WISCONSIN ICECUBE
PARTICLE ASTROPHYSICS CENTER

IceCube Upgrade Work Breakdown Structure (WBS) Dictionary

2019001.5

Approval

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Change Log

Revision	Description : Author	Date
0	Original document : J Haugen	2/5/19
1	Incorporate CR1 and ongoing changes: J Haugen	3/5/19

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2	Incorporate CR15 administrative changes. M. Zernick	4/22/20
3	Harmonize with Change Requests/General Edits: Mike DuVernois	2/22/21
4	Adding names and/or institutions at L4, ensuring clean division of NSF and non-NSF deliverables.	12/01/21
5	Revised 1.2.9 breakout, added 1.2.10, & updated 1.2.1 language D. Tosi & I. McEwen	2/25/22

Level	WBS	Name	Lead	Institution	WBS Dictionary Definition to Level 4 only
2	**1.1**	**Project Office**	**Feyzi**	**UW**	Provide oversight and direction in managing and facilitating the IceCube Upgrade Project. Provide ongoing support for daily activities required and review processes to ensure accuracy of reporting data while providing leadership in developing tools, preparing for purchases and manufacturing equipment required for IceCube Upgrade completion. Staffing, Acquisitions, Organization, Project Definition, and technical coordination are also the responsibility of the Project Management team. Technical Coordination includes the resources required to provide overall technical leadership of the project. Tech Coordination supports the definition of requirements including scientific, logistical, environmental, contractual, reliability, quality and safety, interface control; provides solutions to meet these requirements; and documents and provides configuration management of these solutions. Technical oversight includes preliminary, final, production readiness, and deployment readiness reviewing of systems and subsystems. Production Coordination provides design for manufacturability guidance for engineering work. In production, manages the relationships between the project, the vendors, and the quality assurance process. Oversees the quotation process on serially produced parts.
3	**1.1.1**	**Project Management**	**Feyzi**	**UW**	Creation and maintenance of Project Execution Plan and Project Management Plans; annual reporting to NSF and stakeholders. Liaison to advisory groups and stakeholders.
3	**1.1.2**	**Project Controls**	**Vakhnina**	**UW**	Project Controls develops, maintains and uses a consistent set of cost and schedule baselines for the development, implementation and commissioning of the IceCube Upgrade. These baselines use the IceCube Work Breakdown Structure as the basis for planning. Coordinates and facilitates activities related to project involving report preparation,

					subaward management, financial reporting, document control, and stakeholder related issues.
4	1.1.2.1	EVMS	Vakhnina	UW	Provides oversight of planning operations and Earned Value report preparation to satisfy sponsor-imposed requirements. Conducts detail plan preparation for both cost and schedule representing scope in sufficient detail to manage delivery of key components. Maintains data to support baseline and funding profiles for reporting purposes. Gathers information from appropriate levels to consolidate and prepare periodical reports for sponsor and other project stakeholder reviews. Provides expertise and guidance for reporting Earned Value and Schedule updates as necessary.
4	1.1.2.2	Sub Award Management	Vakhnina	UW	Provides expertise in preparing, awarding, managing and monitoring all aspects of subawards. Prepares documentation and requirements for subaward participation and reporting to IceCube Upgrade. Acts as liaison for reporting and other related issues and communicates with all levels of management.
4	1.1.2.3	Financial Reporting	Vakhnina	UW	Communicates and coordinates with accounting for gathering and reporting of financial data related to the project. Acts as liaison to accounting and management for all issues involving expenditures, funding and collection of financial data. Reviews data and verifies accuracy to prepare for interface with reporting tool and generation of reports for project stakeholder review. Reviews the project financial status and trends with project key stakeholders, advising them on optimal utilization of financial resources within the project.
4	1.1.2.4	Project Reviews	DuVernois	UW	Supports project manager and other project key stakeholders with preparation and management of project internal and external reviews. Includes travel costs for project reviews and internal collaboration meetings, and the expenses incurred for meeting rooms and coordination.

3	**1.1.3**	**Quality and Safety Management**	**Zernick**	**UW**	Quality and Safety Management encompasses non-conforming materials, incoming inspections, document control, audits, and corrective and preventive actions. It is an integral part of the design, procurement, fabrication, and deployment phases. The program objective is to ensure the completion of high quality, reliable advanced detectors. Provide expertise in all areas related to Quality Assurance and Safety. Prepare plans outlining requirements and operation parameters to ensure environs are within acceptable standards. Coordinate and conduct periodic reviews and report findings recommending best course of action to resolve issues. Maintain open communication with all levels of management. Ensures that proper environmental, health, and safety guidelines are followed. Issues PPE (personnel protective equipment) as needed. Provides accident investigation procedures, verifies health insurance coverage, and provides overtime and irregular shift guidance. Manages IEE/CEE (environmental impact documents) required for activities at the South Pole. Tracks failures, parts not accepted from vendors, and reworked components.
4	1.1.3.1	Risk Management	DuVernois	UW	Maintains the risk registry with input from the WBS managers. Coordinates with university council on equipment risk (for example in procurement & shipping) and human risk (in concert with the safety manager). Acts as an ombudsperson for risk concerns raised at any level, including in the field at South Pole.
4	1.1.3.2	Document Control	Zernick	UW	Maintains the document databases with the input from the WBS managers and other key stakeholders.
3	**1.1.4**	**Polar Operations**	**McEwen**	**UW**	This element includes the planning and execution of all of the activities needed at South Pole to successfully install sensor instrumentation into 7 deep drilled holes. It includes working with the Antarctic Support Contract (ASC) to plan movement of cargo and people to the South Pole. It includes working closely with ASC and IceCube Upgrade Drill management to coordinate fuel delivery at Pole.

