



**WISCONSIN ICECUBE
PARTICLE ASTROPHYSICS CENTER**

IceCube Upgrade Risk Register

20200313

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Date	Modified by	Description of changes made
17-Jan-19	J Haugen	Added Change Log tab to track changes made to the Risk Register
6-Feb-19	M. Zernick	Corrected some formulas/Completed analysis for J. Haugen Risks.
11-Feb-19	Zernick/Hanson	Costed Opportunity OPP1. Re-analyzed Risk PM2. Added Average Estimate Column.
15-Feb-19	M. Zernick	Updated PY Remaining Contingency columns to include AVG. Risk Cost. Corrected some earlier risk cost calculations.
19-Mar-19	M. Zernick	Retired the Micro-turbine Risk: EXT1. Retired 5 Holes Only Risk: ORG 7
20-Mar-19	M. DuVernois	Minor edits for style and fixed a couple of calculation errors.
21-Mar-19	T. DeYoung	Reviewed, no changes
23-Mar-19	T. Karg	Reviewed, no changes
23-Mar-19	M. DuVernois	Edited HZC opportunity. Retired it.
28-Mar-19	D. Williams	Reviewed, no changes
28-Mar-19	E. Blaufuss	Reviewed, no changes
31-Mar-19	M. Zernick	Reviewed ORG4. No changes.
4-Apr-19	M. Zernick	Revised Drill Risks as per the 04/03/2019 Drill Risk Meeting. Hid "AVG Cost Column." Changed Drill Lead to Drill MGR. Added Revision Dates.
26-Jun-19	M.Zernick	Reviewed ORG4. No changes. (WBS 1.1.2.1)
26-Jun-19	T. Karg	Reviewed WBS 1.3 risks; no changes
27-Jun-19	T. DeYoung	Clarified wording of TECH2 to reflect baseline geometry. No other changes.
28-Jun-19	D. Williams	Reviewed 1.5 risks, no changes
3-Jul-19	T. Hutchings	Reviewed 1.2 risks, no changes
3-Jul-19	M. DuVernois	Reviewed. No changes.
4-Jul-19	E. Blaufuss	Reviewed. No changed needed now. Tech risk18 no longer applicable.
8-Jul-19	M. Zernick	Tech18 Risk is retired. The IDF is no longer being used by the Icecube Upgrade Project.
24-Sep-19	M. Zernick	Reviewed Risk ORG4. No changes.
25-Sep-19	T. Hutchings	Reviewed 1.2 risks. No changes
27-Sep-19	T. Karg	Reviewed 1.3 risks. Extended ORG5 "Optical moduled by air" into PY5 since the last modules will ship one year later if there is no traverse
30-Sep-19	D. Williams	Reviewed 1.5 risks, no changes
30-Sep-19	E. Blaufuss	Reviewed 1.6 risks, noted retirement of Tech18 per CR#2, dropping IDF from plan.
30-Sep-19	M. Zernick	Added "Last Modified Date" to TECH18 Risk.
2-Oct-19	F. Feyzi	Added revised annual estimates based on PY2 detail planning and PY1 actuals
9-Oct-19	M. Zernick/TH	Added TECH32 and TECH33. (CO2Fire Suppression)/Removed Contingency for retired risks: EXT1, ORG7, and PMI1
20-Dec-19	M. DuVernois	Added TECH34. (PMT w/base production for mDOM before full testing of base)
21-Dec-19	E. Blaufuss	Reviewed 1.6 risks, no changes.
23-Dec-19	M. Zernick	Added Contingency \$ to TECH34.
26-Dec-19	T. Hutchings	Reviewed 1.2 risks. No changes
30-Dec-19	T. Karg	Reviewed 1.3 risks, no changes
30-Dec-19	T. DeYoung	TECH31 probablity very low based on Hexatronic sample. Cost exposure should be recalculated
30-Dec-19	D. Williams	Reviewed 1.5 risks, no changes
2-Jan-20	M. Zernick	Revised TECH 31: recalculated resultant risk exposure/ Contingency for PY18-19 per TY's changes.
6-Jan-20	M. Zernick	Revised TECH31: Changed anticipated risk retirement dates from PY1 (18-19) to PY2 (19-20)
13-Mar-20	TB/MAZ	Added TECH35 to cover frozen drill hose. Clarified distinction between ORG4 and ORG6 regarding injury on the ice.

