Key Assumptions for the IceCube Upgrade Project

Program, Technical, Cost, and Schedule

Approval

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Revision History

Version	Date	Author	Summary of changes
V1.0	2021-08-25	M. Rogal, V. O'Dell	1st version based on the Gen2 Key Assumptions Document.
V1.1	2021-08-26	M. Rogal, C. Vakhnina, V. O'Dell	Updated labor, fringe, indirect tables. UW fringe should be ok. Other institutions need to be queried as to their fringe rates for 2021.
V1.2	2021-08-27	F. Farshid, V. O'Dell	Minor edits for first full draft.
V1.3		M. Rogel	Cosmetic fixes
V1.4	2021-09-14	V. O'Dell	Updated section 4.3, tables 4, 5. Updated chapter 3, especially spares, prototypes, test stands.
V1.5	2021-09-15	V. O'Dell	Added appendix on legacy EU calculation; rewrote section 4.10.
V1.6	2021-09-17	V. O'Dell	General cleanup. Added more details on labor estimates in section 4.
V1.7	2021-09-17	F. Feyzi, K. Hansen, V. O'Dell, M. Rogel	Final editing. Added escalation rate plot to appendix.
V1.8	2021-09-21	V. O'Dell	Rename Gen2 Phase2 -> Upgrade. Added reference to cooperative agreement.
V1.9	2021-09-30	F. Feyzi, K. Hansen, I. McEwen, V. O'Dell, M. Rogel	Addressed comments by R. Yasky, M. Coles. Removed logistics discussion, as it will go into separate documents (referenced).
V1.10	2021-11-15	V. O'Dell	Replaced Table 3 with hourly rates assuming 1800 hrs/year. Updated sections 4.2, 4.5, and 5.3 with comments from NSF.
V1.11	2022-02-04	V. O'Dell	Incorporated latest comments from NSF. Removed Appendix A (the historical cost uncertainty calculation) as it is irrelevant for the rebaseline. Added new Appendix to summarize GAO best practices for scheduling.
V1.12	2022-03-10	V. O'Dell	Corrected contingency table (mislabeling)
V1.13	2022-03-29	V. O'Dell	Updated rate table (Table **3**) with latest data.
V1.14	2022-06-29	V. O'Dell	General scrub. Added schedule task duration guidance and a section on risk (which points to the RMP). Added AIL capacity guidance in the logistics section and Appendix C.

Contents

1. Purpose of this Document

This document describes cost, schedule, technical, and programmatic assumptions for the IceCube Upgrade Project. The document contains key assumptions and is not intended to be all-inclusive. This is a living document, applicable to all NSF elements in the project scope, and will be updated as new information becomes available. Some of the topics in this document are more fully described in other project documents such as the Project Execution Plan.

The Project has been substantially delayed due mainly to the COVID19 pandemic, and its effects on South Pole logistics. As a result, the project's cost and schedule is being updated according to new logistics assumptions as provided by NSF/AIL in February 2022. Given these new assumptions and internal delays due to COVID, the Project has completed a full bottom-up replanning exercise to support the rebaselined cost and schedule. By following the assumptions and guidelines in this document, we ensure that the project schedule, cost methodology, and calculated uncertainties are uniform throughout the project during this effort.

2. Key Programmatic Assumptions

2.1 Funding

- The IceCube Upgrade Project is currently funded by a Cooperative Agreement "IceCube Gen2 Phase 1: An IceCube Extension for Precision Neutrino Physics and Astrophysics" (PHY-1719277).
- The original funding profile is described in the Project's PEP. The original approved total project funding was $22,983k, which includes $2,855k in contingency. Construction funding began Oct. 1, 2018, and the project baseline schedule was for 5 years (until September 30th, 2023).
- We are currently proposing a rebaselined Project, undergoing review by NSF, that will cover the completion of the original Project during FY23-FY26. The assumptions in this document support the updated bottom-up costing for the rebaselined Project. We are assuming this will be funded by a new Cooperative Agreement.