4	1.1.4.1	Logistics	McEwen	UW	Coordination of annual cargo shipments and personnel deployments to and from the South Pole. Also includes management of international and domestic shipping schedules to mesh with USAP flights from Christchurch to Antarctica.
4	1.1.4.2	Antarctic Support Contract	McEwen	UW	Liaison and formal single channel of communications between the project and the Antarctic Support Contractor. Makes personnel schedules for field deployments, arranges PQ (physical qualifying) exams, communicates rules and expectations to field workers, and manages requests to the contractor. support includes fuel, lodging at the South Pole, flight reservations on commercial and military aircrafts, cargo handling, equipment operations at Pole, and waste handling.
3	**1.1.5**	**Project Engineering**	Sandstrom	UW	Determine appropriate standards for purchased or fabricated elements of instrumentation systems. Responsible for standardizing appropriate system definitions, requirements, and interfaces. Provide design engineering support to instrument developers and project management. Provide engineering expertise for milestone design status reviews. Review contract manufacturing proposals for project requirements and manufacturability. Help identify tradeoffs and risks of particular design choices. Communicate system conflicts and potential resolutions to instrument developers and project management. Determine consistent naming conventions for configuration Items and interface elements. Devise a tailored system for tracking design requirements, design status and system interfaces. Provide guidance to WBS L2 and L3s regarding design for reliability and design for manufacture.
2	**1.2**	**IceCube Upgrade Drill**	**McEwen**	**UW**	This WBS includes functional areas that directly support the seven string installation efforts at the South Pole. Primary components are Management, Engineering, Logistics, Drill, and Installation. Northern hemisphere Enhanced Hot Water Drill (EHWD) refit activities included design, procurement, and construction of new drill systems, integration,

					verification, and testing of each system/subsystem, as well as planning and implementation of drill field operations for refit activities and to accomplish required string borehole deliverables. Installation is responsible for sensor/device handling process development, South Pole Acceptance Testing activities, string hardware design and procurements as well as surface cables and optical sensor, calibration and special device string installation activities at the South Pole.
3	**1.2.1**	**Implementation Management & Systems Engineering**	**McEwen**	**UW**	Includes drill & installation system and project management, systems engineering, borehole and system thermal modeling, procurement support, season planning, CAD support, technical reviews, drill safety/EHS, quality assurance, recruitment, training, and documentation.
4	1.2.1.1	Implementation Management & Controls	McEwen	UW	Includes project management for drill and installation systems (WIPAC).
4	1.2.1.2	Drill Management & System Engineering	Gibson/Benson	UW (PSL)	EHWD Upgrade management; Plan, schedule, and budget development; Develops EHWD logistics and support requirements, works closely with 1.1's Polar Operations and the USAP Contractor. Facilitates design, production, and field season readiness reviews; Recruitment; Training; post-drill season close-out. Systems engineering, thermal modeling, fuel analyses, CAD support, procedures, post-drill season wrap up.
4	1.2.1.3	Installation Management & Systems Engineering	Tosi	UW	Installation management and coordination. Develop site plans. Plan & Coordinate String Installation Area. Work closely with 1.3 (DOM's) and 1.4 (CPT, especially Cables) to determine requirements, schedules, logistics, and constraints. Develop procurement lists of Installation related hardware and equipment. Develop detailed plans and procedures hazard analysis and safety plans for deep string installation. Assemble and lead a team of

					"Installers" during 2025/26 season to deploy 7 instrumented strings safely and successfully.
4	1.2.1.4	Implementation Quality and Safety	Zernick	UW	Drill & installation safety, quality assurance, documentation, post-drill season wrap up.
4	1.2.1.5	Implementation Travel		UW	Travel for meetings and reviews, recruitment, and vendor visits.
4	1.2.1.6	Transportation & Logistics		UW	Cargo crating and shipping from UW sites.
3	**1.2.2**	**Thermal Plant**	**Duling**	**UW (PSL)**	Includes the design, procurement, resurrection, construction, integration, and testing of subsystems associated with the drill system's hot water thermal plant: Preheat System, Main Heating Plants, a new Seasonal Equipment Site fuel day tank and fuel distribution system. Legacy Gen 1 EHWD thermal plant subsystems are to be reused. Excludes generator exhaust heat recovery system.
4	1.2.2.1	Main Heating Plants		UW (PSL)	Evaluate, identify and procure upgrades/replacements/spares, retrofitting and testing. Including burner rebuilds, sensor replacements, and integrated networking.
4	1.2.2.2	Pre-Heat System		UW (PSL)	Evaluate, identify and procure Pre-heat System upgrades/replacements/spares. Retrofit subsystems and test.
4	1.2.2.3	Fuel Storage and Delivery		UW (PSL)	Evaluate, design, specify/procure, fabricate and test fuel storage day tank upgrades; Review, specify/procure fuel delivery systems throughout EHWD
3	**1.2.3**	**Tower Operations Site**	**Benson**	**UW (PSL)**	Includes the design, procurement, resurrection, construction, integration, and testing of subsystems located at the drill site (borehole): Tower Operations Structure (TOS), Drill Tower, Drill heads and controls, Main Drill Cable Reel, Main Drill Hose Reel, Main Drill Hose, Return Water Hose Reel, Return Water Cable Reel, and downhole drill cables.
	1.2.3.1	Tower Operations Structures (TOS and Tower)		UW (PSL)	Includes the design, procurement, resurrection, construction, integration, and testing of subsystems located at the borehole. Tower Operations Structure, Drill Tower, Drill heads and controls, Main Drill Cable Reel.
4	1.2.3.2	Drillheads		UW (PSL)	Evaluate, identify, and procure upgrades/replacements/spares, retrofitting and testing. Drill head testing and rebuild.