Table 1. Change Log

Risk Identification and Tracking							Pre-Mitigated Risk Evaluation						Current Risk Response				Major Risk Flag		
Risk ID	Associated WBS	Risk Description	Revision History				Risk Probability	Probability and Impacts			Resulting Risk Exposure			Risk Owner	Risk Occurrence Timeframe	Risk Handling Approach / Response	Risk Trigger	Risk Mitigation Plan and Actions	
			Risk Title	Risk Origin Date	Last Modified Date	Risk Retirement Date		Impact on schedule	Impact on cost	Impact on technical performance	Schedule Risk Score	Cost Risk Score	Technical Performance Risk Score						
ORG6	1.2	Series injury occurs and halts drilling or cancels a season as a result.	Serious Driller/Deployer Injury	12/13/2018	4/4/2019		Very Low	Moderate	Moderate	Moderate	Low	Low	Low	Drill MGR TH	Any Season	Mitigate	Any number of reasons	Thorough safety training as well as systems and individual hazards analysis performed throughout the EHW. All those deploying to Pole will receive Safesite Training. Other mitigations are outlined in the IceCube Upgrade Safety Plan. Further, IceCube Upgrade Management plans to hire experienced persons to deploy to Pole.	
EXT10	1.2	Drilling into obstructions/cables - The tight array is planned in an area with possible "old station" debris	Drill obstructions	12/13/2018	4/4/2019		Moderate	Very low	Very Low	Low	Low	Low	Moderate	Drill MGR TH	21/22 or 22/23	Mitigate	Unknown	Plan ground penetrating radar survey in 2019/20 of proposed array and surrounding area. The Fire Holes will be drilled one year in advance to accommodate potential relocation of holes due to debris.	
ORG7	1.1	The Upgrade Project is funded for only 5 strings.	Only 5 Strings	1/9/2019	4/4/2019	3/1/2019	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Hanson	21/22 and 22/23	Mitigate	Receipt of funding for only 5 strings	Receipt of KIT Funding to cover the additional 2 strings.	
TECH9	1.2	Cut/Damaged Drill Cable - Equipment or unknowns end up damaging the main drill cable.	Damaged Drill Cable	12/13/2018	4/4/2019		Low	Very low	Moderate	Low	Low	Moderate	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Operator error	Proper visible flagging and markings installed. Two brand-new cables will be supplied to the Pole for use in 22-23.	
TECH23	1.2	Fire/Major Equipment Failure - A fire develops resulting in damage to equipment. Drilling is delayed 1 year.	Fire	12/13/2018	4/4/2019		Low	High	High	Low	Moderate	Moderate	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Diligent Hazards Analysis, risk mitigation planning, and training. CO2 fire suppression system testing in 19/20 season. Procure CO2 for 21/22 season.	
TECH20	1.2	Cut/Damaged Drill Hose - Equipment or unknowns damage the main drill hose.	Damaged Drill Hose	12/13/2018	4/4/2019		Low	Very low	Moderate	Low	Low	Moderate	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Operator error	Proper visible flagging and markings installed. There will be 2 spare sections of hose on site in 22-23. A procedure for replacing a section of the hose will be developed.	
ORG1	1.2.3	During hot-water drilling the main drill head is stuck or frozen in due to hole constriction or operator error. If not mitigated this could lead to partial loss of season.	Stuck Drill	8/15/2018	4/4/2019		Low	Very High	Very High	Low	Moderate	Moderate	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Provide robust operator training. Assume hole measuring devices are accurate and reliable. Develop procedure to re-ream narrow areas in hole to assure minimum diameter is maintained. Drill conservatively if possible, purchase additional hose segments and drill head if season appears to be at risk.	
ORG2	1.2.8	Inexperienced Driller Recruitment. EHW experience is a very unique and specific skill set, not having experienced drillers presents a risk cost, schedule, and project success.	Inexperienced Drillers	8/15/2018			High	High	High	Low	High	High	Moderate	Drill MGR TH	Drill season 2022-2023	Mitigate	Recruitment fail	Attract and incentivize experienced drillers to return to the upgrade project.	
ORG3	1.2.8	If logistics preclude the delivery of deliveries for major components, then an additional season might be required.	Season delay	8/2/2018			Moderate	Moderate	Moderate	Very low	Moderate	Moderate	Low	PM Feyli	During 2022-2023 Pole season	Mitigate	Problems during season	Mitigate underlying reasons for Pole season issues, financial contingency to support additional season	
PM1	1.1.1	If we do not find a suitable PM, reviews will be delayed and budgets may not be well controlled.	PM job	8/2/2018		7/1/2019	Moderate	Moderate	Low	Very low	Moderate	Moderate	Low	PI Hanson	PV1	Mitigate	Job search failure	More broadly advertise, raise salary, empower interim and deputy PM	
EXT1	1.2.2	Capstone Microturbine Generators not performing as necessary. Could slow drilling season.	Microturbines	8/2/2018	4/4/2019	3/1/2019	Moderate	High	Moderate	Moderate	High	Moderate	Moderate	Drill MGR TH	Until delivery	Mitigate	Performance	Purchase of additional generator unit after drill IVT (PV4) in 5 Pole environment. The microturbines will not be utilized in GEN 1.	
TECH22	1.2.2	Main Heater Failures - Enough of the heaters fail during drilling operations to impact hole diameter or lifetime below requirements	MHP Failures	12/13/2018	4/4/2019		Low	Very low	Moderate	Low	Low	Moderate	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Procure additional model 75 heaters for complete replacement if needed. Assure adequate spare parts for multiple failure possibility. The SES Wet test will confirm the functionality of the heaters. One GEN1 Heater was disassembled, and the Evaporator Coil was tested for thickness. It was determined that there is 75% wet test.	