2.2 Transition to Operations

- Project deliverables will become part of the integrated IceCube Neutrino Observatory. The IceCube M&O program will cover ongoing detector operations and maintenance. Once material is received, deployed, commissioned, and calibrated at the South Pole, the detector and its data products are turned over to M&O.

2.3 Decommissioning and Decontamination (D&D)

- Project definition includes safe storage of the drill at the South Pole (in the event it will be used again by IceCube-Gen2), and retrograding all "Do Not Freeze" or "Do Not Deep Freeze" equipment to UW. Details of the retrograde cargo for each season can be found in (1) and (2).
- Labor to pack and otherwise prepare equipment for retrograde, and to safely store the drill at the South Pole is included on-project.
- The lifetime of the in-ice instrumentation is at least 15 years. A draft plan for D&D after the lifetime of the experiment can be found in "*Divestment Plan for the IceCube Neutrino Observatory*" (3). Additionally, the Project will follow all Antarctic waste management protocols.

3. Key Technical Assumptions

3.1 Prototypes, Spares, and Test Stands

Due to the variety of objects produced by the project, distributed production and testing facilities and funding sources, there is not a single policy for prototypes, spares, and test stands. Table 1 breaks down the planning for prototypes, spares, preproduction, and test stands as well as the funding source, as a function of equipment type. In general:

- Prototypes are required for all electronic readout systems and all detector systems to validate final designs through design verification testing. The number of prototypes will vary for each system.
- Pre-production items are required for all electronic readout systems and all detector systems before going into production. Pre-production items are considered part of production and are identical to production items. The number of pre-production items will vary by system but should be sufficient to determine the overall yield and quality of the parts, and the reliability of the vendor.
- Production Readiness Reviews (PRRs) are required for all systems before going into production.
- The Resource Loaded Schedule includes time and resources for prototype and preproduction runs.
- Spares (for operations) and devices for test stands are included in the project. In general, the project allows for 10% spares, however, as stated above, it varies by system.
- An overview of prototype, preproduction, production, spares, and test stands for major systems, along with the funding source, is shown in Table 1. Spares for e.g., D-Eggs and mDOMs are limited, as once deployed they cannot be replaced. Experience from IceCube Gen1 shows that once a verified sensor is shipped to the South Pole, acceptance tests at the South Pole rarely fail (i.e., < 0.5%). The cables are difficult to damage, and in general cable damage can be repaired on site. Additional drill hose sections are shipped so that any damaged drill hose section can be

replaced on site, and finally an additional drill cable is shipped to mitigate any catastrophic damage to the drill cable.

Detector part	Total Installed	Prototypes	Pre-production	Spares	Test Stands	Funding Source
Field Hubs	7	20 mini / 1 full-featured	2	3	2	NSF
Surface Cables	7	1 (partial length)	0	0	N/A	NSF
Drill hose	22 sections	2 short sections	0	5 sections	N/A	NSF
Main drill cable	1	Some test sections, working with factory	0	1	N/A	NSF
Downhole Cables	7 (21 quad cables)	1 (partial length)	1	0	2 full length single-quad cables	In-Kind
Optical Modules: D-Eggs	277	10	50	23	Prototype modules are used in test stands [~20 spare modules will ship to SP]	In-Kind
Optical Modules: mDOM	402	10	40	28	Prototype modules are used in test stands [~20 spare modules will ship to SP]	In-Kind

Table 1 List of major items needed for prototypes, preproduction, spares, and test stands. Preproduction items are part of the production, i.e. for the Field Hubs there are a total of 13 full sized items, of which 2 are pre-production items. The funding source is also noted. This list is not exhaustive but lists the main items in each subsystem.

3.2 Performance Margins

- The Project is technically challenging due to its location. For in-ice devices, there is no possibility of repair after deployment. Therefore, in order to achieve the project goals, high reliability is essential. Part of the design process is to identify these uncertainties and mitigate them with performance margins and safety factors. The degree of performance margin will vary from case-to-case depending on the level of uncertainty and criticality. The goal is to avoid operating on the absolute edge of performance capabilities to achieve our science goals.