4	1.2.3.3	Reels & Winches		UW (PSL)	Evaluate, identify, procure, repair and test, Main Drill Hose Reel, Return Water Hose Reel, Return Water Cable Reel, and TU 15/20 components
4	1.2.3.4	Down-hole Main Drill Hose		UW (PSL)	Specify and procure new Main Drill Hose. Review, specify, and fabricate hose strain reliefs.
4	1.2.3.5	Down-hole Main Drill Cables		UW (PSL)	Review specifications and procure new downhole drill cables, including main drill cable and return water pump combo cable, connectorization, & testing.
4	1.2.3.6	Design and Construct Main Hose Reel Heating System		UW (PSL)	Includes the design, procurement, construction, integration, and testing of the Main Hose Reel Heating System.
3	**1.2.4**	**Computing and Control System**	**Laundrie**	**UW (PSL)**	Includes development and verification of new drill control system software and hardware, network, sensors, e-stop, network and e-stop cabling and connectors, motor drives, and the Drill Control Center.
4	1.2.4.1	Architecture		UW (PSL)	Evaluate EHWD system and define IceCube Upgrade Drill requirements, system design.
4	1.2.4.2	Control System Hardware		UW (PSL)	Specify, procure, and prepare motor controllers and readouts, sensors, network controllers, indoor cables (sensor and network).
4	1.2.4.3	Control System Software		UW (PSL)	Design, construct and test motor controllers and readouts, data acquisition, and system operator function software.
4	1.2.4.4	Motor Drives		UW (PSL)	Define functional and electrical requirements, specify and procure drives, program and test.
4	1.2.4.5	E-Stop System		UW (PSL)	Evaluate EHWD system and define IceCube Upgrade Drill requirements. Design system upgrades, specify, procure, assemble and test.
4	1.2.4.6	Drill Control Center		UW (PSL)	Includes computing system and electrical improvements.
4	1.2.4.7	Outdoor Cables		UW (PSL)	Assess existing cabling, design and procure, testing.
4	1.2.4.8	Controls Subsystems (PY5-PY8)		UW (PSL)	Includes control system design, procurement, assembly, and testing for MHPs, PHS & WT2, TOS & Reels, Drillheads, DCC, WT1, Fuel Day Tank, GenSets, HPP, and ARA Rodwell System in Project Years 5 through 8.

3	**1.2.5**	**Electrical Generation and Distribution System**	**Benson/Laundrie**	**UW (PSL)**	Includes evaluation and repairs, logistics and sub-contract arrangements for the overhaul and repairs of the IceCube Gen1 Generators, Power Distribution Module, and Electrical Grid. Design, specification, procurement, integration, and testing of power generation systems, generator exhaust heat recovery systems; Procurement of ISO-3 sled; Procurement and fabrication of replacement skis; Design review/procurement of breakers, connectors, etc replaced/removed by previous custodians.
4	1.2.5.1	Generator 1		UW (PSL)	Develop IceCube Generator -1 overhaul, integration, and tune-up statement of work. Arrange and facilitate sub-contract with Caterpillar engineers to perform overhaul work. Develop specifications, procurement plans, integration and testing, commissioning.
4	1.2.5.2	Generators 2, 3, and PDM		UW (PSL)	Develop IceCube Generator 2, 3, and PDM evaluation and testing plans. Procure Caterpillar sub-contractor to deploy and implement generator tests, tune-up, and identify/perform repairs, as well as troubleshoot PDM synchronization. Develop specifications, procurement plans, integration and testing, commissioning. Fabricate replacement skis for 3 generator modules, 1-PDM, 1-Reel Container
4	1.2.5.3	ISO-3 Sled (Removed - Part of Microturbines)			
4	1.2.5.4	System Electrical Distribution		UW (PSL)	Evaluate EHWD electrical distribution system, define requirements, design/build, testing.
3	**1.2.6**	**Water Handling Systems**	**Oxborough/Benson**	**UW (PSL)**	Includes the design, procurement, resurrection, construction, integration, and testing of subsystems associated with water storage, transfer, and makeup: Water Tanks (WT), High Pressure Pump (HPP) system, and new water filtration and degassing system, all pumps including downhole return pump but excluding Preheat System pumps, all interconnect hoses and plumbing including the surface transfer hose to/from the TOS, and the ARA Hot Water Drill (to replace the Rodriquez Well System).
4	1.2.6.1	Water Tanks		UW (PSL)	Recon, identify/procure upgrades/replacements/spares, retrofit and testing.

4	1.2.6.2	Pumps		UW (PSL)	Recon, identify/procure upgrades/replacements/spares, retrofit/recondition/testing.
4	1.2.6.3	Filtration		UW (PSL)	Define requirements, design and specify, procurement, fabrication and assembly, integration/verification/testing.
4	1.2.6.4	Interconnects - External		UW (PSL)	Recon, identify/procure replacements/spares, includes MDS interconnects and surface hose.
	1.2.6.5	MDS Internal Hoses		UW (PSL)	Evaluate, procure, and replace, as needed, MDS internal water and fuel hoses
4	1.2.6.6	ARA Hot Water Drill Subsystem		UW (PSL)	Recon, identify/procure replacements/spares, subsystem testing, integration and commissioning.
3	**1.2.7**	**Support Equipment**	**Gibson**	**UW (PSL)**	Includes the design, procurement, resurrection, construction, integration, and testing of other drill support systems and equipment: Mobile Expandable Container Configuration (MECC), Mechanical Shop, Electrical Shop, Spares and equipment milvans, Independent Firn Drill (IFD), and special handling equipment. Deployment hardware that directly interfaces with the drill infrastructure is included here.
4	1.2.7.1	Independent Firn Drill		UW (PSL)	Identify/procure replacements/spares, system testing and commissioning.
4	1.2.7.2	Inventory Storage		UW (PSL)	Identify and procure replacements/spares.
4	1.2.7.3	Shops		UW (PSL)	Identify and procure replacements, spares for tooling shops. Repair structure, workbenches, internal systems.
4	1.2.7.4	Test Bed		UW (PSL)	Identify/procure replacements/spares, annual commissioning, maintenance, and decommissioning.
4	1.2.7.5	Tools and Equipment		UW (PSL)	General and specialty tools and equipment, resupply.
3	**1.2.8**	**Drill Field Seasons**	**Gibson/McEwen/Benson**	**UW (PSL)**	Includes procurements, travel and labor hours associated with training prior to Antarctic deployment, deployment costs (PQ, travel costs and labor hours), South Pole labor (UW) in the three field seasons and USAP support tasks. Field Season 1 activities are focused on EHWD drill mechanical/controls refit, Field Season 2 on pre-drill activities, and Season on drilling of seven holes, installation support for 7 strings, and long-term storage/retrograde prep.