TECH25	1.2.3	Tower - Structural Failure - Tower is overloaded and damaged during drilling/deployment operations	Tower failure	12/13/2018	4/4/2019		Low	Low	Moderate	Low	Low	Moderate	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Perform detailed and coordinated load analysis. Perform tower structural analysis. Retro crescents for inspection and rebuild. Confirm tower-2 as a ready back-up.	
TECH26	1.2.3	Drill Head Communication Failure - Communication from drillhead during drilling operations ceases	Drill Head Problems	12/13/2018	4/4/2019		Low	Low	Low	Low	Low	Low	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Thorough system testing in CONUS. Secure consultant (Jumbal) to assist and cross-train. Confirm drill-heads 2 & 3 are ready back-ups. Develop Guidelines for "Drilling Blind."	
TECH27	1.2.3	Main Supply Hose Reef Failure - The MSR develops a major motor, reel, wind, or technical problem and deemed unusable	MSR Failure	12/13/2018	4/4/2019		Low	High	Moderate	Low	Moderate	Moderate	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Thorough inspection and testing during the 19/20 season. Confirm/procure at-risk spare parts.	
TECH24	1.2.4	Computer Control Failure - Network or software problems result in control failure during drilling.	Control failures	12/13/2018			Low	Moderate	Low	Low	Moderate	Low	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Robust testing in CONUS of sub-assemblies. Complete install in 21/22 with full testing.	
TECH6	1.2.5	Motor Drive Problems - New motor drives have unforeseen problems	Motor Drives	12/13/2018	4/4/2019		Low	Low	Low	Low	Low	Low	Low	Drill MGR TH	21/22 or 22/23	Mitigate	Technical problems or Operator Error	Installation, programming, training, and testing of all motor drives while in CONUS. Installation and testing at NPX season prior to drilling. Train multiple drillers/Engineers on how to maintain/troubleshoot the Allen Bradley Motor Drives.	
TECH21	1.2.6	High Pressure Pump Failure - Pump or pump motor fails prior to or during drilling operations	HPP Failure	12/13/2018	4/4/2019		Low	Very low	Moderate	Low	Low	Moderate	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Procure additional spare pumps and motors. Provide driller training for field replacement during prior off-ice season.	
TECH8	1.2.6	Return Water Pump Failure - The RWP fails during drilling operations.	RWP Failure	12/13/2018	4/4/2019		Low	Low	Low	Low	Low	Low	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Procure spare, develop replacement procedure, train drillers	
TECH9	1.2.7	Independent Firm Drill Failure - Serious problems result in the inoperability of the ID during the 21/22 season	ID Failure	12/13/2018	4/4/2019		Low	Moderate	Moderate	Low	Moderate	Moderate	Low	Drill MGR TH	21/22 Season	Mitigate	Technical problems or Operator Error	Locate and update original plans and equipment (carrot with leaker circuit) to firm drill using hot water.	
TECH1	1.2.8	A majority of the EHW equipment has been stored/cold-soaked for 6+ years at the South Pole. Risk of old EHW equipment failure.	Old EHW Failure	8/15/2018	4/4/2019		Low	Moderate	High	Moderate	Moderate	Moderate	Moderate	Drill MGR TH	Drill season 2022-2023	Mitigate	Failure upon initial drill inspection 18/19 season.	Thorough and robust testing performed in seasons prior to deep drilling. Identify most at-risk equipment and procure additional spare parts or refurbish and repair equipment.	
TECH30	1.2.9	String Installation Winch Failure - The TU20 winch fails during installation operations.	TU-20 Failure	12/13/2018	4/4/2019		Low	Low	Moderate	Low	Low	Moderate	Low	Drill MGR TH	Drill season 2022-2023	Mitigate	Technical problems or Operator Error	Inspect and repair both TU-20's to full operation. Create Deployment Cable Swap-Out Procedure.	
TECH31	1.4.3	Comms bandwidth. If comms protocol cannot provide bandwidth needed for required number of DOMs per wire pair, on-board triggering is needed	Comms bandwidth	8/18/2018		1/6/2020	Moderate	High	Moderate	Low	High	Moderate	Moderate	CPT lead DeYoung	Until cable procurement	Mitigate	Inability to identify cable assembly partner for Heatsonic or alternative	Design protocol for efficiency and robustness, deploy all elements to KITS for integration testing, begin Firmware development early if needed	
ORG4	1.1.2.1	Major injury occurs during drilling. Work stoppage occurs until review is performed and "safe to proceed" determined.	M&O Injury	8/2/2018			Moderate	Low	Moderate	Very low	Moderate	Moderate	Low	Safety Mgr Zernick	Drill season 2022-2023	Mitigate	Injury	Extensive safety program training before and on the ice, procedure for handling injury root cause analysis, procedure for reauthorizing work. Design engineered safety controls throughout to assist mitigation.	
TECH2	1.3.1 1.3.2	If glass spheres have higher than expected radioactive contamination, then quality of optical module data suffers	Bad glass	8/2/2018			High	Very low	Very low	Moderate	Low	Low	High	OM lead Karg	Before mDOM / D-Egg FDR	Mitigate	Test failures	Monitor manufacturing, test samples at prototype stage. Some effort may be necessary to handle additional bandwidth in sensor firmware.	