3.3 Production and Storage

- Any storage at McMurdo and/or the South Pole must be prioritized and arranged in advance through the Project Office.
- The project office will prepare logistics and project plans, including assumptions on shipments and storage availability along the route to the South Pole as approved by the USAP. These assumptions and plans are communicated to the project team as they develop their plans to ensure the project schedule as proposed is supportable by the logistics team.
- We assume institutions will supply any necessary production infrastructure unless explicitly stated in the project plans.

4. Key Cost Assumptions

4.1 Cost Estimating Guidance

The project attempts to use best practices from the GAO accounting guide (4) and the NSF Research Infrastructure Guide (5).

- The cost estimating guidance given below is consistent with best practices in cost estimating, as described in:
  - Government Accountability Office (GAO) cost estimating guide (4).
  - NSF Research Infrastructure Guide (5), and the
  - Cost Estimating Plan for the IceCube Upgrade Project (6).
- Cost Managers, with input from Subject Matter Experts, are instructed by the Project Manager to use their best judgment, consistent with these Key Assumptions, to develop realistic estimates of equipment and labor for each task for which they are responsible.
- All cost estimates are documented in the Basis of Estimates (BoEs). They are structured according to the Project's Work Breakdown Structure (WBS) and document the cost basis of estimate to the lowest levels of the WBS. The BoEs support the presentation of the costs both by WBS and by NSF Budget Categories.
- The BoEs should include references to supporting materials, in particular:
  - Equipment costs are to be supported by vendor quotes or by reference to previous purchases. The estimate types must be flagged with the appropriate codes from Table 2.
  - Labor hours are to be supported by documented estimates. Labor hours may be estimated using methods in Table 2. In particular:
    - If hours are extrapolated from experience with the original IceCube efforts, these efforts must be documented, and any deviations from the historical, documented number of hours must be well-motivated and documented (A).
    - Hours for new efforts for which there is no appropriate analogy in the original IceCube are estimated by Subject Matter Experts using their experience in previous projects or research. The hours for the estimates must be justified and documented (D).
    - Labor hours may be estimated from efforts on current prototypes, supported by the appropriate documentation from the prototype efforts (E).
    - Finally, where appropriate, learning curves must be considered; i.e., the first item(s) will take longer, and require more effort, than subsequent items due to streamlining processes or training new people (L). This is in addition to the methods listed above. (That is, an item may be flagged as A,L, meaning "analogy with learning curves".)
  - The base equipment costs and labor hours should not be padded with any "hidden contingency" – see below for how to explicitly handle contingency.
- As detailed above, both for labor and equipment, several cost estimating techniques may be used; these should be documented in the BoEs using the codes in Table 2 (for more details, see page

103 of (4)). Note that estimates may employ more than one technique (i.e., E,L for example, when the impact of learning curves could be significant).

Code	Name	Short definition (see the reference for more details)
A	Analogy	uses the cost of a similar program to estimate the new program costs and adjusts for differences
C	Engineering Buildup	develops the cost estimate at the lowest level of the WBS, one piece at a time, and the sum of the pieces is the program estimate
D	Expert Opinion	relies on subject matter experts to give their opinion on what an element should cost
E	Extrapolation from Actuals	Uses actual costs and data from prototypes to predict the cost of future elements
F	Parametric	relates cost to one or more technical, performance, cost, or program parameters through a statistical relationship.
L	Learning Curves	Considers the cost / item for the first, average, and last piece.

Table 2 Cost estimating techniques.

- Estimate uncertainty (EU) contingency for each task is to be calculated based on the maturity of design and the confidence of the cost estimate, using the guidelines and tables described in section 4.10.

4.2 Labor Cost Assumptions

- Effort included in the resource-loaded schedule (RLS) and paid on project includes but is not limited to: scientists, postdocs, students, engineers, technicians, computing professionals, project controls, schedulers, and financial &administrative support.
- Off-project scientific labor consists of scientists, postdocs, or graduate students with salaries provided by NSF base funding and faculty supported by universities. The associated costs are not charged to the project. Summer salaries for faculty members who serve as institutional PIs or WBS L2 managers, commensurate with their effort, are provided on-project. All labor and materials supplied to the project for completion of the items contributed in kind are the responsibility of the institution and are not included in the BoEs.
- All NSF funded labor, including scientific labor, needed to complete the NSF part of the project is "on-project". Off-project NSF funded scientific labor is used to exploit the physics of the device but is not critical to the production or deployment of the upgrade.
- The ongoing M&O program remains responsible for software or firmware development targeting existing IceCube detector systems (e.g., DAQ/Online systems). Software or firmware

development targeting new detector instrumentation (such as D-Egg or mDOM modules) or the production and testing systems to support these are supported by the Project.

