DOM Production Testing	Dec 2019	**In progress**	1.4.3.1.1.5
	Calibration and Characterization			
1.5	Onboard Device PDR, Determine Scope of non-Flasher Devices	Apr 2019	**Completed**	1.5.2.1.2.4
1.5	Module Production Calibration Review	Aug 2019	**Re-planned**	1.5.1.1.5

ID	Level 2 Milestones	Completion Dates	Status	WBS
1.5	Final Design Reviews for Onboard Devices	Sep 2019	**Completed**	1.5.2.1.4
1.5	FDR Camera and Light	Sep 2019	**Completed**	1.5.2.3.7
1.5	Onboard Devices Ready for Integration into DOMs (Camera + Light)	Nov 2019	**In progress**	1.5.2.3.9
1.5	Preliminary Design Reviews for Standalone Devices (PDR)	Nov 2019	**Re-planned**	1.5.2.2.1.2
	Data Systems and M&O Integration			
1.6	Provide Design Verification Simulation Samples	Feb 2019	**Completed**	1.6.3.3.2
	DAQ/Experiment Control/OM Software Interfaces Defined (DAQ)	Jun 2019	**Completed**	1.6.1.1.1.2

1.1.3. Earned Value Management System (EVMS)

During project year 1, an earned value management system was established at the detail level. All level 2 managers can update status monthly in an interactive environment. Earned value, planned value, and actual cost are tracked by the project office and reported on a monthly basis. The system has been operational in this form since June 2019.

1.1.4. 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 tech board call discussions and presentations, and the technical review process. The baseline library and the technical board have been developed from scratch during PY1. Technical reviews began very early in PY1 (as the optical module designs had a history 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.

1.1.5. 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.

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" 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
- 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.
- 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.

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.

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.

1.1.6. 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 PY1 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.

1.1.6.1. D-Egg Mechanical Review

To support the need for long-term procurement of large-diameter high-quantum-efficiency photomultiplier tubes, deep-ocean glass pressure vessels of high UV optical transparency, and optical gel, an early D-Egg mechanical PDR was held at the start of PY1. The successful review authorized the long-lead procurements.

1.1.6.2. ***D-Egg DAQ Electronics Review***

There was a teleconference on the preliminary design review of the D-Egg DAQ electronics in June 2019, with a final design review expected in early PY2. The D-Egg mainboard is in revision 2 testing with a revision 3 expected to be ordered soon. Results have been encouraging.

1.1.6.3. ***D-Egg High Voltage Subsystem Review***

Also, in D-Egg electronics, there have been a couple of smaller, informal reviews of progress on the high-voltage subsystem for the D-Egg. This subsystem has evolved significantly and is now close to a final design review, expected in early PY2.

1.1.6.4. ***mDOM Mechanical Review***

In December 2018, we convened a preliminary design review of the mDOM mechanicals (including the gel, glass, mechanical mounting structures, and associated testing) to understand how these quite complicated modules will be integrated and how the calibration devices will be installed in the optical modules. A final mDOM design review is expected in the summer of 2020, combining both the mechanical and electronic parts.

1.1.6.5. ***mDOM DAQ Electronics Review***

A preliminary design review of the mDOM DAQ electronics was conducted in August 2019 (combined with preliminary reviews of the high-voltage and ice communications subsystems) to check on electronics developments for the mDOM at DESY. This development has a somewhat more flexible schedule than the corresponding D-Egg parts, but it will rely on the D-Egg design verification processes as well. Progress is good, and the review has started new discussions on parts reliability requirements, which will be applied across in-ice electronics boards.

1.1.6.6. ***mDOM High Voltage Subsystem Review***

The mDOM has 24 separate high-voltage boards, and we held a preliminary design review looking at this hardware design with an eye towards EMI compatibility and noise immunity. There is an active test program and an expected new hardware revision of the board coming soon.

1.1.6.7. ***Ice Communications Module Review***

The ice communications module will be used in all of the in-ice modules (mDOMs, D-Eggs, and calibration devices) as part of our requirement that all hardware in the ice speaks a common "language." This module was designed at DESY and is based on similar communications hardware used in the Gen1 IceCube but with a flexible board-level interface. Firmware for this board is nearly complete and will be assessed soon with the integrated design verification of D-Eggs.

1.1.6.8. ***In-Ice Optical-Module Calibration Devices Review***

We have held preliminary (May 2019) and final (September 2019) design reviews for the calibration subsystems that reside within the in-ice optical modules. This hardware needs to be finalized early to allow for sensible integration into the optical modules. The devices reviewed included the magnetometer, pressure sensor, tilt sensor, temperature monitoring suite for slow control, and the flashers, cameras, and acoustic positioners. The acoustics were removed from the optical modules to reduce integration risk in light of their limited scientific scope.

1.2. Drilling and Deployment - WBS 1.2

1.2.1. Activities Northside

A significant effort was initiated in the WBS 1.2 drilling and deployment area during PY1. Thorough review and inspections have begun for several major components of the EHWD, with repair and upgrade plans developed and launched. Project support, logistics, activities and requirements, along with population plans were developed and coordinated with the Antarctic Support Contractor (ASC).

- Seasonal on-ice activities and support plans for PY2 have been developed in coordination with ASC; EHWD repair, inventory, and testing activities and related logistics plans are in place; on-ice team safety and technical training occurred in August.
- The independent firn drill has been thoroughly tested and repaired, and the main system will ship in October 2019; the “drill carrot” will remain to continue testing and repair at PSL.
- One of three power generators has been completely overhauled, tested, and accepted in CONUS; a plan has been developed for a small team with subcontractors to deploy to McMurdo to repair the power distribution module and test/tune generators 2 and 3.
- The drill control system has been evaluated and a plan is developing that delineates and defines where legacy systems remain and new/replacement components are to be integrated. A design review is scheduled for early November. Replacement subsystems are being tested at PSL with positive results.
- Replacement motor drives and programmable logic controllers (PLCs) have been successfully tested for compatibility and system simplification; field integration and testing on-ice will begin this season.
- The main drill replacement hose is being procured; historical specifications were reviewed and updated; a statement of work was developed; a vendor site visit and negotiations with the original manufacturer (IVG) occurred in July/August; fabrication is to begin in October 2019. Hose strain-relief design has been reviewed, material procurement has begun, and fabrication will commence in November 2019.
- The PSL test-bed facility was recommissioned for subcomponent testing (control systems, pumps, heater, sensors, and safety) and new driller training and familiarization.
- Initial inspection and testing of a drill head was completed with positive results; sensors and telemetry instrument testing has begun.

1.2.2. South Pole Field Season

A team of two driller/engineers deployed to the South Pole for approximately three weeks during the 2018/19 season. They were joined by two (Gen1) driller/leads for two weeks. The team assisted with the excavation of the enhanced hot water drill (EHWD) equipment, accomplished a bulk-level inventory of the major components, performed a high-level inspection of the components for obvious damage or missing equipment, removed and retrograded damaged or suspect components, and photographed and documented components.