PM2	1.1.1.1	If project office is not able to closely track international finances, then those cost controls may not succeed, causing schedule delays.	In-kind tracking issues	8/2/2018			Moderate	High	Moderate	Low	High	Moderate	Moderate	PM Feyli	Throughout project execution.	Mitigate	Milestones of in-kind contributions missed	Maintain milestones for in-kind detailed tracking by L2 cost account manager.	
ORG5	1.1.3	If schedule delays lead to less than full compliance of optical modules for delivery, then air shipment is required	Optical modules by air	8/2/2018			Moderate	Very low	Low	Very low	Low	Moderate	Low	OM lead Karg	Ahead of 2021 shipping deadline	Mitigate	Schedule slip	Plan for some air shipments which could cover last modules, keep on top of deliveries	
TECH3	1.5.1.1	If there are delays in implementation of common calibration database for production calibration, calibration constants may not be stored in easily usable condition	Production calibration database	8/17/2018			Low	Low	Very low	Moderate	Low	Low	Moderate	1.5.1 L3 Lead Williams	Module Production	Better communications	Deliverable delay in 1.5.1.1	Coordinate early between module production sites and 1.5.1 L3 lead but add software labor if needed PV4 latest.	
TECH4	1.5.1.2	Different module designs may delay implementation of Flashers and other calibration devices, DOM calibration software and interface to DAQ/experiment control	DOMcal equivalent	8/17/2018			Low	Low	Very low	Moderate	Low	Low	Moderate	1.5.1 L3 Lead Williams	Module deployment	Better communications	Deliverable delay in 1.5.1.2	Be pro-active on module calibration implementation and on the software and hardware implementation of the collection of module calibration information; additional SW development may be necessary by PV4 latest.	
EXT7	1.1.3.2	ASC Support Impacts - Equipment and labor support is reassigned to other projects, or unavailable.	ASC Support	12/13/2018	1/16/2019		Low	Low	Moderate	Low	Low	Moderate	Low	Haugen	21/22 or 22/23	Mitigate	Communication from ASC Science Support staff that Upgrade project will not get agreed upon support.	Detailed planning meetings with ASC. Review submitted SIP each year. Confirm support in RSP matches needs identified in the SIP.	
EXT8	1.1.3.1	Traverse Delays - Weather or equipment problems precludes a traverse moving IceCube equipment to NPX.	Traverse Delays	12/13/2018	1/16/2019		Low	Moderate	Low	Very low	Moderate	Low	Low	Haugen	21/22 or 22/23	Mitigate	Communication from Traverse Leader that delivery to NPX is delayed.	Detailed planning meetings with ASC. Track traverse metrics on meeting delivery to NPX commitments.	
EXT9	1.1.3.2	Winter Storage DNF Failure - McMurdo hose storage heat failure, or NPX drill head storage heater/power failure.	DNF Failure	12/13/2018	1/16/2019		Very low	High	High	Very low	Moderate	Low	Low	Haugen	21/22 or 22/23	Mitigate	Technical problems or Operator Error	Work with ASC to develop back-up plan in the event of long term power failure. If there is a major power failure at Pole during the winter, the Winterover staff will make corrections ASAP.	
EXT11	1.1.3.1	Domestic/International Shipping Delays - Equipment being shipped to PH, or via vessel are delayed en route.	Shipping Delays	12/13/2018	1/16/2019		Low	Moderate	Moderate	Very low	Moderate	Moderate	Low	Haugen	21/22 or 22/23	Mitigate	Poor performance during the Production phase for Upgrade instrumentation.	Schedule CONUS shipments of most critical items with additional time. Plan vessel/traverse shipments with a backup IC330 fly-in plan.	
TECH2	1.2.8.4	Major Fire w/ CO2 Fire Suppression System. CO2 System is disconnected.	CO2 Fire System Removal	10/9/2019	10/9/2019		Low	High	High	Moderate	Moderate	Moderate	Moderate	Hutch	21/22 and 22/23	Mitigate	Fire in a Hot MDS	1. Fire extinguishers 2. Heat Rate Indicator to DCC 3. Smoke Detectors to DCC 4. CO Monitors to DCC 5. Routine checks 6. Training 7. Hardware Safety Mechanisms	
TECH3	1.2.8.5	Discharge of CO2 Fire Suppression System-Asphyxiation	CO2 Discharge	10/9/2019	10/9/2019		Low	High	High	Moderate	Moderate	Moderate	Moderate	Hutch	21/22 and 22/23	Mitigate	Fire or Accident	1. Disconnect CO2 System.	
TECH4	1.3.1	Hamamatsu starts production of PMTs plus HV bases before full base testing is completed	Hamamatsu production	12/20/2019	12/20/2019		Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Timo	First half of 2020	Mitigate	Test failures	1. Work with Hamamatsu for a partial production plan to minimize cost impact if different base required. 2. Improve communications between project and Hamamatsu. 3. Expedite testing.	
TECH5	1.2.6	Drill Hose gets exposed to deep freeze conditions. < 40 C, increased rate of hose failure during drill season.	Frozen Drill Hose	3/10/2020	3/10/2020		Very High	Very low	Low	High	Moderate	Moderate	High	1.2 L2	Drill season 2022-2023	Mitigate	Environmental	Implement hose heating system to heat hose on reel over winter. This was done successfully on GEN1. Keep hose temperature above brittle transition point of ASC. Monitoring will be in place.	
EXT12	1.1.3.2	Fuel Delivery/Station Delays - Drilling fuel is not available or reallocated in the 22/23 season	Fuel Delays	12/13/2018	1/16/2019		Very low	High	Low	Low	Low	Low	Low	Haugen	22/23	Mitigate	ASC communication in 2022	Communicate fuel requirements to ASC and NSF as early as possible and monitor. Fuel requirements will be in the SIP and are confirmed by the RSP.	