4	1.2.8.1	Seasonal Staffing & Training, Off-Ice Coordination		UW (PSL)	Includes safety equipment procurements, travel and labor hours associated with training prior to Antarctic deployment.
4	1.2.8.2	18/19 On-Ice Activities		UW (PSL)	Reconnaissance of EHWD assets at South Pole Station. Perform preliminary inspection and bulk inventory of major EHWD components.
	1.2.8.2	19/20 On-Ice Activities		UW (PSL)	Complete a thorough inspection, evaluation and inventory of EHWD components. Begin initial subsystem testing, repairs and upgrades. Perform testing of generators 2, 3, and PDM in McMurdo.
	1.2.8.3	20/21 Season Cancelled			IceCube Upgrade Team deployments cancelled.
	1.2.8.3	21/22 Season Cancelled			IceCube Upgrade Team deployments cancelled. USAP activities included drill pad and road grooming, Transportation & Logistics support.
	1.2.8.4	22/23 (Field Season 0) No On-Ice Activities, USAP Support Only			IceCube Upgrade Team deployments cancelled. Drill Pad and road grooming, storage berm maintenance, Transportation and Logistics support. Major ICU cargo movement on-ice via South Pole Overland Traverse (SPOT).
4	1.2.8.5	23/24 (Field Season 1) On-Ice Activities		UW (PSL)	Repair and re-fit EHWD subsystems. Commission Independent Firn Drill (IFD) and Antarctic Rodwell Apparatus (ARA Drill). Set-up Seasonal Equipment Site (SES).
4	1.2.8.6	24/25 (Field Season 2) On-Ice Activities		UW (PSL)	Complete SES set-up and remaining interconnects. Integrate and test sub-systems including Generator & PDM system integration, verification, and testing. Perform control system testing and "wet-testing" of EHWD subsystems. Firn drill all holes.
4	1.2.8.7	25/26 (Field Season 3) On-Ice Activities		UW (PSL)	Deep drilling all holes; Assist with string installation; Drill system decommissioning and storage/retro.
3	**1.2.9**	**Installation – Off-ice**	**Tosi**	**UW**	Development of tools, equipment and procedures to ensure smooth and safe handling and testing of sensors at the South Pole and installation of 7 strings.
4	1.2.9.1	Sensor Handling & Testing: Process & Equipment	Tosi	UW	Define and develop the handling process for sensors and special devices at the South Pole, including execution of the South Pole Acceptance Testing (SPAT). Coordinate with ASC to secure use of suitable support equipment at the South Pole.

4	1.2.9.2	Rigging for String Installation	Tosi	UW	Determine & procure rigging hardware to be used during installation to connect safely the sensors to the Main Down Hole Cable.
4	1.2.9.3	Installation Monitor Equipment: Depth Monitor and Handheld Testers	Tosi	UW	Development of tools to be used during and after installation to monitor the depth of the string and connectivity to the sensors through hand-held devices.
4	1.2.9.4	Logging & Calibration Support	Tosi	UW	Support bore hole logging. Implementation of electronic logbook for geometry record.
4	1.2.9.5	Develop Installation Training Package	Tosi	UW	Develop training and training tools for installation personnel
3	1.2.10	Installation Field Seasons	Tosi	UW	This WBS includes: detailed activities list and on-site management of polar field season work for installation; on-ice installation activities, including pre-installation activities and installation proper activities coordinated with deep drilling; labor, travel, M&S for installation lead; all the remaining labor is provided by in-kind personnel and personnel from other WBS (1.6 and 1.4)
4	1.2.10.1	Seasonal Staffing & Training, Off-Ice Coordination	Tosi	UW	Off ice training (installation team, drillers and management is trained for installation activities at the South Pole)
4	1.2.10.2	Installation Field Season 0 (FY23)	Tosi	UW	Activities and cargo movement related to installation in FS0 (FY23)
4	1.2.10.3	Installation Field Season 1 (FY24)	Tosi	UW	Activities and USAP cargo movement related to installation in FS1 (FY24)
4	1.2.10.4	Installation Field Season 2 (FY25)	Tosi	UW	USAP cargo movement related to installation in FS2 (FY25). Installation of Field Hubs, patch panels and patch cables. Surface Cables Assemblies are installed into the into the ICL through the ICL west tower and connected to the Field Hubs. Surface Junction Boxes are installed for all the 7 Strings. The Sensor Testing Setup, sleds and tent are prepared. Two strings worth of sensors are fully tested.

4	1.2.10.5	Installation Field Season 3 (FY26)	Tosi	UW	Activities and USAP cargo movement related to installation in FS3 (FY26). Test of 7 strings of sensors. Installation of 7 strings. Coordination with Drill Activities.
2	**1.3**	**Deep Ice Sensor Modules**	**Karg**	**DESY**	This element is responsible for the design and production of the deep-ice optical sensor modules. The modules connect mechanically and electrically to the downhole cable assembly (WBS 1.4.1) and shall communicate with the Field Hub (WBS 1.4.3). The modules must provide interfaces for calibration assemblies (WBS 1.5.2) and shall support in-situ calibration (WBS 1.5.1). Deliverables are up to 800 deployment-ready optical sensors that meet the high-level design requirements of the IceCube Upgrade.
3	**1.3.1**	**mDOM**	**Kappes**	**Münster**	This element is responsible for the design and production of the mDOM, including software and firmware to integrate it into the IceCube Upgrade data acquisition system, acceptance tests, and procedures and tools for safe transport and deployment. Deliverables are up to 500 deployment-ready mDOMs delivered to Port Hueneme that meet the high-level design requirements of the IceCube Upgrade.
4	1.3.1.1	mDOM DAQ Electronics	Sulanke	DESY	Design, development, production, and testing of the electronic circuit PCB or PCBs responsible for PMT analog signal processing, digitization, time-stamping, and transmission to the surface.
4	1.3.1.2	mDOM PMT		KIT	Selection and procurement of the photomultiplier tube detectors (24) in each mDOM. The photomultiplier, or PMT, is the fundamental detecting element of the sensor.
4	1.3.1.3	mDOM High Voltage Subsystem	**C. Wendt**	UW	Design, development, procurement, and production of the subassemblies to produce the high voltage bias to the photomultiplier tubes. Includes generator, base, and digital control / interface to the DAQ electronics.
4	1.3.1.4	mDOM Pressure Vessel		Münster	The delicate mDOM photomultipliers and electronics are housed in borosilicate glass pressure housings to protect them from the high pressure environment of deployment. Material UV transparency and background light production through a combination of intrinsic radioactivity and