2018/2019 Season Performance – Planned vs. Actual

Performance Indicator	Planned	Actual
Season Start	Nov 20, 2018	Nov 20, 2018
Season End	Dec 14, 2018	Dec 14, 2018
On-Ice Person-Days (effective)	38	58*
Tasks Performed:		
Assisted the excavation of the EHWD equipment		
Performed bulk-level inventory of major components (towers, MDS modules, reels, spares, pumps, etc.)		
Performed high-level inspection for damage, missing components, cold and storage effects		
Preliminary collection and retrograde of damaged or suspect components		
Photographed and documented, as allowable, component specs and model numbers		
*20 person days were contributed from UNL-SALSA personnel (previous IceCube drill leads)		

1.3. Sensors - WBS 1.3

mDOM: During PY1, the multi-PMT digital optical module transitioned from the preliminary design phase to the final design phase. In February 2019, the planned number of mDOMs was increased from 360 to 430 while at the same time reducing the number of PDOMs as additional funding from the Karlsruhe Institute of Technology (KIT) became available.

A trade study was completed that allowed selecting the optimal readout system for the mDOM: a 100-MSPS ADC for each PMT complemented by nanosecond-precision time-stamping of the leading-edge time. A total of 150 PMTs from two different manufacturers (Hamamatsu and HZC Photonics) were characterized for vendor qualification, and final PMT specifications have been submitted and discussed with PMT vendors. In December 2018, a preliminary design review of the mDOM PMT, optical gel, PMT support structure, and pressure vessel was conducted in Münster, Germany. Initial mechanical prototype modules have been built and cold-tested, revealing issues with different thermal expansion coefficients of subcomponents for which alternative solutions have been developed. Prototype test boards have been developed, built, and characterized for the high-voltage PMT bases, the analog front-end electronics, and the digital electronics of the mDOM. A test of the full data acquisition chain of PMT, PMT base, analog front-end, ADC, and separate precision time-stamping has been performed successfully. In August 2019, a preliminary design review of the mDOM PMT high-voltage base and data acquisition electronics was conducted in Zeuthen, Germany.

D-Egg: The D-Egg development is driven by the Japanese funding schedule, requiring production and testing of the first batch of 100 D-Egg sensors by March 2020. A design review of the D-Egg was carried out in Chiba, Japan, in September 2018, allowing for purchases of PMTs, glass pressure housings, and optical gel. Vibration and mechanical shock tests for preliminary integrated D-Egg sensors have been conducted successfully. The D-Egg assembly facility at Nippon Marine Enterprises, Ltd. has been commissioned and initial prototype modules have been produced. Prototype boards for the D-Egg mainboard and high-voltage system have been developed, built, and tested and a preliminary design review of these subsystems has been conducted. Final designs of the magnetic shielding and the high-voltage system have been presented and positively reviewed.

PDOM: The PDOM is an IceCube Gen1 DOM refurbished with new readout electronics and a new high-voltage subsystem. After additional mDOM funding from KIT became available, a change request was approved to reduce the number of PDOMs to be deployed from 116 to 14. While this reduces the complexity of the IceCube Upgrade detector from three to only two major types of optical sensors, it still allows using PDOMs to cross-calibrate IceCube Gen1 with the IceCube Upgrade detector. A unified design of the PDOM and D-Egg mainboards was developed. Both items are identical on the schematics level, which allows sharing of parts selection, firmware, and software.

Ice Communications Module: The ice communications module (ICM) is the unified communications and timing module used by all in-ice sensors and calibration devices. With many other systems depending on it, its interfaces were defined and validated in December 2018. A design review of the ICM was conducted in August 2019. The first 15 prototype ICMs have been built, commissioned, and delivered to the developers of optical modules and in-ice standalone calibration devices.

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 call has been issued to identify potential contributed devices and clarify their scope and requirements. A selection of devices and the start of their development is planned for May 2020.

1.4. __Communications, Power, Timing - WBS 1.4__

The primary PY1 activities related to communications, power, and timing focused on the main cables, penetrator cable assemblies, and FieldHubs (surface readout electronics).

In discussion with ASC and NSF, it was determined that the main cables should be transported by airlift rather than overland traverse, and the schedule was realigned to this plan. Design discussions are underway with the two main cable suppliers for Gen1, Hexatronic (formerly Ericsson) and JDR, as well as two other possible suppliers. Hexatronic has developed a new design tailored to their current production capabilities, and a prototype of the key subsystem has been produced for technical evaluation.

After review by ASC and NSF, it was determined that the initial plan to house IceCube Upgrade electronics in an intermediate distribution facility on the surface was not feasible. An alternative to connect the downhole cables directly to the ICL via separate surface cables was implemented via a change request 2. Preliminary plans for the surface cables were developed, pending reconnaissance and GPR survey at the Pole in the 2019/20 season.

Designs for penetrator cable assemblies were completed in coordination with the DOM electronics group (WBS 1.3). Prototypes were ordered from three potential vendors and will be used in D-Egg design verification testing (DVT). A draft request for proposals has been written and will be issued for competitive bidding early in PY2.

PY1 FieldHub development activities focused on the "mini-FieldHub," a first working version with core functionality suitable for use in DOM DVT and production testing (FAT). The mini-FieldHub will also provide a platform for firmware and software development and integration with both DOM systems and the IceCube DAQ. Mini-FieldHub production is underway, with the first versions produced in PY1 and additional units for distribution to collaboration institutions in the first weeks of PY2.

Other WBS 1.4 activities completed in PY1 include renovation of space for the northern test system integration facility at MSU, procurement of the first GPS clock timing distribution systems, and development of a prototype smart power distribution hub for the Upgrade strings in the ICL.

1.5. Calibration - WBS 1.5

During PY1, we have focused on the scope and design of calibration devices that are co-located with photosensors (mDOMs and D-Eggs), called onboard devices. To that end, we achieved the L2 milestones of a preliminary onboard device review in April 2019 and a final onboard device review in September 2019, both coinciding with IceCube Collaboration meetings. The onboard device scope was finalized at 12 LED flashers and three cameras per D-Egg and 10 LED flashers plus three cameras per mDOM. Additionally, the mainboards of both mDOMs and D-Eggs will host accelerometers, magnetometers, and pressure and temperature sensors.

Photosensors within a given category will host an identical complement of devices. All LED flashers use the same type of LED and a common circuit, which was finalized in August 2019. Mechanical integration of the LEDs uses a ring structure in the D-Egg and postage stamp PCBs mounted to the PMT support structure in the mDOM. Preliminary software and firmware for the LEDs has been written. The camera system will use off-the-shelf components and a dedicated illumination board. Mechanical integration models for the camera have been chosen for the D-Egg and mDOM. Software for the camera is in progress.

The standalone calibration modules will be the precision optical calibration module (POCAM) and the PencilBeam and acoustic sensor/receiver assembly. These devices will have their initial reviews in October (POCAM) and January (PencilBeam and acoustic assembly). The purpose of the POCAM is to provide a uniform (isotropic) illumination source, and the purpose of the PencilBeam is to provide a directed and collimated multiwavelength light source. These devices will be able to add calibration information which cannot be obtained with the onboard LED flashers.

A draft plan for lab calibration of the photosensors is being circulated, and a review will be held sometime in September/October. A common JSON database will be used to hold calibration results from all module production sites.

1.6. 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 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 PY1 of the Upgrade project, significant progress has been made in the areas focused on software that will reside within the new optical sensors and calibration devices. First, all new hardware designs will include a common microcontroller hardware package to ensure a uniform interface and programming environment, vastly reducing the potential complexity of programming tasks for the new hardware. Developers across the project now have access to a software development environment and testing boards and have made significant progress in writing software for planned components to be included in the new module and in writing testing software to help verify the functionality of the new hardware. Figure 10 shows a prototype D-Egg mainboard programmed with custom software to test functionality. This software effort will continue, adding testing and data readout functionality to support full design verification testing and final acceptance testing needs as hardware construction gets underway.