- Labor hours are estimated for each activity in the WBS and are documented in the BoEs. One FTE year is 1800 working hours (out of a maximum of 2080 hours), which considers the average paid time off during the year, including vacation and sick time.
- The resource types used by the Project (see Table **3**) is contained in the resource-loaded schedule.
- A cloud based Smartsheet® (7) system is currently used for Earned Value, and hours for each type of labor resource are captured in the software.
- The Project is transitioning to enterprise level tools and will be using this upgraded system starting in FY23.

4.3 Institute Labor and Overhead Rates

- Labor rates will be calculated by the project office and are supported by actual employee salary agreements, BLS information, or particular market research associated with the proposed position.
- Where known, labor rates are entered using the exact salaries of the person. Where not known (i.e., tasks that have a labor type assigned, but not yet a specific person assigned), labor rates are estimated by using an average rate for the corresponding job role.
- Labor and fringe rates are collected for each institution for each job type required for the Project.
  - The labor rates include project management roles (finance, administration, project controls, etc.), engineers and technicians, postdocs, graduate students, and undergraduates. The engineer and technician roles may be further categorized as e.g., electrical or mechanical, each with varying levels of experience.
- The labor rates used in the resource-loaded schedule for WIPAC and universities include the direct hourly rate but do not include the fringe benefits and indirect overhead. Fringe benefits and indirect overhead are calculated in Cost Workbook and added to the total labor cost. Labor rates from the Physical Sciences Lab (PSL) are already fully burdened, and no additional overhead is added.
- Escalation rates for labor are applied as discussed below (see section 4.7),
- Table **3** shows the average labor rates by institution as of 2022, which are escalated by 2.15%/year (see Section 4.7). The labor rates are given for different labor types: AD – Administration, EN – Engineer, GR – Graduate Student**,** KE – Key Personnel / Faculty**,** MA – Management**,** PO – Post-doctoral Scientist**,** SC – Scientist**,** SE – Senior Engineer**,** SS – Senior Scientist**,** TE – Technician**,** UG – Under-graduate Student**,** SH – Machine Shop (PSL)
- Fringe rates (see Table **3**) are updated in July of every year and are propagated through the RLS.
- Indirect rates (see Table **4**) were set at the start of the Project's Cooperative Agreement. These rates may be updated, if necessary, through an updated Cooperative Agreement. These rates apply both to labor and M&S (see next section).

Labor Base Rates (2022) assuming 1800 hours/year															
Institution	AD	EN	GR	KE	MA	PO	SC	SE	SS	TE	UG	SH	EN-EE	EN-ME	EN-S
PSU	$41.00	$58.00	$23.00	$116.00	$64.00	$35.00	$52.00	$64.00	$66.00	$29.00	$11.00		$58.00	$58.00	$58.00
UA	$41.00	$58.00	$23.00	$116.00	$64.00	$35.00	$52.00	$64.00	$66.00	$29.00	$11.00		$58.00	$58.00	$58.00
MSU	$41.00	$69.00	$23.00	$97.00	$64.00	$31.00	$52.00	$64.00	$66.00	$46.67	$14.00		$72.00	$62.00	$62.00
UMD	$41.00	$58.00	$31.00	$116.00	$64.00	$35.00	$52.00	$64.00	$66.00	$29.00	$11.00		$58.00	$58.00	$58.00
UW	$41.00	$49.00	$35.00	$121.00	$46.00	$35.00	$52.00	$55.00	$66.00	$29.00	$11.00		$46.00	$46.00	$46.00
PSL		$115.00								$77.00		$77.00	$115.00	$115.00	$115.00
Institutional Fringe Rates by Job Category															
PSU	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
UA	32%	32%	32%	32%	32%	17%	32%	32%	32%	32%	32%	32%	32%	32%	32%
MSU	32%	0%	32%	8%	32%	31%	32%	32%	32%	0%	32%	32%	0%	0%	0%
UMD	35%	35%	24%	29%	29%	29%	29%	35%	29%	35%	29%	30%	35%	35%	35%
UW	35%	35%	19.90%	35%	35%	18.90%	35%	35%	35%	35%	2.90%	35%	35%	35%	35%
PSL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 3 Estimated Labor and Fringe rates at participating institutions by labor type. The labor rates shown are from 2022 and are escalated by 2.15% / year at each institution. When current salaries are known for each individual, then they are used, otherwise these estimated rates are used. The fringe rates are current as of June, 2022.