Table 2a. Risk Register Part 1

Risk Identification and Tracking				Comments / Notes	Risk Cost Calculation				Risk Retirement Timeframe		Remaining Contingency				
Risk ID	Associated WBS	Risk Description	Risk Title		Risk Cost Exposure	Low Estimate	Average Estimate	High Estimate	Expected	Actual	PY1	PY2	PY3	PY4	PY5
ORG6	1.2	Serious injury occurs and halts drilling or cancels a season as a result.	Serious Injury	Full season labor (\$825,824), deployment/travel costs	\$983,000	\$49,150	\$147,450	\$245,750	2022-2023		\$147,450	\$147,450	\$147,450	\$147,450	\$147,450
EXT10	1.2	Drilling into obstructions/cables - The tight array is planned in an area with possible "old station" debris	Drill obstructions	1-week delay, full drill team (\$70,214)	\$70,000	\$3,500	\$10,500	\$17,500	2021-2022		\$10,500	\$10,500	\$10,500	\$10,500	\$10,500
ORG7	1.1	The Upgrade Project is funded for only 5 strings.	Only 5 Strings	The KIT Funding is pretty much a given. Risk Exposure Cost is	\$500,000	\$25,000	\$75,000	\$125,000	2018-2019	2018-2019	\$0	\$0	\$0	\$0	\$0
TECH19	1.2	Cut/Damaged Drill Cable - Equipment or unknowns end up damaging the main drill cable.	Damaged Drill Cable	1-week delay, full drill team (\$70,214)	\$70,000	\$3,500	\$10,500	\$17,500	2022-2023		\$10,500	\$10,500	\$10,500	\$10,500	\$10,500
TECH23	1.2	Fire/Major Equipment Failure - A fire develops resulting in damage to equipment. Drilling is delayed 1 year.	Fire	Full season labor (\$825,824) & deployment/travel costs	\$983,000	\$245,750	\$368,625	\$491,500	2022-2023		\$368,625	\$368,625	\$368,625	\$368,625	\$368,625
TECH20	1.2	Cut/Damaged Drill Hose - Equipment or unknowns damage the main drill hose.	Damaged Drill Hose	1-week delay, full drill team (\$68,818)	\$70,000	\$3,500	\$10,500	\$17,500	2022-2023		\$10,500	\$10,500	\$10,500	\$10,500	\$10,500
ORG1	1.2.3	During hot-water drilling the main drill head is stuck or frozen-in due to hole constriction or operator error. If not mitigated this could lead to partial loss of season.	Stuck Drill	Full season labor (\$825,824) & deployment/travel costs (\$157,156). ~(\$400,000) Potential cost of replacement hose (<\$1M), drill head (\$160k), and support cables (\$80k) if deemed necessary (no other mitigation plan by late 2020). 1 week additional field labor held until drill season completed.	\$1,384,000	\$13,840	\$41,520	\$69,200	2022-2023		\$41,520	\$41,520	\$41,520	\$41,520	\$41,520
ORG2	1.2.8	Inexperienced Driller Recruitment. EHWI experience is a very unique and specific skill-set, not hiring experienced drillers presents a risk cost, schedule, and project success.	Inexperienced Drillers	Increased salary costs to recruit/entice experience. 16 direct hires increased salaries across 2 seasons	\$144,000	\$7,200	\$21,600	\$36,000	2022-2023		\$54,000	\$54,000	\$54,000	\$54,000	\$54,000
ORG3	1.2.8	If logistics preclude the delivery of deliveries for major components, then an additional season might be required.	Season delay	Cost of additional seasonal drill and deployment crew for partial season, assuming first season not total miss.	\$1,332,000	\$66,600	\$199,800	\$333,000	2022-2023		\$199,800	\$199,800	\$199,800	\$199,800	\$199,800
PM1	1.1.1	If we do not find a suitable PM, reviews will be delayed and budgets may not be well controlled.	PM job	Cost of higher PM salary over 4.5 yr	\$137,356	\$34,339	\$51,508	\$68,678	2018-2019	2018-2019	\$0	\$0	\$0	\$0	\$0
EXT1	1.2.2	Capstone Microturbine Generators not performing as necessary. Could slow drilling season.	Microturbines	Cost of additional C200 cabinet (REMOVE)	\$333,000	\$16,650	\$49,950	\$83,250	2018-2019	2018-2019	\$0	\$0	\$0	\$0	\$0
TECH22	1.2.2	Main Heater Failures - Enough of the heaters fail during drilling operations to impact hole diameter or lifetime below requirements	MHP Failures	Failures add schedule slip - 1/2 week	\$35,000	\$1,750	\$5,250	\$8,750	2022-2023		\$5,250	\$5,250	\$5,250	\$5,250	\$5,250
TECH25	1.2.3	Tower - Structural Failure - Tower is overloaded and damaged during drilling/deployment operations	Tower failure	1-week delay, full drill team (\$70,214)	\$70,000	\$3,500	\$10,500	\$17,500	2022-2023		\$10,500	\$10,500	\$10,500	\$10,500	\$10,500
TECH26	1.2.3	Drill Head Communication Failure - Communication from drillhead during drilling operations ceases.	Drill Head Problems	1-week delay, full drill team (\$70,214)	\$70,000	\$3,500	\$10,500	\$17,500	2022-2023		\$10,500	\$10,500	\$10,500	\$10,500	\$10,500
TECH27	1.2.3	Main Supply Hose Reel Failure - The MSHR develops a major motor, level-wind, or technical problem and deemed unusable	MSHR Failure	1-week delay, full drill team (\$70,214)	\$70,000	\$3,500	\$10,500	\$17,500	2022-2023		\$10,500	\$10,500	\$10,500	\$10,500	\$10,500
TECH24	1.2.4	Computer Control Failure - Network or software problems result in control failure during drilling.	Control failures	1-week delay, full drill team (\$70,214)	\$70,000	\$3,500	\$10,500	\$17,500	2022-2023		\$10,500	\$10,500	\$10,500	\$10,500	\$10,500
TECH5	1.2.5	Motor Drive Problems - New motor drives have unforeseen problems	Motor Drives	2-week delay, full drill team (\$70,214/week)	\$150,000	\$7,500	\$22,500	\$37,500	2022-2023		\$22,500	\$22,500	\$22,500	\$22,500	\$22,500
TECH21	1.2.6	High Pressure Pump Failure - Pump or pump motor fails prior to or during drilling operations	HPP Failure	1/2 week delay	\$35,000	\$1,750	\$5,250	\$8,750	2022-2023		\$5,250	\$5,250	\$5,250	\$5,250	\$5,250