					scintillation are key performance parameters. This element covers design, development, and procurement of these housings.
4	1.3.1.5	mDOM PMT Support Structure		Münster	The PMT support structure provides the mechanical interface for the 12 PMTs, reflector rings to shape the PMT angular acceptance profile, the calibration devices, and the containment of the optical gel in one hemisphere of the integrated mDOM. This element covers design, development, and production of the support structures and the reflector rings.
4	1.3.1.6	mDOM Gel		Münster	The gel provides optical coupling between the PMT entry window and the pressure vessel. It further protects the PMT during transport. This element covers the selection and procurement of the optical gel.
4	1.3.1.7	mDOM Harness	Pollmann	Wuppertal	The harness provides the mechanical interface to mount the mDOM to the main cable. This element covers the design, development, and procurement of the mDOM harness.
4	1.3.1.8	Integrated mDOM	Schust	DESY	This element covers the design of the integrated mDOM sensor module and includes: the physical subcomponents such as mechanical support structures and fasteners; integrated module design verification testing; packaging and shipping; deployment tools and procedures.
4	1.3.1.9	mDOM Production Facilities	Schust	DESY	The labor, material, and capital equipment to design, purchase, and operate facilities for mDOM series production and final acceptance testing. Deliverables are production facilities, including procedures and tools, with the capacity for series production of up to 600 mDOMs in one year. This element also includes the development, purchase, and production of unified facilities, procedures and tools for final acceptance testing of mDOMs during series production.
4	1.3.1.10	mDOM Production and Testing	Schust	DESY	This element captures labor and consumables expended during production and testing of up to 600 mDOMs. This element also includes the expenses of delivery to Port Hueneme.

3	**1.3.2**	**D-Egg**	**Ishihara**	**Chiba**	This element is responsible for the design and production of the D-Egg, including software and firmware to integrate it into the IceCube Upgrade data acquisition system, acceptance tests, and procedures and tools for safe transport and deployment. Deliverables are about 300 deployment-ready D-Eggs delivered to Port Hueneme that meet the high-level design requirements of the IceCube Upgrade.
4	1.3.2.1	D-Egg DAQ Electronics		Chiba	Design, development, production, and testing of the electronic circuit PCBs for PMT analog signal processing, digitization, time-stamping, and transmission to the surface.
4	1.3.2.2	D-Egg PMT		Chiba	Selection and procurement of the photomultiplier tube detectors (2) in each D-Egg. The photomultiplier, or PMT, is the fundamental detecting element of the sensor.
4	1.3.2.3	D-Egg High Voltage Subsystem		Chiba	Design, development, procurement, and production of the subassemblies to produce the high voltage bias to the photomultiplier tubes. Includes high voltage generator, PMT base, and the interface to the DAQ electronics.
4	1.3.2.4	D-Egg Pressure Vessel		Chiba	The delicate D-Egg photomultipliers and electronics are housed in borosilicate glass pressure housings to protect them from the high pressure environment of deployment. The UV transparency of the material and background light production through a combination of intrinsic radioactivity and scintillation are key performance parameters. This element covers the design, development, and procurement of these housings.
4	1.3.2.5	D-Egg Gel		Chiba	The gel provides optical coupling between the PMT entry window and the pressure vessel. It further protects the PMT during transport. This element covers the selection and procurement of the optical gel.
4	1.3.2.6	D-Egg Harness		Chiba	The harness provides the mechanical interface to mount the D-Egg to the main cable. This element covers the design, development, and procurement of the D-Egg harness.
4	1.3.2.7	Integrated D-Egg		Chiba	This elements covers the design of the integrated D-Egg sensor module and includes: the physical subcomponents such as mechanical support

					structures and fasteners; integrated module design verification testing; packaging and shipping; deployment tools and procedures.
4	1.3.2.8	D-Egg Production Facility		Chuba	The labor, material, and capital equipment to design, purchase, and operate facilities for D-Egg series production and final acceptance testing. Deliverables are production facilities, including procedures and tools, with the capacity for series production of 300 D-Eggs in one year. This element also includes the development, purchase, and production of unified facilities, procedures and tools for final acceptance testing of D-Eggs during series production.
4	1.3.2.9	D-Egg Production and Testing		Chiba	This element captures labor and consumables expended during production and testing of 300 D-Eggs. This element also includes the expenses of delivery to Port Hueneme.
3	**1.3.3**	**PDOM**	**Sandstrom**	**UW**	This element is responsible for upgrading 20 spare IceCube Gen1 DOMs with PDOM readout electronics, HV systems, calibration devices, and penetrators. This includes software and firmware to integrate it into the IceCube Upgrade data acquisition system, acceptance tests, and procedures and tools for safe transport and deployment. Deliverables are 20 deployment-ready refurbished IceCube DOMs delivered to Port Hueneme that meet the high-level design requirements of the IceCube Upgrade.
4	1.3.3.1	PDOM DAQ Electronics		UW	Design, development, production, and testing of the electronic circuit PCBs for PMT analog signal processing, digitization, time-stamping, and transmission to the surface.
4	1.3.3.2	PDOM High Voltage Subsystem		UW	Design, development, procurement, and production of the subassemblies to produce the high voltage bias to the photomultiplier tubes. Includes high voltage generator, PMT base, and the interface to the DAQ electronics.
4	1.3.3.3	IceCube DOM Refurbishment		UW	The labor, material, and capital equipment to refurbish IceCube DOMs with PDOM readout electronics, HV systems, calibration devices, and penetrators. The expected yield is 20 PDOMs. This element also includes final acceptance testing and the expenses of delivery to Port Hueneme.