Indirect Rates	
Institution	Rate
PSU	58.1%
UA	49.0%
MSU	55.0%
UMD	54.5%
UW	53.0%
PSL	53.0%

Table 4 Indirect overhead rates for participating institutions. These rates apply both to labor and M&S.

4.4 Equipment Costs

- Equipment costs include Capital Equipment (CapEx), and M&S (Materials and Supplies). Overhead rates generally apply only to M&S, which includes items such as laboratory consumables and shipping costs.
- Equipment costs are estimated for each task and are documented in the Basis of Estimates.
- Equipment cost estimates are done in FY2022 dollars for the rebaselining exercise. Currently no escalation is used for equipment costs, as experience shows that the costs are as likely to go down as they are to go up due to manufacturing and sourcing improvements.
- All costs in the resource-loaded schedule are in US dollars. The NSF scope has very little exposure to non-US currency fluctuations.
- Uncertainty in equipment cost estimates is managed using contingency, as described below.

4.5 Travel Costs (non-South Pole)

- Travel will be costed on the project for:
  - International travel (reviews, workshops, etc.)
  - Domestic travel for reviews, workshops, and working with IceCube Upgrade collaborators.

- Travel for external reviewers and the project office is covered in the project management travel costs. Travel for L2/L3 managers for reviews, coordination, and workshop will be covered in the relevant L2 management area.
- For reviews coordinated by in-kind partners, any external reviewers and project office personnel travel is covered in the project management travel cost. Review travel for in-kind partners is covered in the in-kind budget.
- Travel estimates assume $3.2k in direct costs for international trips, and $1.8k in direct costs for domestic trips for typical 1-week trips. For longer/shorter trips, different numbers may be used, but must be justified. The analysis of travel costs, including historic data to justify these costs can be found in (8).
- No escalation is applied to travel.

4.6 South Pole deployment costs

- For South Pole deployment, the project covers the cost of the hotel and per diem in Christchurch. The costs for South Pole deployment are standardized at $1.8k in direct costs per deployment (i.e., per trip, independent of the length of deployment).
- The plane ticket to Christchurch, travel from Christchurch to the South Pole, and subsistence at the South Pole is covered by the Antarctic Services Contract, however the total number of people to be supported at the pole must be maintained and updated for each pole season.
- All South Pole deployments are done through WIPAC, who incurs additional costs (Supplies) per person deployed (in additional to the travel costs above), including:
    - Physical Exams (PQ) necessary for deploying personnel, which currently costs $700/person.
    - Additional cold weather gear, which currently costs $250/person.
- South Pole travel and supplies are not escalated.

4.7 Escalation Rates for Labor

- The base year for cost estimates for rebaselining is FY2022. Costs in out years are calculated by applying standard escalation rates discussed above.
- Labor rate escalations are standardized across all institutions at 2.15% per year. This rate was calculated using average escalation data from the US Bureau of Labor Statistics (9) averaged over 2010-2021(see Figure 1).
- An overall risk uncertainty on labor escalation is included in the risk register.
- Costs are specified in FY2022 dollars and are escalated to the year the activity is scheduled.