TECH28	1.2.6	Return Water Pump Failure - The RWP fails during drilling operations.	RWP Failure	1 day delay	\$12,000	\$600	\$1,800	\$3,000	2022-2023		\$1,800	\$1,800	\$1,800	\$1,800	\$1,800
TECH29	1.2.7	Independent Firm Drill Failure - Serious problems result in the inoperability of the IFD during the 21/22 season	IFD Failure	1-day delay - longer season (short crew)	\$7,000	\$350	\$1,050	\$1,750	2021-2022		\$1,050	\$1,050	\$1,050	\$1,050	\$0
TECH1	1.2.8	A majority of the EHWI equipment has been stored/cold-soaked for 6+ years at the South Pole. Risk of old EHWI equipment failure.	Old EHWI Failure	Risk to retire with early inspection of drill subsystems at Pole	\$150,000	\$7,500	\$22,500	\$37,500	2018-2019		\$22,500	\$0	\$0	\$0	\$0
TECH30	1.2.9	String Installation Winch Failure - The TU20 winch fails during installation operations	TU-20 Failure	1-day delay - longer season (short crew)	\$3,000	\$150	\$450	\$750	2022-2023		\$450	\$450	\$450	\$450	\$450
TECH31	1.4.3	If comms protocol cannot provide bandwidth needed for required number of DOMs per wire pair, on-board triggering is needed	Comms bandwidth	Add engineering effort - 1 FTE yr - to develop better communications protocol.	\$189,338	\$9,467	\$28,401	\$47,334	2018-2019		\$28,401	\$0	\$0	\$0	\$0
ORG4	1.1.2.1	Major injury occurs during drilling. Work stoppage occurs until review is performed and "safe to proceed" determined.	Drill injury	Cost of 2 week work stoppage at Pole.	\$136,000	\$6,800	\$20,400	\$34,000	2022-2023		\$20,400	\$20,400	\$20,400	\$20,400	\$20,400
TECH2	1.3.1 1.3.2	If glass spheres have higher than expected radioactive contamination, then quality of optical module data suffers	Bad glass	Additional engineering effort to mitigate - 0.5 FTE yr	\$91,571	\$22,893	\$34,339	\$45,785	2019-2020		\$34,339	\$34,339	\$0	\$0	\$0
PM2	1.1.1.1	If project office is not able to closely track international finances, then those cost controls may not succeed, causing schedule delays.	In-kind tracking issues	L2 cost account managers may need additional effort to develop and track milestones. Model as one additional month of key program staff per year for all project years.	\$127,181	\$6,359	\$19,077	\$31,795	2019-2020		\$19,077	\$19,077	\$0	\$0	\$0
ORG5	1.1.3	If schedule delays lead to less than full compliment of optical modules for delivery, then air shipment is required	Optical modules by air	Shipping estimate - difference truck PTH vs COMAIR to CHC	\$40,000	\$2,000	\$6,000	\$10,000	2021-2022		\$6,000	\$6,000	\$6,000	\$6,000	\$6,000
TECH3	1.5.1.1	If there are delays in implementation of common calibration database for production calibration, calibration constants may not be stored in easily usable condition	Production calibration database	2 months software developer effort	\$25,314	\$1,266	\$3,797	\$6,329	2021-2022		\$3,797	\$3,797	\$3,797	\$3,797	\$0
TECH4	1.5.1.2	Different module designs may delay implementation of Flashers and other calibration devices, DOM calibration software and interface to DAQ/experiment control	DOMcal equivalent	2 months software developer effort	\$25,314	\$1,266	\$3,797	\$6,329	2021-2022		\$3,797	\$3,797	\$3,797	\$3,797	\$0
EXT7	1.1.3.2	ASC Support Impacts - Equipment and labor support is reassigned to other projects, or unavailable.	ASC Support	If ASC support is not available, will have to make a plan for it	\$50,000	\$2,500	\$7,500	\$12,500	2022-2023		\$7,500	\$7,500	\$7,500	\$7,500	\$7,500
EXT8	1.1.3.1	Traverse Delays - Weather or equipment problems precludes a traverse moving IceCube equipment to NPX.	Traverse Delays	Risk Cost is related to additional labor needed to recover from	\$10,000	\$500	\$1,500	\$2,500	2022-2023		\$0	\$1,500	\$1,500	\$1,500	\$1,500
EXT9	1.1.3.2	Winter Storage DNF Failure - McMurdo hose storage heat failure, or NPX drill head storage heater/power failure.	DNF Failure		\$50,000	\$2,500	\$7,500	\$12,500	2022-2023		\$7,500	\$7,500	\$0	\$0	\$0
EXT11	1.1.3.1	Domestic/International Shipping Delays - Equipment being shipped to PTH, or via vessel are delayed en route.	Shipping Delays	Add cost for shipping via air to CHC.	\$10,000	\$500	\$1,500	\$2,500	2022-2023		\$1,500	\$1,500	\$1,500	\$1,500	\$1,500
TECH32	1.2.8.4	Major Fire w/o CO2 Fire Suppression System. CO2 System is disconnected.	CO2 Fire System Removal		\$983,000	\$245,750	\$368,625	\$491,500	2022-2023		\$368,625	\$368,625	\$368,625	\$368,625	\$368,625
TECH33	1.2.8.5	Discharge of CO2 Fire Suppression System-Asphyxiation	CO2 Discharge		\$0	\$0	\$0	\$0	2019-2020		\$0	\$0	\$0	\$0	\$0
TECH34	1.3.1	Hamamatsu starts production of PMTs plus HV bases before full base testing is completed	Hamamatsu production		\$180,000	\$9,000	\$45,000	\$45,000	2020		\$0	\$27,000	\$0	\$0	\$0
TECH35	1.2.6	Drill Hose gets exposed to deep freeze conditions. < -40 C, increased rate of hose failure during drill season.	Frozen Drill Hose	Hose failure mode: Blister formation on outside layer, not ca	\$50,000	\$2,500	\$7,500	\$12,500	2022-2023		\$0	\$0	\$7,500	\$7,500	\$7,500
EXT12	1.1.3.2	Fuel Delivery/Station Delays - Drilling fuel is not available or reallocated in the 22/23 season	Fuel Delays	Will monitor this each year. Additional fuel can be shipped to	\$10,000	\$100	\$300	\$500	2022-2023		\$0	\$0	\$0	\$0	\$300