For the broader software support, work has concentrated on updating and modernizing the IceCube software development tools and environment to support Upgrade efforts. This work has focused on bringing in more modern software code repositories, identifying software that will need additional development work to be compatible with Upgrade hardware, and developing simulation tools to model the planned hardware. This includes production of simulated data samples that are in active use for design studies underway within the project. Additionally, computing systems support for the NTS testing system has been purchased and will be brought online in late 2019, creating a unified testing environment that links the NTS location at MSU with the long-standing South Pole testing system located at UW into a single unified testing environment.

2. Last Month Achievements

This annual report also fulfills the requirement for the last monthly report of project year 1, which is September 2019. The table below lists achievements for this month.

WBS 1.1. Project Management
• In-ice calibration devices final design review (magnetometer, inclinometer, barometer, flashers, cameras, and interfaces). • Manufacturing audit of the Nippon Marine Enterprises (NME) capabilities and integration facility for D-Eggs. • Unified procurement for high-precision LEDs for the flasher boards (same parts for D-Eggs and mDOMs).
WBS 1.2. Drilling and Deployment
• Field season: All McMurdo and South Pole activities, personnel, and cargo is coordinated and confirmed w/ASC. • ASC/UW support meeting was held on the 24th in Madison. • Generator 1: was tested and accepted at vendor, shipping to Port Hueneme is in process. • Drill hose: governor's waiver was received, purchase order with deposit has been submitted. • Independent firn drill: testing and repairs are complete, preparation for shipping is underway • Tower crescents: were inspected, repaired, and shipped. • Equipment for McMurdo generator work was packaged and shipped on the 19^{th}. • Equipment for early South Pole work was packaged and shipped on the 26^{th}. • Control system: replacement subsystem testing continues, PDR is scheduled for early November. • EHWD inventory: methods and checklist is being developed and confirmed for all installed and loose components. • Schedule and cost replanning input was competed.
WBS 1.3. Sensors
• Test stand for mDOM test-mainboards commissioned at DESY. • Meeting with engineers from Hamamatsu to discuss production and integration of PMT bases • mDOM pressure vessels for DVT modules delivered. • Half-mDOM prototypes with alternative optical gel and materials for PMT support structure built and tested in freezer. • D-Egg Rev. 2 mainboards evaluated. • D-Egg Rev. 3 mainboards schematics finalized. • Final shipment of D-Egg PMTs (640 pcs. in total) received in Chiba, and specifications entered into database. • D-Egg integration lab damaged by typhoon; relocation to new building is not expected to affect schedule. • Ice comms modules delivered to WIPAC.
WBS 1.4. Communication, Power, and Timing
• Revision of storage plan to enable main cable storage temperature specification to be reduced to -50ºC. • Production of sample main cable component from Hexatronic complete, evaluation underway. • Assembly of first prototype mini-FieldHub PCBs complete. • Production of penetrator cable assemblies underway. • Power budgets refined using updated surface cable plan and string geometry. • Contingency strategy for excess DOM power usage identified by using adjustable-voltage supply modules.

WBS 1.5. Calibration
• 1.5.1: Module calibration: We had a lunch meeting at the collaboration meeting in Chiba to discuss the plans for module calibration. Discussion still ongoing. • 1.5.2.1: Onboard LED flashers: During testing, it was discovered that the LED model selected had a double-peaked emission structure, contrary to what was on the data sheet. We have been investigating what effect this will have on calibration and looking at alternate LED models, including narrower beams. Mechanical mounting of the LEDs and electronic circuit layout in D-Eggs and mDOMs was reviewed at the calibration onboard device final design review in Chiba. Control software for the flashers has been written. • 1.5.2.2: Standalone light sources: A proposal has been made for a common “mini-mainboard” for standalone light sources. Design of this is ongoing. • 1.5.2.3 Cameras and light detection: Cameras were reviewed at the calibration onboard device final design review in Chiba. Money was requested from contingency to cover the shortfall in the cost of the camera mounting in the D-Egg, which was more expensive than expected. D-Egg camera mounting design options are still being finalized. • 1.5.2.4 Acoustic sensors: The new baseline plan is to include acoustic sensors in the same module as the acoustic transmitter. Plans to review this in January. • 1.5.2.5 Inclinometers and compasses: Slow control software has been written for the inclinometers and is in progress for the other slow control devices. The inclinometer performance was reviewed at the calibration onboard device final design review in Chiba and meets the stability requirements for detector. • 1.5.3 Array calibration: Simulation studies of flashers on mDOMs and D-Eggs have been presented at the collaboration meeting in Chiba.
WBS 1.6. Data Systems
• NTS computing systems on order, test systems available in next month. • Software development of MB software packages for initial design verification of first D-Egg underway. • NTS computing system components in hand and tested. Will be installed and ready for wider use Oct 2019. • Continued development of mainboard software testing applications in preparation for design verification testing this fall. • Finalized PY2 planning activities.

3. *Cost Performance and Contingency Status*

3.1. *Funding Profile*

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-FY2021): $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.

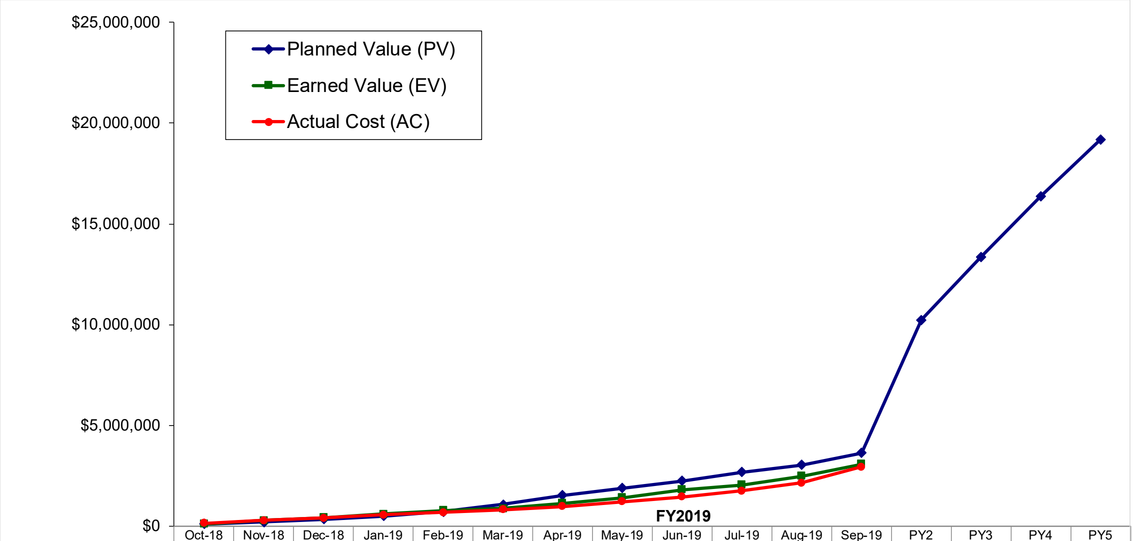
	FY19 (Actual)	FY20 (Proposed)	FY21 (Pending)	FY22 (Pending)	FY23 (Pending)
Readiness Preparation & Design Stage					
NSF Approved Budget (R&RA)	$4,069,959				
Allocated Budget (R&RA)	$4,069,959				
Development & Design (Other)					
Total	$4,069,959				
Construction Stage					
NSF Approved PMB Budget		$5,130,419	3,638,072	$3,604,047	$3,685,016
NSF Approved Contingency Budget	$664,979	$575,002	$362,229	$464,748	$788,853
Total	$664,979	$5,705,421	$4,000,301	$4,068,795	$4,473,869
NSF Allocated PMB Budget		$5,130,419	3,638,072	$3,604,047	$3,985,016
NSF Allocated Contingency Budget		$575,002	$362,229	$464,748	$788,853
Total		$5,705,421	$4,000,301	$4,068,795	$4,473,869

3.2. ***Cost Performance – NSF-Funded***

The table below is used to compare actual cost and schedule to planned cost and schedule using Earned Value Management System methodology.