3	**1.3.4**	**Ice Comms Module**	**Sulanke**	**DESY**	Common to all 3 sensor types, may be implemented completely on the main board or as a standalone module that can be fitted onto all 3 sensor main boards. Will also be used in Standalone Calibration devices. Directly 'talks' to the Surface Comms Module that is located in the FieldHub. This element includes the firmware running on the ICM, including the golden image with boot loader and firmware update functionality, communications and error detection, and device addressing, and RapCal functionality.
4	**1.3.4.1**	ICM Electronics	Sulanke	DESY	This element includes the development, schematics design, PCB layout, and production of 900 ICM electronics modules.
4	**1.3.4.2**	ICM Firmware	Meures	UW	This element includes the firmware running on the ICM, including the Golden Image with boot loader and firmware update functionality, communications and error detection, device addressing, and RapCal functionality.
4	**1.3.4.3**	Mini-FieldHub ICM Firmware	Meures	UW	This element includes the firmware running on the two ICMs located in the mini-FieldHub (in WBS 1.4.3.1) to allow lab testing of the power, communication and timing distribution for all sensors and calibration devices. Its development is closely intertwined with and happens in parallel to the ICM Firmware (WBS 1.3.4.2).
3	**1.3.5**	**Special Devices**	**Böser**	**Mainz**	This element is responsible for the coordination of R&D optical modules that can be co-deployed in small numbers. It ensures that all R&D modules meet the interface requirements of the IceCube Upgrade and that they do not add any unnecessary risk to the project goals. It may also include R&D devices that are not optically based.
2	**1.4**	**Comms, Power, and Timing (CPT) Distribution System**	**DeYoung**	**MSU**	This category is responsible for the physical and electronic systems providing the interface between new sensor and calibration instrumentation and ICL/station infrastructure (power, communications for control and readout, global timing). Deliverables include the physical cables to which new instruments are connected, surface readout electronics and associated software and firmware other than the Comms Module, and the systems for connecting these readout electronics to the station

					network and power system and the IceCube master clock. This category also includes construction of a test system in the Northern Hemisphere for testing DAQ and control software and firmware prior to deployment at Pole.
3	**1.4.1**	**Downhole Cable Assemblies**	**Ferguson**	**MSU**	This element includes design, procurement, and quality assurance of the physical cable assemblies running to the in-ice sensors and calibration devices, as well as their delivery to Port Hueneme.
4	1.4.1.1	Main Cable Assembly (MCA)	Ferguson	MSU	The labor, material, and capital equipment required to design, spec, purchase and assure quality of the main downhole cables with breakout connectors. This element is responsible for cable vendor selection, including purchase and testing of samples as required for final selection, and for delivery of the completed cables to Port Hueneme.
4	1.4.1.2	Breakout Cable Assemblies (BCA)	Ferguson	MSU	The labor, material, and capital equipment required to design, spec, purchase and assure quality of the breakout cable assemblies connecting the main cable to the deployed instruments.
4	1.4.1.3	Penetrator Cable Assembly (PCA)	Ng	MSU	The labor and materials required to design, procure and assure quality of the common penetrator assembly carrying conductors from the breakout cable assemblies through the pressure vessels surrounding DOMs and calibration instruments.
4	1.4.1.4	String Hardware	Ng	MSU	The labor, material, and capital equipment required to design, spec, purchase and assure quality of deployment chains and attachment points, cable weights, cable stops, penetrator assemblies used by in-ice sensors, and miscellaneous cable hardware. This element also includes specification of common requirements (size, load capacity, attachment points, etc.) for harnesses used to connect DOMs and stand-alone calibration devices to the cables. Delivery of related equipment to Port Hueneme is also included.
3	**1.4.2**	**Surface Cables**	**Kelley**	**UW**	This element includes design, procurement, and quality assurance of the physical cables running along the surface from the IceCube Laboratory (ICL) building to the Upgrade strings. It also includes labor and materials associated with modifications to the ICL required by the Upgrade

					project which are not provided by ASC, and transportation of equipment to Port Hueneme.
4	1.4.2.1	Surface Cable Assemblies	Ferguson	MSU	The labor, materials, and capital equipment required to design, spec, purchase and assure quality of the cable assemblies carrying power, communications, and timing information from the ICL to the terminations of the MCAs in the surface junction boxes.
4	1.4.2.2	Surface Junction Boxes	Ng	MSU	Labor, material, and equipment required to design and construct or purchase the junction boxes housing the connections between the MCAs and SCAs.
4	1.4.2.3	ICL Upgrade	Kelley	UW	The labor to support definition of requirements for SCA entry into the ICL and infrastructure support of CPT surface electronics within the ICL. Includes surface cable entry, power usage, and heat load; any modifications of the ICL are implemented by ASC.
3	**1.4.3**	**FieldHub**	**Sulanke**	**DESY**	This element includes design, production and testing of the FieldHubs, which will control, read out, and supply power and timing signals to the instrumentation and calibration devices connected to the downhole cables. The FieldHub hosts Comms Modules that communicate with the in-device Ice Comms Module over the downhole cable assembly.
4	1.4.3.1	FieldHub Electronics	**Sulanke**	**DESY**	The labor and materials required to design and produce the FieldHub electronics. The labor and materials required to design and produce the surface readout FieldHub electronics, including the mini-FieldHubs used in DOM development and production testing, the FieldHubs to be deployed at South Pole, and all related prototype and development stages.
3	**1.4.4**	**CPT Central Infrastructure**	**Kelley**	**UW**	This element includes design, production and testing of the electronics infrastructure required to distribute timing signals from the IceCube master clock to the FieldHubs in the ICL. This element also includes the power supplies which will supply power to in-ice devices through the FieldHubs.