Table 2b. Risk Register Part 2

Risk Identification and Tracking							Pre-Mitigated Risk Evaluation							Current Risk Response					Major Risk Flag
Risk ID	Associated WBS	Risk Description	Risk Title	Revision History			Risk Probability	Probability and Impacts			Resulting Risk Exposure			Risk Owner	Risk Occurrence Timeframe	Risk Handling Approach / Response	Risk Trigger	Risk Mitigation Plan and Actions	
				Risk Origin Date	Last modified Date	Risk Retirement Date		Impact on schedule	Impact on cost	Impact on technical performance	Schedule Risk Score	Cost Risk Score	Technical Performance Risk Score						
Opportunities																			
OPP1	1.3.1	Opportunity to switch from Hamamatsu to HZC PMTs. HZC tubes are larger and less costly.	Better PMTs at Lower Cost	10/1/2018		3/23/2019	High	Very Low	Very High	moderate	Low	High	High	1.3 LEAD Karg	1st Half 2019	Comparison Study	Result of Study	HZC tubes appear to meet general requirements. Purchase order using new money from KIT will allow Hamamatsu or HZC tube options. Cost impact is within the KIT budget. No remaining risk/opportunity on the NSF end of the project.	
Low Priority Risks																			
Tech7	1.4.4.1	If CPT timing system does not provide necessary precision, synchronization of new and old arrays suffers	CPT timing	8/13/2018			Very low	Very low	Moderate	Low	Low	Low	Low	CPT lead	Until testing	Mitigate	Test failures	Construct IDF season prior to string deployment to test synchronization	
Ext6	1.1.1	Weather/flight delays of equipment or personnel to South Pole delays drilling .	Logistics Delays	8/15/2018			Low	Moderate	Moderate	Low	Moderate	Moderate	Low	PM	Drill season 2022-2023	Watch	Weather/Aircraft	Monitor logistics and maintain communications throughout the logistics chain for potential technical impacts	
Ext2	1.3.1 1.3.2	If there is an earthquake in Japan, PMT manufacturing could be severely disrupted	Quake PMTs	8/2/2018			Low	High	High	Low	Moderate	Moderate	Low	OM lead	Until delivery	Mitigate	Earthquake	Alternate PMTs (from Chinese company HZC) could be qualified, cadence of acquisition checked to keep surplus on hand	
Tech5	1.3.1 1.3.2	If one of the planned sensor types does not pass FDR as scheduled the project schedule could be severely disrupted	OM FDR	8/13/2018			Low	High	Moderate	Low	Moderate	Moderate	Low	OM lead	Until FDR	Mitigate	FDR fails	Design and plan the production capacity of all production facilities with sufficient flexibility to be able to fall back to a different OM type	
Ext3	1.3.1	If other experiments (KM3NeT, Hyper-K) purchase Hamamatsu 3-inch PMTs in the same time frame as us, Hamamatsu's production capacities might be insufficient to complete mDOM production in time	mDOM PMT	8/13/2018			Moderate	High	Low	Low	High	Moderate	Moderate	mDOM lead	Until delivery	Mitigate	Procurement fails	Qualify alternate PMT manufacturers; keep close contact with Hamamatsu and responsables from other experiments	
Tech3	1.4.1.2	If cable is not tied in to structural load member correctly, slippage is possible during deployment	Cable mechanical	8/18/2018			Low	Very low	Very low	High	Low	Low	Moderate	CPT lead	Until deployment	Research	Deployment	Review engineering design of cables and attachments	
Tech15	1.6.1	If there are delays in delivery of CPT infrastructure for testing (Field Hubs, IDF, NTS) then the development of Online Systems will be delayed	CPT milestone delays	8/17/2018			Low	Moderate	Very low	Very low	Moderate	Low	Low	1.6 L2 lead	CPT Hardware delivery date	Better communications	Delivery delays	Work closely with CPT L2 and L3s to ensure at least partially hardware delivery for development and testing	
Tech16	1.6.1.1	If optical sensor or calibration device software interfaces specifications are delayed will impact DAQ software development	DAQ software interface delays	8/17/2018			Low	Moderate	Very low	Very low	Moderate	Low	Low	1.6 L2 lead	Sensor software delivery milestones	Better communications	Delivery delays	Work closely with Sensor and Calibration devices L2s to ensure software interfaces are developed and adhered to. Interface specification workshop	
Tech17	1.6.1.1	If DAQ software is unable to accommodate the increased trigger rate from new Optical sensors in detector readout	DAQ trigger too high	8/17/2018			Very low	Low	Low	Moderate	Low	Low	Low	1.6 L2 lead	DAQ software testing	Mitigate	DAQ trigger testing failures	Refactor DAQ trigger algorithms to allow for higher rates, including developing noise rejection methods	
Tech18	1.6.4	If there are delays in design of the IDF, computing infrastructure equipment ordering and shipping could be delayed	IDF late design	8/17/2018	7/4/2019	7/4/2019	Low	Low	Moderate	Very low	Low	Moderate	Low	1.6 L2 lead	IDF facility design delivery	Mitigate	IDF Design delays	Separate network/computing design elements in the IDF design process, preventing delays in other areas from largely impacting 1.6	