EVM Metrics		$M	Description
EVM Reporting Date		Sept. 2019	Budget and schedule reporting date
Total Project Cost (TPC)		$22,983,324	PMB + approved contingency budget
NSF Funding To-Date		$10,440,359	Cumulative funding received to date
NSF Approved Contingency budget		$2,855,811	Total contingency budget approved
NSF Allocated Contingency to date		$2,855,811	Amount of contingency budget allocated
Budget at Completion (BAC)		$19,185,126	Sum of all budgets established for the work to be performed
	Planned Value ($M)	$3,628,039	
	Earned Value ($M)	$3,068,585	
	Actual Costs ($M)	$2,925,655	
% Complete (Planned)		18.9%	PV/BAC*100%
% Complete (Actual)		16.0%	EV/BAC*100%
% Complete (Spent)		15.3%	AC/BAC*100%
Cost Variance (CV)		$142,930	EV-AC
	Cost Performance Index (CPI)	1.05	EV/AC
Schedule Variance (SV)		-$559,454	EV-PV
	Schedule Performance Index (SPI)	0.85	
Estimate at Completion (EAC)	EAC	$18,291,513	AC+(BAC-EV)/(CPI*SPI)
Estimate to Complete (ETC)	ETC	$15,365,858	EAC-AC
	ETC	$16,431,792	Bottom-up estimate to complete
	Date of last ETC_2 update	09-2019	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		18.6%	
Contingency balance against NSF Allocated Contingency to-date		$2,855,811	
Schedule Contingency (calendar days)		In preparation	Award completion – PMB completion
Monte Carlo simulation confidence level		70%	N/A
PMB completion date		09-2023	Forecast project end date based on Integrated Master Schedule
Award completion date		09/30/2023	As specified in CSA
Risk exposure		$859K	See Section 5.2.1

This S-curve below shows data comparing the actual cost of work performed (ACWP) with the budgeted cost of work performed (BCWP) up until the present quarter. Beyond the present quarter, it shows data for the budgeted cost of work scheduled (BCWS), extending to the end of the construction phase of the project.



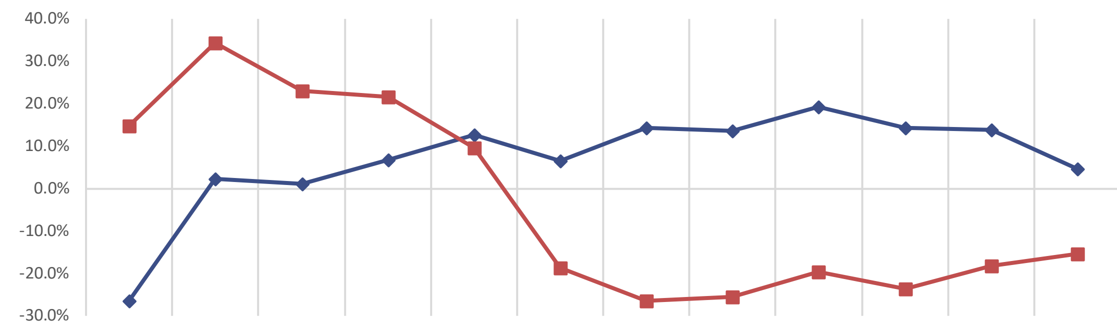
	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	PY2	PY3	PY4	PY5
Planned Value (PV)	90,941	207,152	332,360	495,224	704,391	1,068,260	1,535,754	1,890,692	2,243,588	2,668,146	3,031,674	3,628,039	10,230,95	13,363,78	16,377,20	19,185,12
Earned Value (EV)	104,286	278,378	408,689	601,758	771,919	868,886	1,127,096	1,409,500	1,800,697	2,036,677	2,476,186	3,068,585				
Actual Cost (AC)	131,840	272,344	404,305	561,336	675,023	812,943	965,077	1,218,215	1,456,100	1,748,004	2,137,507	2,925,655				

This S-curve reflects the Upgrade project to date. PY1 has detailed plans and is shown by month. Detail planning for PY2 to PY5 are not available at this time. Therefore, they are shown by year. The project office is in the process of detail planning for PY2 at this time and will include it in future reports.

The apparent sharp increase in planned values for PY2 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 2019, to yearly beyond September 2019. The yearly planning process is now underway for PY2. This planning is being done by month and will eliminate the issue of scale change.

	WBS Earned Value Variance Report as of September 30, 2019												
	CURRENT PERIOD					CUMULATIVE TO DATE					AT COMPLETION		
WBS L2	PLANNED	EARNED	ACTUAL	SV	CV	PLANNED	EARNED	ACTUAL	SV	CV	BAC	EAC	VAC
1.1	86,459	70,905	130,104	-15,554	-59,199	670,900	839,752	868,105	168,852	-28,353	4,271,373	4,415,590	-144,216
1.2	346,089	378,842	581,010	32,754	-202,168	1,483,754	1,483,339	1,590,665	-415	-107,326	11,044,969	11,844,120	-799,151
1.3	100,678	82,844	16,478	-17,834	66,366	612,522	333,887	93,119	-278,635	240,767	1,255,213	350,072	905,140
1.4	16,962	33,632	27,408	16,670	6,224	451,974	229,434	291,417	-222,540	-61,983	1,151,777	1,462,936	-311,160
1.5	5,605	7,896	4,614	2,291	3,282	33,740	18,107	37,525	-15,632	-19,417	340,361	705,349	-364,987
1.6	40,571	18,279	28,534	-22,292	-10,255	375,149	164,066	44,824	-211,083	119,242	1,121,434	306,383	815,051

ICECUBE UPGRADE PROJECT SCHEDULE VARIANCE AND COST VARIANCE %



	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19
CV%	-26.4%	2.2%	1.1%	6.7%	12.6%	6.4%	14.4%	13.6%	19.1%	14.2%	13.7%	4.7%
SV%	14.7%	34.4%	23.0%	21.5%	9.6%	-18.7%	-26.6%	-25.5%	-19.7%	-23.7%	-18.3%	-15.4%

Project year 1 cost and schedule performance data are shown above in dollar amounts and as indices. The project schedule variance and project cost variance show that the project is approaching planned performance parameters.

3.3. In-Kind Contributions

The table below shows in-kind contributions from sources other than NSF. The schedule for deliverables is managed by the level 2 managers and the project office. Cost of deliverables for in-kind contributions is managed by level 2 managers in accordance with requirements of the sponsor.

