IceCube Upgrade: Risks & Risk Registry

IceCube Upgrade NSF Rebaselining Review

26-28 April 2022

Michael DuVernois
UW—Madison
Upgrade Technical Coordinator

Brief Bio

- Technical Coordinator for the IceCube Upgrade
- 10+ years with WIPAC science & engineering and the IceCube Collaboration (2010-)
- 25+ years of experience with spacecraft, balloon, remote observatory, particle detector, and telescope hardware (1993-)
- 25+ years of fieldwork leadership (1996-), >10 Antarctic excursions
- Successful project construction experience as a senior designer: Pierre Auger Observatory, ANITA/CREAM/CREST balloon payloads, ARA experiment, HAWC Observatory
- As a junior participant: Ulysses HET, CRRES satellite, HEAT balloon experiment, MINOS

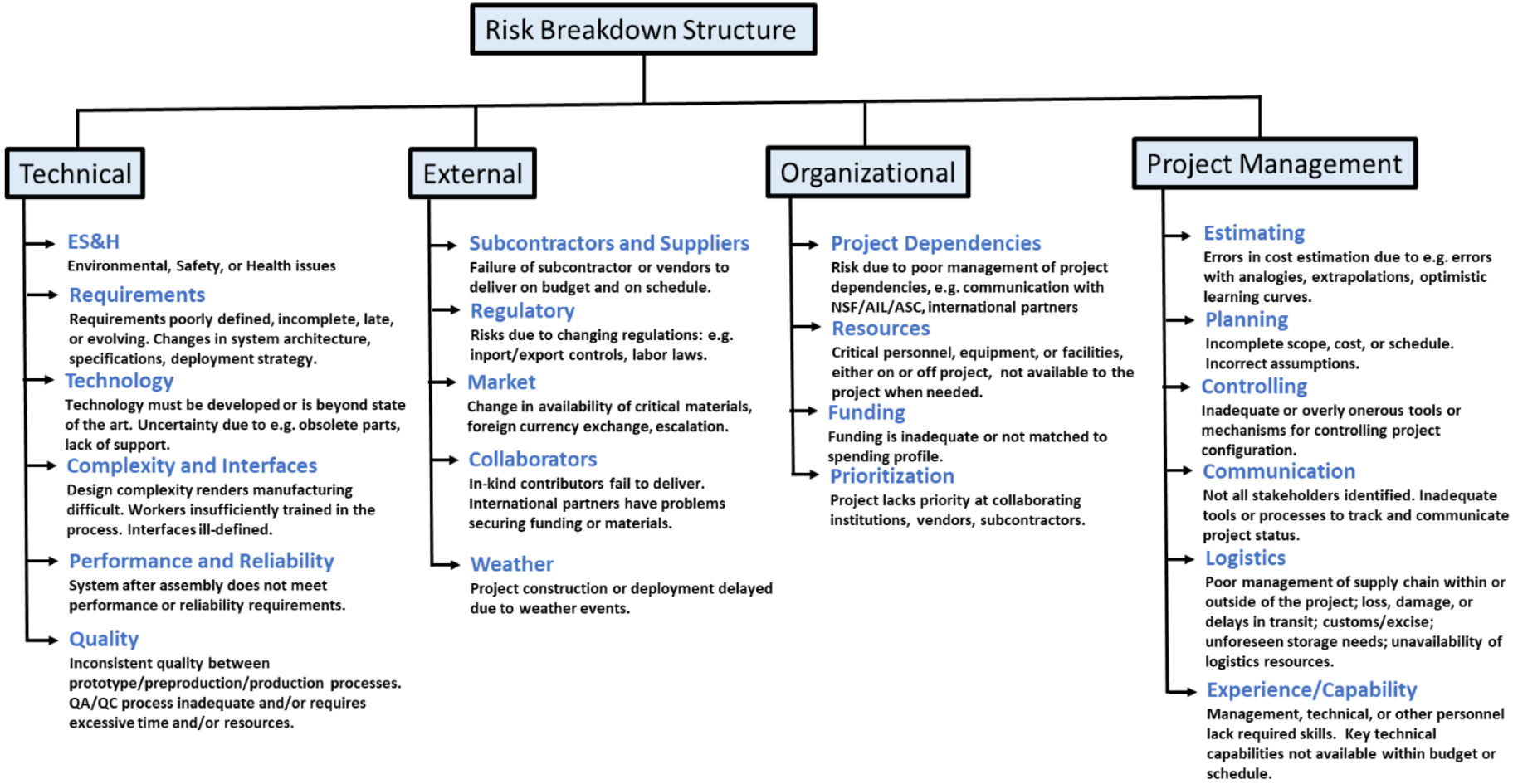
In parallel to the Risk Registry, we have a cargo-logistics plan with an analysis of schedule delays, and a failure mode and effects analysis (FMEA), which is more technical, and hooked to quality assurance rather than to cost and schedule