Table 3b. Risk Register Part 4

		Risk Identification and Tracking		Comments / Notes	Risk Cost Calculation				Risk Retirement Timeframe		Remaining Contingency				
Risk ID	Associated WBS	Risk Description	Risk Title		Risk Cost Exposure	Low Estimate	Average Estimate	High Estimate	Expected	Actual	PY1	PY2	PY3	PY4	PY5
Opportunities															
OPP1	1.3.1	Opportunity to switch from Hamamatsu to HZC PMTs. HZC tubes are larger and less costly.	Better PMTs at Lower Cost	Cost savings and impacts are in the budgets and schedules now.								\$0	\$0	\$0	\$0
Low Priority Risks															
Tech7	1.4.4.1	If CPT timing system does not provide necessary precision, synchronization of new and old arrays suffers	CPT timing	Minor cost impact											
Ext6	1.1.1	Weather/flight delays of equipment or personnel to South Pole delays drilling.	Logistics Delays	Minor cost impact											
Ext2	1.3.1 1.3.2	If there is an earthquake in Japan, PMT manufacturing could be severely disrupted	Quake PMTs	Off NSF budget											
Tech5	1.3.1 1.3.2	If one of the planned sensor types does not pass FDR as scheduled the project schedule could be severely disrupted	OM FDR	Off NSF budget											
Ext3	1.3.1	If other experiments (KM3NET, Hyper-K) purchase Hamamatsu 3-inch PMTs in the same time frame as us, Hamamatsu's production capacities might be insufficient to complete mDOM production in time	mDOM PMT	Off NSF budget											
Tech3	1.4.1.2	If cable is not tied in to structural load member correctly, slippage is possible during deployment	Cable mechanical												
Tech15	1.6.1	If there are delays in delivery of CPT infrastructure for testing (Field Hubs, IDF, NTS) then the development of Online Systems will be delayed	CPT milestone delays	Minor											
Tech16	1.6.1.1	If optical sensor or calibration device software interfaces specifications are delayed will impact DAQ software development	DAQ software interface delays	Minor cost impact											
Tech17	1.6.1.1	If DAQ software is unable to accommodate the increased trigger rate from new Optical sensors in detector readout	DAQ trigger too high												
Tech18	1.6.4	If there are delays in design of the IDF, computing infrastructure equipment ordering and shipping could be delayed	IDF late design	Minor cost impact. The IDF is no longer being used in the IceCube Upgrade Project.											

Table 3a. Risk Register Part 3

#	Associate d WBS Group	Risk Description	Y1	Y2	Y3	Y4	Y5	total
PM11	1.1.1.1	Project Administration	\$22,502	\$31,262	\$29,604	\$31,686	\$30,275	\$145,331
PM12	1.1.2.1	Project Control	\$321	\$9,299	\$9,691	\$9,885	\$10,083	\$39,278
PM13	1.1.3.1	Q&A, Safety	\$2,868	\$8,300	\$8,782	\$9,132	\$9,314	\$38,396
PM14	1.1.4.1	Polar Operation Management	\$1,755	\$9,270	\$9,857	\$10,053	\$10,252	\$41,188
PM15	1.1.5.1	System Engineering	\$11,373	\$27,896	\$22,806	\$23,920	\$24,397	\$110,391
PM16	1.2.1.0	EHWD Project Management, Controls and Engineering, Safety and Quality	\$28,560	\$25,407	\$25,670	\$27,913	\$21,498	\$129,048
PM17	1.2.2.0	Fuel Systems Spares, Refurbishment	\$5,750	\$16,281	\$0	\$0	\$0	\$22,031
PM18	1.2.3.0	Tower System Operation and Main Cable Equipment	\$13,478	\$129,253	\$11,529	\$0	\$0	\$154,260
PM19	1.2.3.4	Main Drill Hose	\$368	\$183,740	\$0	\$0	\$0	\$184,108
PM20	1.2.4.0	EHWD and Associated Equipment	\$37,538	\$86,799	\$111,731	\$24,840	\$9,246	\$270,154
PM21	1.2.5.0	Generators Refurbishment, Procurement and Testing	\$43,535	\$17,099	\$808	\$0	\$0	\$61,441
PM22	1.2.6.0	Hot Water Pumps	\$29,868	\$40,792	\$901	\$0	\$0	\$71,561
PM23	1.2.7.0	Firn Drill, Motor Testing, Maintenance	\$24,079	\$11,663	\$6,041	\$6,130	\$400	\$48,313
PM24	1.2.7.5	Skidsters and Snowmobiles, Tools, Equipment, Procurement	\$1,454	\$12,177	\$2,596	\$2,618	\$2,466	\$21,311
PM25	1.2.8.0	On-Ice Activities	\$8,640	\$138,242	\$65,161	\$61,934	\$158,303	\$432,280
PM26	1.2.9.0	String/Cable Installation Plan and Coordination	\$4,064	\$14,383	\$6,803	\$9,819	\$8,443	\$43,511
PM27	1.3.1.0	mDOM	\$35,755	\$15,238	\$2,209	\$0	\$0	\$53,202
PM28	1.3.3.0	PDOM	\$42,331	\$33,797	\$10,609	\$0	\$0	\$86,737
PM29	1.3.5.0	Special Devices	\$0	\$0	\$0	\$533	\$0	\$533
PM30	1.4.0.0	CPT Engineering and Management	\$7,122	\$3,832	\$0	\$667	\$0	\$11,621
PM31	1.4.1.0	Main Cable / CPT	\$41,066	\$82,949	\$42,864	\$8,541	\$6,115	\$181,535
PM32	1.4.2.0	Surface Cables Installation	\$4,890	\$22,843	\$1,903	\$1,116	\$0	\$30,753
PM33	1.4.4.0	CPT Communication and Timing, Design and Procurement	\$15,651	\$20,223	\$64,079	\$428	\$0	\$100,381
PM34	1.4.5.0	NTS Cables, Facility, Operation	\$5,238	\$4,831	\$0	\$0	\$0	\$10,068
PM35	1.5.3.0	Timing, Geometry, Ice Properties Calibration	\$0	\$3,204	\$12,256	\$0	\$0	\$15,459
PM36	1.5.4.0	Calibration Management and Travel	\$0	\$826	\$150	\$332	\$0	\$1,308
PM37	1.6.0.0	IceCube Data Systems Integration	\$31	\$0	\$0	\$73	\$0	\$104
PM38	1.6.1.0	DAQ and OEM Software Development, Testing, Deployment, Calibration	\$30,047	\$42,998	\$28,001	\$54,470	\$52,974	\$208,490
PM39	1.6.2.0	Core Software for Offline Systems	\$0	\$0	\$0	\$0	\$0	\$0
PM40	1.6.4.0	Computing Infrastructure SPTS/NTS and Distributed Computing Needs	\$15,323	\$23,863	\$138	\$399	\$495	\$40,219

Table 4. Risk Register based upon the Cost Uncertainty