Secured
Pending

IceCube Upgrade In-Kind Contributions

	1.2 IceCube Upgrade drill	1.3 Deep ice sensor modules	1.4 Comms Power and timing	1.5 Calibration and Characterization	1.6 M&O data systems integration
German Universities (BMBF)		mDOM modules ($0.6M); 1.5 FTE Tech		Acoustic sensors and pinger (0.09M) 1.2 FTE Tech; 0.3 FTE EE	
Chiba (JPS/MEXT)		DEgg modules ($3M)			
DESY		Procurement, production and testing of mDOM modules ($3.25M); 2 FTE EE, 1 FTE ME; 3 FTE	1 FTE EE	0.5 FTE	0.5 FTE
Geneva		module hardware ($0.5M)			
IceCube					M&O- DAQ/ExpControl/ Icetray, etc. Collaboration- simulation/ reco software
Karlsruhe Institute of Technology		mDOM modules ($2.5M)			
Muenster		mDOM hardware ($0.07M) 3 FTE			
T.U. Munich				POCAM sensor modules ($0.6M)	
Michigan State University		Production and test facilities ($0.8M); Labour for module production and testing (3 FTE)	7 main cables and breakout assemblies ($2.56M)		
SKKU				Camera systems ($0.04M), 3 FTE; (0.2M), 2.5 FTE	
Uppsala/Stockholm (Swedish research Council)	drill crew ($0.8M)	mDOM modules ($1.6M)	($0.5M)	pencil beam source ($0.05M)	
Total	$0.8M	$9.62M, 10.5 FTE; $2.7M	$2.56M, 1 FTE; $0.5M	$0.73M, 4.5 FTE; $0.25M, 2.5 FTE	

3.4. Contingency Status

	Change Log					
CR No	Description	Approval Date	Total Baseline	Allocated Budget	Allocated Budget Change	Contin-gency Budget
CR1	Remove PDOM	02/27/2019	0	0	0	0
CR2	Remove IDF, cables route to ICL.	06/05/2019		300,000		
CR3	Adjust main cable lengths	06/05/2019	0	0	0	0
CR4	Changes to hole order and X,Y geometry	06/05/2019	0	0	0	0
CR5	Minor schedule changes in calibration	06/11/2019	0	0	0	0

3.5. Risk Management

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 risk register is reviewed quarterly by the L2/CCB members. All risks are being reviewed for Q4 of 2018-19. The IceCube Upgrade risk register will be revised accordingly.

3.5.1. 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.

Project Item	Value ($k)	Notes
Risk Register Probability Weighted Cost Estimate	$559	The value for this item should not include risks that have a pending Change Request (CR) for contingency budget.
Project Liens List	$300	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	$859	Sum of all entries.

3.5.2. *Risk Change Table (August 2019)*

New	**Risk ID**	**Risk Title**	**Probability Weighted Cost Exposure ($k)**
			0
Modified	Risk ID	Risk Title	Probability Weighted Cost Exposure ($k)
			0
Retired	Risk ID	Risk Title	Probability Weighted Cost Exposure ($k)
	ORG7	Only 5 Strings	75
	PM1	PM Job Fulfillment	51.5
	EXT1	Microturbines	199.8

Red and Orange Risks				
Risk ID	WBS Element	Risk Title	Probability Weighted Cost Exposure ($k)	Mitigation
				We have no orange or red risks.
Yellow Risks ID List: Risk ID #TECH23, Risk ID #ORG3, Risk ID #TECH2, Risk ID #ORG4, Risk ID# TECH31, Risk ID #TECH1, Risk ID #ORG #2, Risk ID #PM2, Risk ID #TECH27, Risk				

3.5.3. *Risk Heat Map*

		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%					
	25%-50%					
	10%-25%		1	9		
	5%-10%					
	<5%					

The risks in the medium impact category are:

1. TECH 23: Fire or major equipment damage
2. ORG 3: Season delay and logistics
3. TECH 2: Bad optical module glass Sphere or excessive radioactive material
4. ORG 4: Driller injury during drilling
5. TECH 31: Insufficient Communication Cable Bandwidth for Optical Modules
6. TECH 1: Old enhanced hot water drill failure
7. ORG 2: Inexperienced drillers
8. PM 2: In-kind contribution financial issues experienced by project management office
9. TECH 27: Main supply hose reel failure

4. Safety

- The IceCube quality and safety manager attended the Polar Planning Meeting with ASC in Denver on 06/12/2019 and met with the ASC safety engineer. Mutual safety plans to align and focus our efforts at keeping people safe have been outlined.
- The safety and South Pole team training was completed during the week of August 5th. The Red Cross provided us with first aid, CPR, AED, and frostbite care training. Lock-out/tag-out training and SafeStart training were also provided to the team. Various technical topics on drilling were presented, reminding us all of the job-related hazards.
- All required safety equipment for the South Pole has been ordered and is staged for shipment at the end of September.
- The IceCube Upgrade project is reviewing, with the NSF, the necessity for use of the CO2 fire suppression systems in the hot buildings in the IceCube Upgrade drill camp. In light of deaths in Antarctica last December, along with the near miss in the Gen1 drill camp, it is worth considering the necessity for the continued use of the CO2 fire suppression systems.
- In the 3rd quarter of 2018/19 (June), the IceCube Upgrade seasonal safety plan was rolled out to the entire project. This plan focuses primarily upon the safety of the individuals deploying to Pole in the upcoming seasons, that “You are your own best safety manager. The project has your back.” The plan includes training, safety audits, safety meetings/discussions, hazards analyses, incident reports; and other safety-related efforts.

5. Quality Assurance

- The mDOM preliminary design review was completed in August. The mDOMs are on track for further development. The testing is underway.
- 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 D-Egg OM mainboard electronics review was completed in July. The mainboards look good. The testing is underway.
- The engineering change request (ECR) process was up and running in February.

6. Environmental

Work started on the initial environmental evaluation (IEE). We are working with Ted Doerr, ASC coordinator of the effort. We reviewed the IceCube Gen1 CEE (comprehensive environmental evaluation) and have revised certain sections of it for use in developing the IEE. ASC is using a third party to write the IEE. The ASC plan is to have the final draft of the IEE completed in November 2019.