Risk Register

Risk Management Plan

- Based on the US GAO cost estimating guide, NSF Research Infrastructure Guide, and ANSI standard and industry best practice PM-Book of Knowledge
- Risk Register is built from the risks, organized by WBS and also by Risk Breakdown Structure (External, Organizational, PM, Technical)
- Risks are mitigated or accepted
- Evaluate their impact in cost and schedule of realized risks
- Monte Carlo is run for the full set of risks (threats and opportunities) using the @Risk tool within Excel
- Upgrade project takes the 80% confidence level for additional contingency required to cover the identified risks
- Mitigation and monitoring of risks continues

Risk Breakdown Structure



Impact x Probability = Rank

Probability	Impact Level				
	Very Low	Low	Moderate	High	Very High
Very High (75%-95%)	**Moderate Rank**	**Moderate Rank**	**High Rank**	**High Rank**	**High Rank**
High (50%-75%)	**Low Rank**	**Moderate Rank**	**High Rank**	**High Rank**	**High Rank**
Moderate	**Low Rank**	**Moderate Rank**	**Moderate Rank**	**High Rank**	**High Rank**
Low (5%-25%)	**Low Rank**	**Low Rank**	**Moderate Rank**	**Moderate Rank**	**Moderate Rank**
Very Low (1%-5%)	**Low Rank**	**Low Rank**	**Low Rank**	**Low Rank**	**Moderate Rank**

Scale for Impacts in each performance metric

	Very Low	Low	Moderate	High	Very High
Technical Impact	No impact	Somewhat substandard	Significantly substandard	Extremely substandard	Scientific objectives in jeopardy
Cost Impact	Less than $10k	$10k - $50k	$50k - $250k	$250k - $1M	> $1M
Schedule Impact	Less than 1 week	1 month	3 months	6 months	Greater than 6 months
Scope Impact	Scope decreases barely noticeable	Minor areas of scope affected	Major areas of scope affected	Scope reduction unacceptable to sponsor	Project item is effectively useless
Quality / Performance Impact	Quality / performance degradation barely noticeable	Only very demanding applications are affected	Quality / performance reduction requires sponsor approval	Quality / performance degradation unacceptable to sponsor	Project item is effectively useless