4	1.4.4.1	Network and Timing	Kelley	UW	The labor and materials required to design, test, and install custom or semi-custom electronics necessary for distributing timing signals from and network communications from the IceCube DAQ to the FieldHubs in the ICL
4	1.4.4.2	Power Supply Modules	Kelley	UW	The labor and materials required to design, test, and install power supplies in ICL, for distribution to in-ice instrumentation through the FieldHubs
3	**1.4.5**	**Northern Test System**	**Ng**	**MSU**	This element includes design, construction and maintenance of a string-scale test facility in the Northern Hemisphere suitable for testing of DAQ software and firmware. The test facility will be remotely accessible to IceCube developers.
4	1.4.5.1	IceCube Emulator	Ng	MSU	The labor, materials, and capital equipment required to set up compute servers, GPS receivers, etc. capable of emulating the IceCube DAQ, master clock, control systems, and CPT central infrastructure. The actual software emulating the IceCube DAQ and control systems, and the compute servers hosting this software, are the responsibility of WBS 1.6.
4	1.4.5.2	Cable/Quad	Halliday	MSU	The labor, materials, and capital equipment required to procure and install a downhole cable or substitute in the Northern test facility.
4	1.4.5.3	Dark Facility	Halliday	MSU	The labor, materials, and capital equipment required to design and install a dark facility to house the sensors and calibration instruments included the Northern Test System.
4	1.4.5.4	NTS Operations	Ng	MSU	The labor and materials required to maintain and operate the Northern Test System after construction.
2	**1.5**	**Characterization and Calibration System**	**Williams**	**Alabama**	This category is responsible for calibrating and characterizing the detector, which consists of both modules and ice. The deliverables are well characterized modules which meet the high level design requirements of the IceCube upgrade for stability and performance, and improved measurements of the modules and the ice relative to our current knowledge of the detector.
3	**1.5.1**	**Module Calibration**	**Kauer**	**UW**	This element is calibration of the individual module response. Includes calibration in the lab and after deployment.

4	1.5.1.1	Production Calibration		UW	Calibrates module response in the laboratory as a function of angle, wavelength and intensity. Each element under 1.3 (Deep Ice Sensor Modules) must have a calibration plan. Deliverable is a usable database of calibration constants which can be incorporated into simulation and analysis.
4	1.5.1.2	*In situ* sensor response calibration		UW	Responsible for design of in-situ individual module response calibration (equivalent to IceCube DOMCal), using onboard light sources such as LED, pulses and dark noise. Integrated array calibration, including ice, is handled under 1.5.3.
3	**1.5.2**	**Calibration Assemblies**	**Resconi**	**Munich**	This element is responsible for design, testing, production and integration of devices whose purpose is calibration of modules, the ice or both.
4	1.5.2.1	Onboard LED flashers	Nuckles	UW	This element is responsible for light sources which are integrated into modules, expected to be LEDs. Responsible for design, integration, production and testing of LEDs and supporting electronics, including LED mechanical holder, optical interface to the glass and LED driver circuit. All light sources must be integrated into the module data flow in such a way that light sources are always flagged as such in the data stream. Includes responsibility for demonstrating with simulation that the light source as designed will meet high level requirements of improving detector an ice characterization. Onboard light sources must not negatively impact normal operation of the module. Deliverables are stable, well characterized, light sources with complete coverage of the deployed modules.
4	1.5.2.2	Standalone light sources	Resconi	Munich	This element is responsible for design, integration, production and testing of light sources which are not included in photosensor modules, including glass, interface to cable and electronics. Design must include integration into the data stream so that operation of standalone light sources is always flagged as such in the data stream. Testing must include stress testing, freeze-testing and any other survivability testing which would normally be done for a photosensor module under section 1.3. Includes responsibility for demonstrating with simulation that the light source as designed will

					meet high level requirements of improving detector and ice characterization. Standalone light sources must not negatively impact the normal operations of the detector.
4	1.5.2.3	Camera and Light Detection	Rott	Sungkyunkwan University	Responsible for light detection devices (other than the modules themselves), such as cameras, specifically designed for detector calibration. Includes design, testing and integration of cameras into modules where applicable. Includes responsibility for demonstrating with simulation that the camera as designed will meet high level requirements of improving detector and ice characterization. Cameras integrated into modules must not negatively impact normal module operation and must meet power and communication requirements for integration in the module. Where cameras use light sources, such light sources must be integrated into the data stream so that operation of standalone light sources is always flagged as such in the data stream.
4	1.5.2.4	Acoustic Sensors	Wiebusch	Aachen	Responsible for design, testing, production and integration of acoustic sensors and transmitters in modules. Responsible for demonstrating that these sensors will deliver precise geometry measurement in excess of what we can achieve with LEDs, either in the upgrade or in the larger Gen2 detector.
4	1.5.2.5	Inclinometers, Compasses	DuVernois	UW	Responsible for design, testing, production and integration of inclinometers, compasses and other devices meant to measure absolute direction and orientation.
4	1.5.2.6	Mini Mainboard	Feldhauser	Aachen	Responsible for design and testing of a small ICM compatible mainboard which will be a common interface for standalone calibration devices.
3	**1.5.3**	**Array Calibration**	**Blot**	**DESY**	This element is responsible for characterization and calibration of the deployed array.
4	1.5.3.1	Calibration benchmarks		DESY	Responsible for final establishment of benchmarks for 1) calibration and characterization of the newly deployed detector elements and 2) improved calibration of the existing detector.

4	1.5.3.2	Timing calibration		DESY	Responsible for verification of the timing precision and overall timing accuracy of the deployed instruments.
4	1.5.3.3	Geometry calibration		DESY	Responsible for measurement and correction of the geometrical position of the deployed modules with respect to the surface and with respect to other IceCube modules. Includes development of deployment instrumentation such as pressure sensors and laser rangers, and measurement of geometry post-deployment with LED flashers, acoustic sensors and muons.
4	1.5.3.4	Ice properties calibration	Chirkin	UW	Responsible for using newly deployed and existing instrumentation to measure the ice properties, for verifying the hole ice properties of newly drilled holes.
4	1.5.3.5	Pre-deployment Hole measurement		UW	Responsible for devices such as the dust logger which measure the drillhole properties before freeze-in.
3	**1.5.4**	**Calibration Management**	**Williams**	**Alabama**	Responsible for management of the calibration effort.
4	1.5.4.1	Calibration Management		Alabama	Coordinate all calibration elements, organize reviews, monthly reports, oversee schedule and budget.
4	1.5.4.2	Calibration Travel		Alabama	Travel to reviews and working meetings
2	**1.6**	**M&O Data Systems Integration**	**Blaufuss**	**UMD**	This element is responsible for the seamless integration of all new systems from the IceCube upgrade project into the existing IceCube detector maintenance and operations structures. This includes integration with online software systems, databases, offline software components, simulation software packages, and computing infrastructure needed to support this effort.
3	**1.6.1**	**Online Software**	**Braun**	**UW**	This element will ensure that all hardware seamlessly integrates into the current IceCube online software systems. This include: The IceCube DAQ, where new systems will integrate at the trigger, event readout, control and monitoring levels with the current DAQ system, yielding a completely unified data readout system. The IceCube experiment control: new systems will be fully controlled and configured by existing IceCube control systems, including storage of configuration