7. Photographs and Drawings

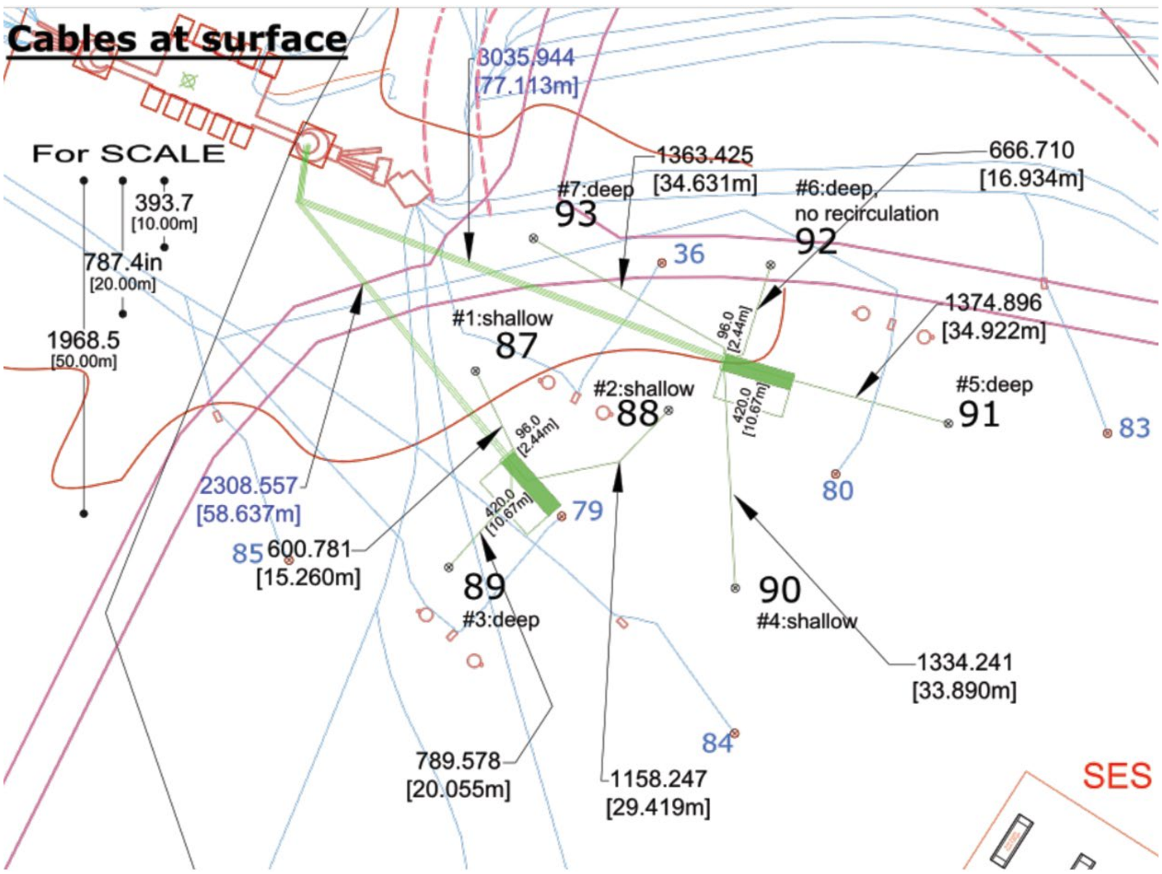


Figure 1: Map of the IceCube Upgrade region of IceCube, with the drill hole nominal locations for Upgrade strings 87-93 indicated. New surface cables and surface junction boxes (in green) are shown with straight paths (still be to be surveyed) back to the IceCube Laboratory cable entry tower. "Shallow" here refers to holes to be drilled to 2450 m and "deep" for 2700 m depths.

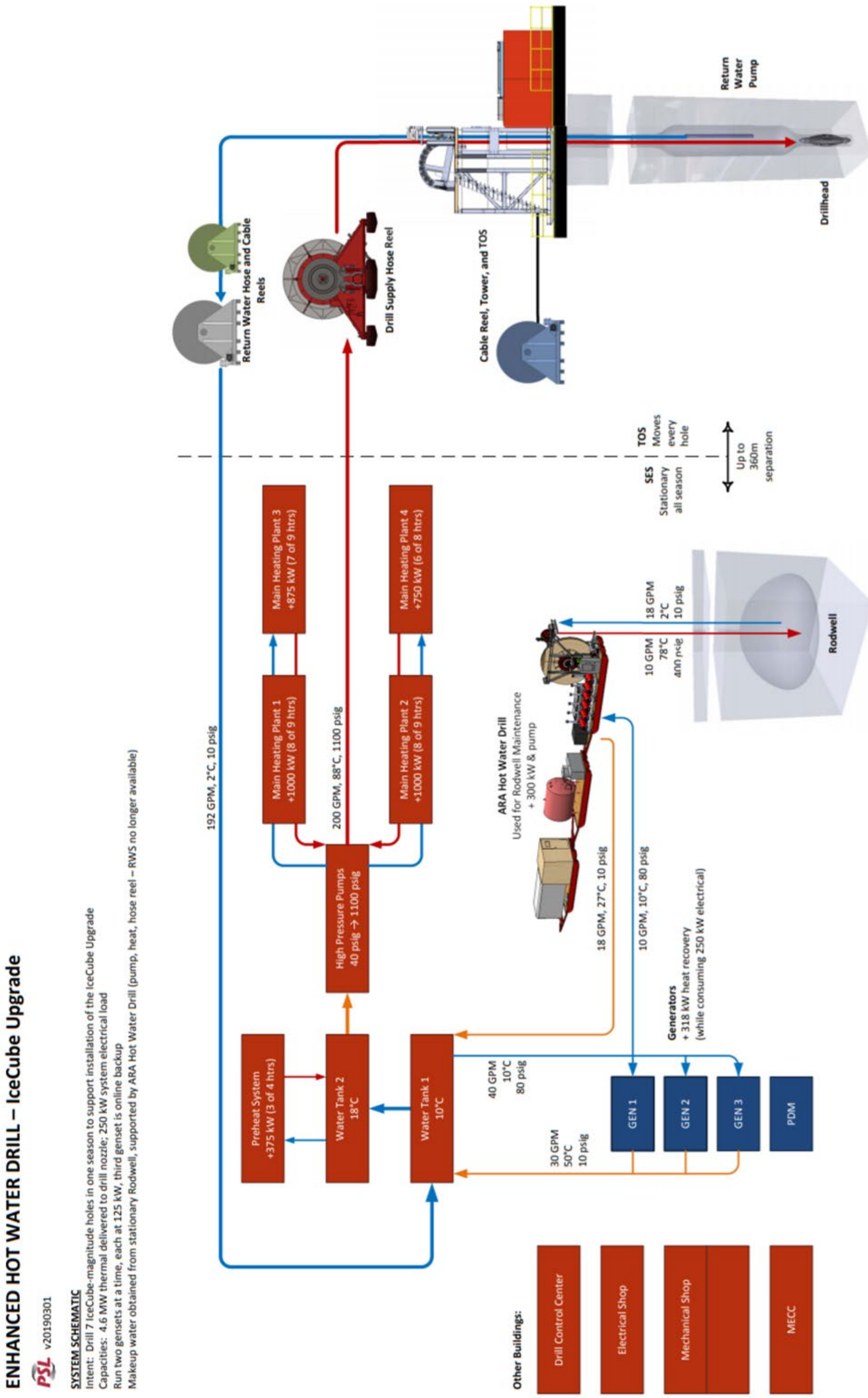


Figure 2: Operational schematic of the IceCube Upgrade enhanced hot water drill showing the major subsystems and their interconnections and graphically calling out important parts.

Figure 3: The IceCube Upgrade firn drill undergoing test operations at University of Wisconsin–Madison's Physical Sciences Laboratory (PSL). This subsystem will ship this fall for Antarctica.

Figure 4: Heater assembly under testing at the IceCube test bed at UW's PSL. A complete slice of the enhanced hot water drill is kept operational in Madison for training and upgrading purposes.