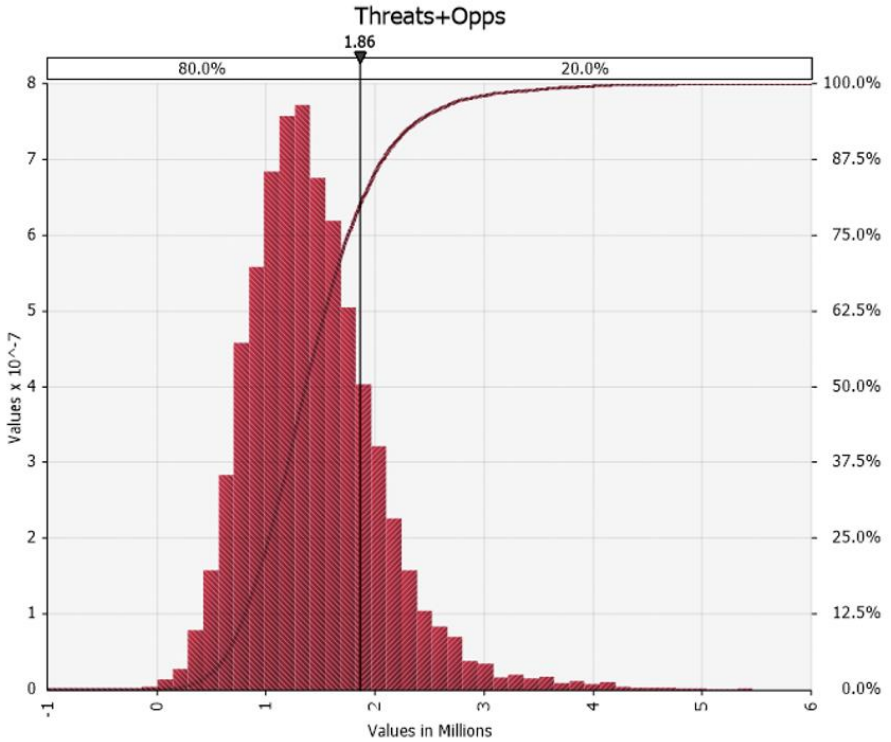
Risk Register

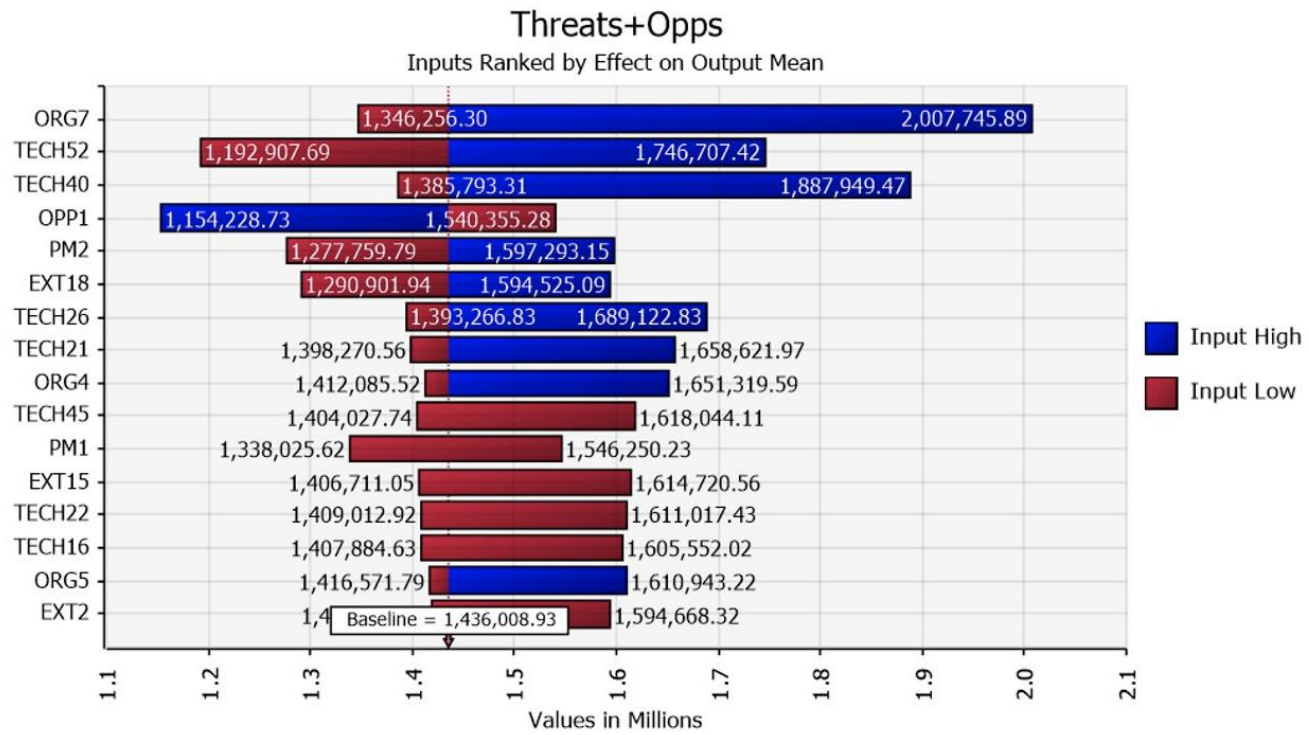
Charge Question R2 & R4

- Held a risk workshop (25 Jan 2022) and rebuilt the Risk Registry essentially from scratch for the re-baselined project (project office + L2s + SMEs)
- Total of 77 threats, 1 opportunity
- Will give a quick tour of the Risk Registry
- Risks are re-evaluated quarterly
- New risks, or risk retirement, any time
- Many significant risks are tied to drill season
- Some risks are in logistics, out of direct control
- These logistics risks were also costed separately

WBS L2	Active Threats	Retired Threats
1.1	10	7
1.2	35	4
1.3	10	6
1.4	15	1
1.5	2	2
1.6	5	3
Total	77	23

Risk Monte Carlo (@risk)





	Confidence Level		
	70%	80%	90%
All Threats + Opportunities	$1,663,149	$1,861,241	$2,170,439

Top Five Risks (we can look at others in RR directly)

		Risk Identification and Tracking	Major Risk Flag	Post-Mitigated Risk Evaluation							Comments / Notes	Risk Cost Exposure		
				Probability and Impacts				Exposure				NSF $		
Risk ID	Associated WBS	Risk Description		Risk Probability	Impact on schedule	Impact on cost	Impact on technical performance	Schedule Risk Score	Cost Risk Score	Technical Performance Risk Score	Basis for the risk and schedule exposure	Risk Cost Exposure	Low Estimate	High Estimate
ORG7	1.2.8	Driller Talent Aquisition and Retention - EHWD drill operation in Antarctica is unique and specific skill-set. Recruiting experienced drillers key for project success		Low	Low	Moderate	Low	Low	Moderate	Low	Increased salary costs to recruit/entice experience. 16 direct-hires increased salaries (average) across 2 seasons TECH rate -> ENGR rate, delta $38/hr, 525 hr/season 16*2*38*525 = 640k	$640,000	$300,000	$800,000