					and calibration items into databases, and realtime and long-term monitoring of new systems. The IceCube online filtering system: data from new systems will be included in the online event filtering system and used as part of the event filtering decision process.
4	1.6.1.1	DAQ	Bendfelt	UW	Integrate new optical sensors and calibration devices into a unified data acquisition system, providing seamless triggering and data readout across all optical sensors
4	1.6.1.2	Experiment control and configurations	Frere	UW	Provide support for configuration management of all optical sensors and calibrations in operations in IceCube. This includes control of all calibration devices during operation, and database storage of configuration information.
4	1.6.1.3	Online filtering	Blaufuss	UMD	Provide support to extend the online event filtering system to provide online filters for the unified data readout from existing and new optical sensors.
4	1.6.1.4	OM Software and testing	Braun	UW	Provide OM resident software for testing, calibration, and data collection for all types of OMs, including South Pole module acceptance testing.
4	1.6.1.5	FieldHub Software	Kelley	UW	Provide Field-Hub resident software that provides the interface between CPT infrastructure, including the Comms Module and associated firmware, and the IceCube DAQ infrastructure.
4	1.6.1.6	OM Firmware	Fienberg	PSU	Provide OM resident firmware for testing, calibration, and normal (in-ice) data collection for all types of Oms.
3	**1.6.2**	**Offline Software**	**Olivas**	**UMD**	This element will ensure that offline software packages are updated to include classes and methods to accommodate data produced by new systems. This can include raw data readout classes; calibration, configuration and monitoring information; as well as adapting core software packages to properly utilize this additional information in reconstruction algorithms, and verification of software functionality against simulation and calibration information.
4	1.6.2.1	Core Software	Olivas	UMD	provide extensions to IceCube core software (IceTray framework and data structures) to support

					new optical sensors and calibration devices (including data structures and supporting software for raw data readout, calibration and configuration information)
4	1.6.2.2	Reconstruction support	Meagher	UW	Provide software support to IceCube reconstruction software to include information from new optical sensors and calibration devices for use in event reconstruction. Including photon feature extraction from calibration sensor data and integration into advanced likelihood reconstruction algorithms.
4	1.6.2.3	Tools and infrastructure	LaDieu	UMD	Provide support for Upgrade software development and testing within the IceCube systems, including: source code revision control management, and build and testing infrastructure.
3	**1.6.3**	**Simulation Software**	**Stuttard**	**NBI**	This element will ensure that all new systems are accurately simulated within the IceCube simulation packages, including new optical sensors, calibration systems, and software systems used in readout (triggering) and calibration, as well as production of data samples for verification comparisons with data.
4	1.6.3.1	Electronic readout and digitization simulation	Stuttard	NBI	Provide accurate simulation of optical sensor signal digitization, readout electronics and data acquisition software in the IceCube simulation package.
4	1.6.3.2	Calibration device simulation	Stuttard	NBI	Provide accurate simulation of calibration devices within the IceCube simulation package
4	1.6.3.3	Simulation Production	Stuttard	NBI	Ensure complete simulation packages are available for design verification, calibration tasks and data simulation verification tasks.
3	**1.6.4**	**Computing Infrastructure**	**Auer**	**UW**	This element will provide computing infrastructure needed by data systems to support new systems. This includes: Computing systems at South Pole (SPS), northern hemisphere testing hardware (SPTS), as well as local and distributed computing (processing and storage) needs for data and calibration verification tasks.
4	1.6.4.1	SPTS/NTS computing needs	Auer	UW	Provide computing and networking hardware and OS/admin support for software and hardware development in the north is available at the northern hemisphere test setups (SPTS and NTS)

4	1.6.4.2	SPS computing needs	Auer	UW	Provide computing and networking hardware and OS/admin support for the integration of new optical sensors and calibration devices in the ICL at South Pole.
4	1.6.4.3	Distributed computing needs	Barnet	UW	Provide support for mass processing and storage needs within the IceCube computing system to support IceCube Upgrade design and verification activities.
3	**1.6.5**	**Upgrade String Commissioning**	**Blaufuss**	**UMD**	This element will ensure that all newly deployed hardware is operating properly following deployment, will monitor hardware through the refreeze process, and deliver modules to IceCube detector operations that are ready for inclusion in standard run configurations
4	1.6.5.1	Upgrade OM module commissioning	Blaufuss	UMD	Provide commissioning plans, software and support activities for all deployed OM devices
4	1.6.5.2	Upgrade calibration device commissioning	Blaufuss	UMD	Provide commissioning plans, software and support activities for all deployed calibration devices

IceCube Upgrade WBS Dictionary_04112022

Final Audit Report 2022-04-18

Created:	2022-04-11
By:	Mike Zernick (zernick@wisc.edu)
Status:	Signed
Transaction ID:	CBJCHBCAABAA84VuN6N6J2TrgauTdrDXLOCamrASkjFi

"IceCube Upgrade WBS Dictionary_04112022" History

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Signature Date: 2022-04-11 - 7:56:33 PM GMT - Time Source: server- IP address: 144.92.38.238

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2022-04-16 - 4:01:18 AM GMT- IP address: 104.28.111.166

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2022-04-17 - 9:59:28 PM GMT- IP address: 104.28.50.117

Document e-signed by Erik Blaufuss (blaufuss@icecube.umd.edu)
Signature Date: 2022-04-18 - 1:55:10 PM GMT - Time Source: server- IP address: 128.8.164.160

Agreement completed.
2022-04-18 - 1:55:10 PM GMT