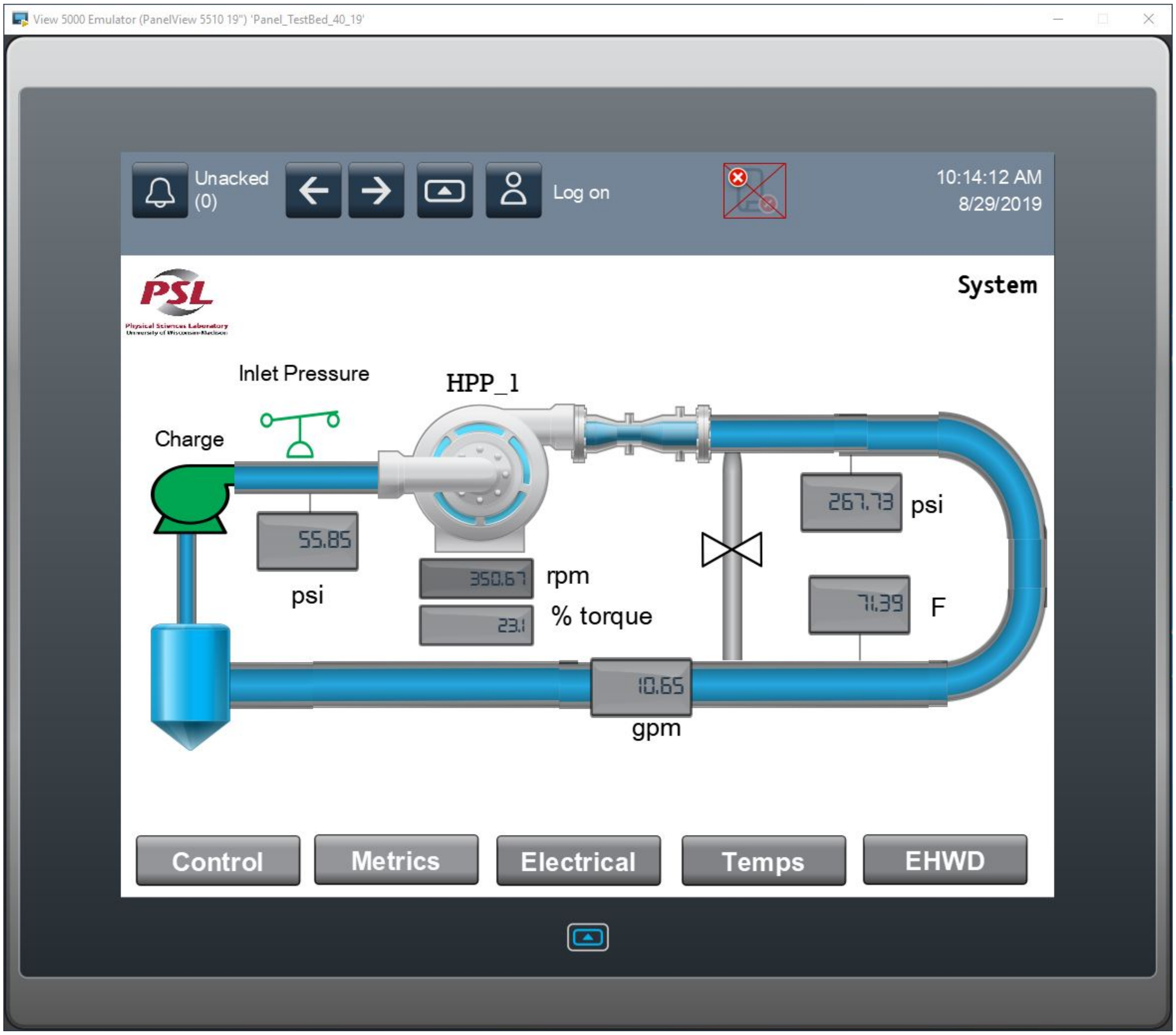


Figure 5: Screengrab of the high-pressure pump (HPP) control system software while under testing.

Figure 6: In-ice optical module mDOM test article undergoing cold tests of new optical gel materials at the University of Muenster.

Figure 7: The second revision of the D-Egg in-ice optical module main electronics board, produced at the University of Chiba, currently undergoing testing.

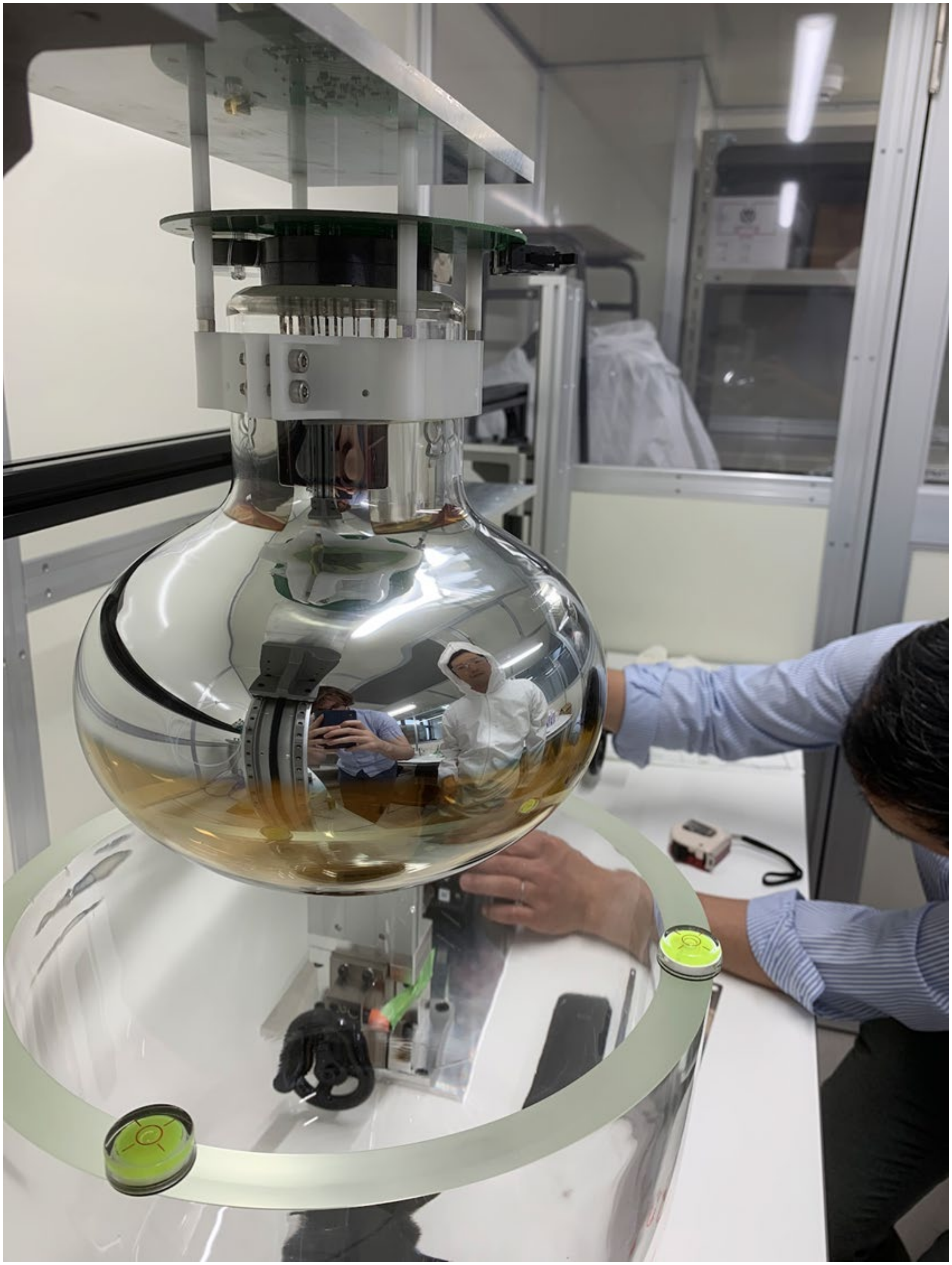


Figure 8: A photomultiplier tube (PMT) assembly being installed into a D-Egg half-sphere and potted with optical gel. This work is being performed at a contractor facility near Chiba, Japan, Nippon Marine Enterprises, which specializes in deep ocean hardware.