TECH52	1.4.1.1	Because MCA breakout terminations are a custom solution, the costs of breakout installation may exceed the MSU commitment, requiring project support for MCA costs		High	Low	High	Very low	Moderate	High	Low	High cost estimate based on initial bids from two suppliers (JDR and HGS), cost exposure reflects some assumed cost reductions. Schedule risk reflects possibility of extended design phase	$400,000	$0	$750,000
TECH40	1.4.1.1	Because the MCA prototype has not completed mechanical testing, we may need to select an alternate Main Cable supplier, which will necessitate project support for cost and/or impact communications and timing performance		Very Low	High	Very High	Moderate	Low	Moderate	Low	Likely to be delays in switching to new main cable supplier, most vendors are less responsive than Hexatronic.	$ 1,500,000	$300,000	$3,500,000
OPP1	1.1	If contributed drillers (from collaborating institutions) are provided as in-kind contributions, the project can save seasonal driller labor costs.		Moderate	Very low	High	Very low	Low	High	Low	Contributed drillers (up to 10 person*seasons) replace $50000 in direct costs.	$250,000	$100,000	$500,000
PM2	1.1	The great resignation can affect the project team, and could result in departures of personnel in critical roles.		High	Moderate	Moderate	Very Low	High	High	Low	20% increase on 10% of key roles for PY5-8 labor rates, difficulties in finding new personnel	$240,000	$200,000	$400,000

Logistics Delay Sensitivity Analysis

Our approach to logistics sensitivity analysis

- Follow our project general Risks Registry rubric of impacts and probabilities
- For each shipping package (72) and personnel flights arriving at Pole (11), assess probability of delays and estimate cost of recovery from those delays
- Delay probabilities and costs of recovery are assessed for 48 hour delay, one week, two week, and four week delays
- Cost of recovery is based on the personnel cost of extending stays at South Pole or bringing in alternates later in the season for catchup work, this is worked out in detail for each season's on-ice drill network flow

- Note: This only includes paid labor, and does not track contributed labor

Excerpt from the Cargo delay spreadsheet

Cargo Item #	WBS L2	Item Description	Contents	Date Item expected or *arrived* to MCM	Date/Month for Items needed at South Pole	Logistical Mode	48hrs		168hrs (1 wk)		336 hrs (2 wks)		672 hrs (4 wks)		1 week delay impact notes	2 week delay impact notes	4 week impact notes
							Probability	Estimated Cost Impact	Probability	Estimated Cost Impact	Probability	Estimated Cost Impact	Probability	Estimated Cost Impact			
		UW/PSL															
20	1.2	ARA Drill System Components - Crate 1	ARA (Antarctic Rodwell Appartus) - downhole pump controller, ePump controller, splash cam kit, and accessories - Do Not Freeze	2/6/2023	12/6/2023	LC-130	Moderate	0	Low	0	Low	0	Very Low	25760			224 hours of labor pushed - season extended to accomodate
21	1.2	Computing/controls components # 1	Motor drives, PLCs, electrical hardware, and motor drive mounting kits. Components and equipment to support field season 1 controls system tasking - ComSur - Do Not Freeze	2/6/2023	11/15/2023	LC-130	Moderate	0	Low	12420	Low	24840	Very Low	82915	work stoppage of 108 hours	work slowdown of 216 hours	216 hours lost in field season 1 additional EE FTE added to field season 2, 505 hours (on-ice labor is not reallocated elsewhere -
22	1.2	Computing/controls components #2	Computing and controls equipment (Motor drives and other sensitive electronics) - Do Not Freeze	11/1/2023	11/15/2023	LC-130	Moderate	0	Low	26335	Low	52670	Very Low	85445	229 hours of labor delayed	458 hours of labor delayed	743 hours of labor delayed
23	1.2	Computing/controls components #3	Computing and controls equipment (Sensor, motor drives and other sensitive electronics) - Do Not Freeze	11/1/2024	11/15/2024	LC-130	Moderate	0	Low	173880	Low	347760	Very Low	983000	Drill season extended by 1 week 1512 hours	Drill season extended by 2 weeks 3024 hours	Drilling can no longer be accomplished
24	1.2	20' Refit Container C	Bull wheel assembly - used to install main cable on reel in event of main cable damage/failure; Spare cable for Return Water Cable Reel - on spool; ARA new downhole pumps, spares, accessories and tools	2/6/2023	1/22/2025	SPoT	Moderate	0	Low	24840	Low	49680	Very Low	99360	work stoppage 8 people 3 days or 216 hours	work stoppage 8 people 6 days or 432 hours	work stoppage 8 people 12 days or 864 hours
25	1.2	Driller resupply/refit components - 8' Container FY25	8' Mini Milvan; Consumables/drill components - difficult to estimate. Placeholder for emergent items	11/1/2024	11/15/2024	LC-130	Moderate	0	Low	4140	Low	8280	Very Low	24840	36 hours potential delay	72 hours potential delay	216 hours potential delay

Notes: These are items 20-25, all currently in Wisconsin.
Includes one item, item 23, which if 4 weeks late, causes a project failure (”drilling cannot be completed”)
Shipping dates, required at Pole dates, and float are all for the new agreed-to logistics plan
Significantly fewer routes to failure than in old logistics plans
And in all cases would know about these delays in real time, for potential mitigation

Monte Carlo treatment

- Thousand realizations of the three field seasons
- Cost impacts calculated for each realized risk instance
- Events which lead to failure are excluded, but these are <1.5% of simulations
- Annual 95% confidence level cost exposures:

Risk Exposures

	95% Level	Hours
FS1	**$26,258**	**228**
FS2	**$81,420**	**708**
FS3	**$70,171**	**610**

	Population	Available Hours	Risk Hours	percentage needed for risk coverage
FS1	8	4128	228	6%
FS2	14	7224	708	10%
FS3	28	14448	610	4%

Monte Carlo Shortcomings

- Assumes all events are uncorrelated, so impact on the critical path is determined by latest item in a season
- And mitigated with more person-hours on ice, whether through alternates or extended season
- More nuanced analysis is difficult to automate
- Roughly this cost agrees with the Risk Registry cost of just the logistics-related items of $240k versus the $180k here