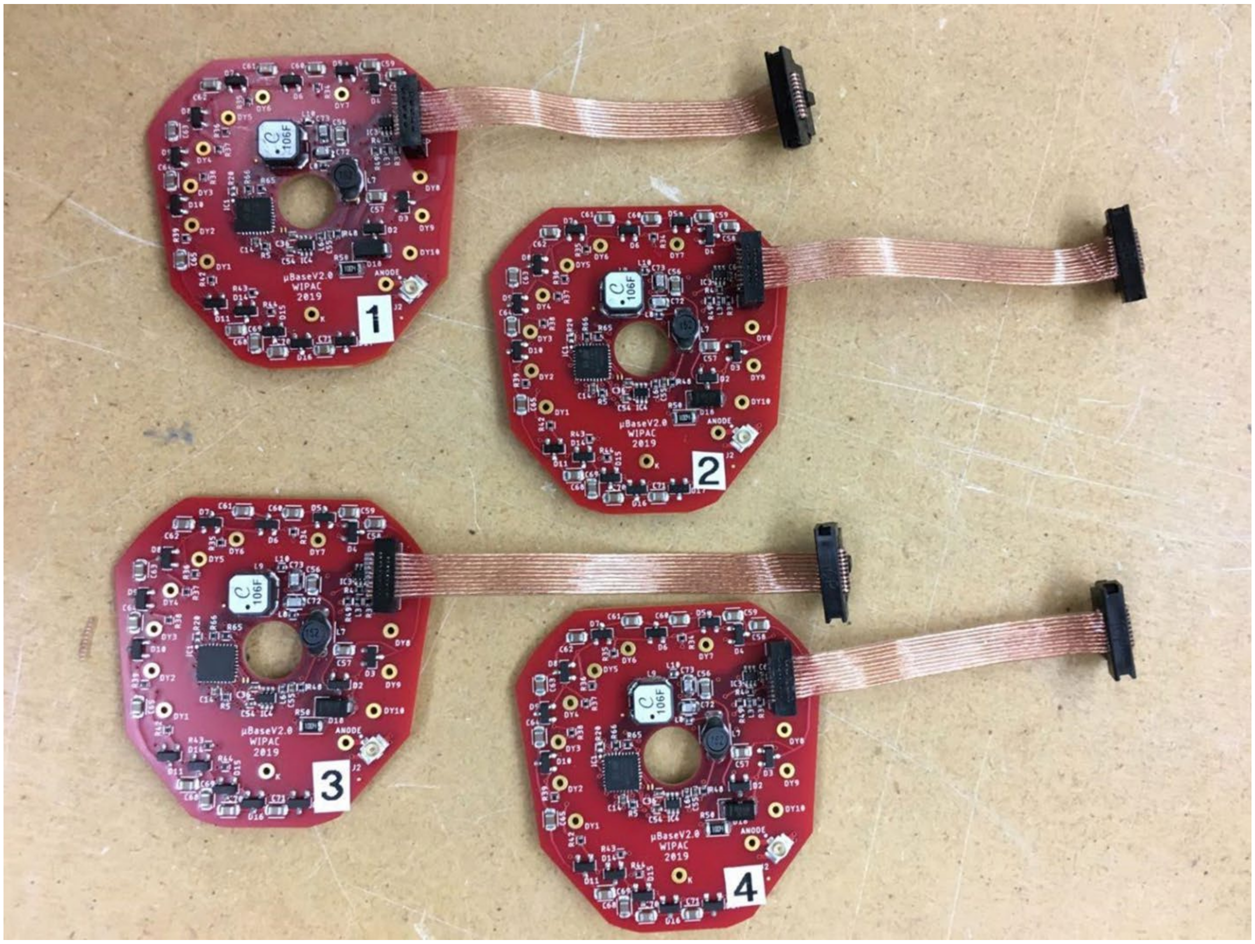


Figure 9: Four micro-base active high-voltage divider boards for mDOM PMTs connectorized and ready for testing. Board design took place at UW–Madison, contract production in the US, and testing underway in Germany. Final production boards will be produced and installed onto the PMTs by the PMT vendor.

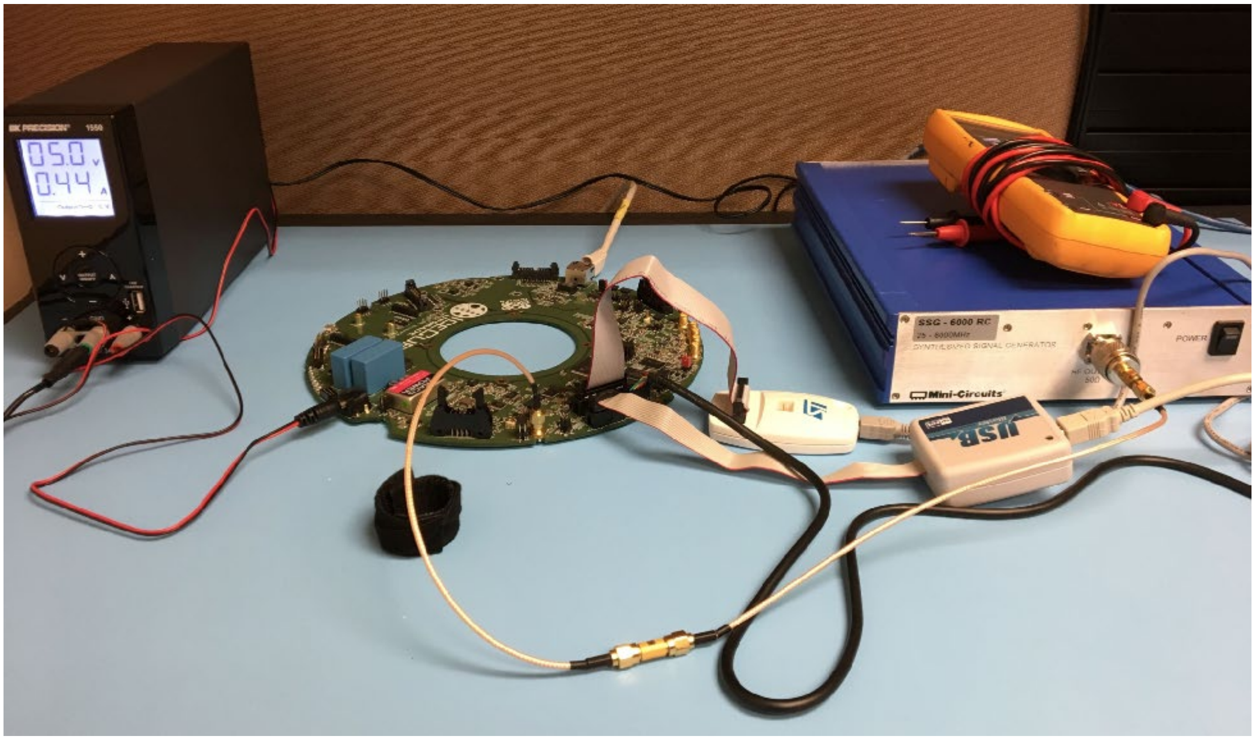


Figure 10: A revision 2 D-Egg mainboard programmed with custom testing software applications at WIPAC as part of the hardware verification program. (J. Braun/WIPAC)