Failure Mode & Effects Analysis

Upgrade In-Ice Failure Modes & Effects Analysis (FMEA)

- Explicit FMEA was not done in Gen1
- Hazard analyses were conducted for processes, human safety, *etc*. and will be done in the Upgrade as well
- FMEA was suggested by the Project Advisory Panel
- We adopted an industry standard form, and launched an FMEA effort
- Ultimately changed the form significantly to better match the project characteristics, and zoomed in on in-ice/string failures
- FMEA is focused strictly on the in-ice, deployed string, where processes and production mistakes are non-reversible
- In March 2022, we rebuilt the Risk Registry, harmonized the FMEA with the Risk Registry, and put the FMEA into revision control

IceCube Upgrade

NSF

FMEA clipped section

		Top Item Name	Upgrade String			Analysis (FMEA)								
		Subsystem	All											
		Component	All											
		Design Lead	L2s											
		Initial Team	Haugen, Sandstrom, Zernick, Duvernois											
													Action Plan	
Original Entry Order	Parent Item(s)	Failed Item Name (sub components of "Parent Item")	Failure mode (How requirements for item are not met)	Observable symptoms and impact of failure mode (Potential Effect[s] of Failure)	Additional notes on Impacts (Potential Cause[s] / Mechanisms of Failure)	Item location	Failure prevention or mitigation / detection method OR Process Control OR Design result (Current Design Controls)	Sev	Prob	Det	RPN	Additional notes on failure mode	Recommended Action(s)	
12	**xDOM, Calibration, or R&D Instruments**	**xDOM main board**	insufficient ESD protection	Immediate or latent damage to DOMs during preparation or deployment		any	Validate design of ICM, xDOM mainboard and Mini-Mainboard for ER3 of Ice Comms Module. Ensure reliable bond between MCA, BCA, PCA during deployment. Ensure bond between MCA shield and TOS during deployment. Use conductive brush to neutralize surface charge on MCA during deployment.	4	5	3	60	probability based on Gen1 failure rates	Ensure charge neutralization between MCA/BCA cable shields and TOS frame during deployment.
13	**xDOM, Calibration, or R&D Instruments**	**ICM firmware/main cable**	comms provides insufficient S/N over real cable	high bit error rate (BERR) leads to insufficient bandwidth over real cable	Cable related	any	comms must be tested on realistic/actual cable as early as possible	8	3	1	24	If we have a final cable prototype soon, detectability for this should be much better, no? (TK) Agree, detectability changed to 1	
14	**xDOM, Calibration, or R&D Instruments**	**ICM Hardware**	Latent failure in one or more ICM components	Comms loss of sensors where part failure is manifest.		any	Review BOM and assembly procedure for potentially unreliable parts or steps. Include ICMs into Mainboard burn-in / HASS	4	6	2	48		Extensive testing
15	**xDOM, Calibration, or R&D Instruments**	**ICM Hardware**	insufficient ESD protection	Comms loss of sensors where part failure is manifest.		any	Review BOM and assembly procedure for potentially unreliable parts or steps. Explicit ESD testing during ICM and Integrated xDOM design verification	4	6	2	48		
16	**xDOM, Calibration, or R&D Instruments**	**xDOM Mainboard, Mini-Mainboard**	Latent failure in one or more mainboard components	Partial or complete loss of any proportion of devices with failure-prone part in their BOM.		any	Review schematics of ICM and host boards	4	6	2	48		

Main Technical Risks/Response Summary

- Accepted mDOM high radioactivity PMTs
  - We take as a lesson learned that we need to have somewhat more oversight than we were able to exercise at Hamamatsu during COVID
  - Some noise data can be mitigated in firmware and software (ongoing work)
  - Minimal physics impact
- Supply chain problems
  - Several impacts, especially electronics part availability on mDOM mainboards
  - Working to mitigate this with new designs and early purchases
- Drill control system progress
  - Held a status review
  - Will monitor progress over the next 9-10 months going into a final review
  - The current plan ships hardware this season, with software design finalizing in early 2023