4.8 Indirect Costs on NSF funds managed through WIPAC

- For Institutions participating in the NSF scope of the project:
  - Money is allocated as an NSF sub-award from the NSF host university (UW).
  - The sub-awards have already been set up and the UW overhead (53%) on the first $25k has been paid. No further UW overhead on the subawards is anticipated.
- The 53% overhead at UW is the same for supplies, travel, and labor, however capitalized equipment has no overhead, nor does tuition remission**.**

4.9 Facilities and Administration (F&A) Indirect Costs at Institutes

- Institutions performing federally supported research negotiate Facilities and Administration (F&A) rates with the federal government. The F&A rates are applied as a fraction of the direct research costs as an administratively efficient mechanism to reimburse the institution for the costs of their facilities and administration.
- The F&A rates agreements for all Project institutions are summarized in Table **3**.
- For labor, there are additional charges to cover employees' fringe benefits. This is also shown in Table **3**.
- The Basis of Estimates describe the direct costs for materials, and hours for labor. The labor rates, fringes, and indirect (F&A) costs are then calculated depending on the specific institution performing the work and the applicable rate.
- Institutions are responsible for responding to Project requests for current fringe and overhead rates for each labor type working on the project. These rates will be updated project wide every year.
- Labor fringe is given as a percentage of the base salary. Overhead is then applied to the base salary plus the labor fringe.
- Indirect rates are given as a percentage of the materials cost.
- For travel, the standard indirect rates for the institution are applied.
- Most institutions' federal F&A agreements provide an exemption from indirect costs on equipment (costing above a threshold of typically $5000), and capital expenditures.

4.10 Cost Estimate Uncertainty Contingency

The fidelity of the cost estimate correlates closely with the maturity of the design. The Association for the Advancement of Cost Engineering International (AACEI) has formulated 5 classifications of estimates, ranging from mostly 1 (most defined, i.e., purely deterministic estimate) to 5 (least defined, i.e., purely stochastic estimate). Most estimates are a mixture of these two. Table 5 shows an example estimate matrix for the process industry (10).

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**DEGREE OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	70% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Table 5 AACEI estimate classifications for the process industry.

- For the rebaselining effort we have done a full bottom-up estimate including the estimate uncertainty using the information from Table **6**. The approximate linkage to the corresponding AACEI estimate is shown in the last column.

Code	Type of Estimate	Contingency % Range	Description	ASCII Estimate Class
C1	Level of Effort Tasks	3%-15%	**Labor:** Support type activities that must be done to support other work activities or the entire project office, where estimated effort is based on the activities it is supporting.	1
			M&S/Equipment: items such as travel, software purchases and upgrades, computers, etc. estimated to support LOE efforts and other work activities.	1
C2	Advanced	5%-20%	**Labor** based on experience with documented identical or nearly identical work. Development of activities, resource requirements, and schedule constraints are highly mature. Technical requirements are very straightforward to achieve.	2
			M&S/Equipment: items for which there is a catalog price or recent vendor quote based on a completed or nearly completed design or an existing design with little or no modifications and for which the costs are documented.	2
C3	Preliminary	10%-30%	**Labor**: Based on direct experience with similar work. Development of activities, resource requirements, and schedule constraints are defined at a preliminary (beyond conceptual) design level. Technical requirements are achievable and with some precedent.	3
			M&S/Equipment items that can be readily estimated from a reasonably detailed but not completed design; items adapted from existing designs but with moderate modifications, which have documented costs from past projects. A recent vendor survey (e.g. budgetary quote, vendor RFI response) based on a preliminary design belongs here.	3
C4	Conceptual	20%-50%	**Labor** based on expert judgment using some experience as a reference. Development of activities, resource requirements, and schedule constraints are defined at a conceptual level. Technical requirements are moderately challenging.	4
			M&S/Equipment items with a documented conceptual level of design; items adapted from existing designs which have documented costs from past projects, but with extensive modifications.	4
C5	Pre-conceptual	40%-60%	**Labor** based only on expert judgment without similar experience. Development of activities, resource requirements, and schedule constraints is largely incomplete. Technical requirements are challenging.	5
			M&S/Equipment items that do not have a documented conceptual design, but do have documented costs from past projects. Use of this estimate type for M&S indicates little confidence in the estimate. Should be minimized when completing the final estimate.	5c

C6	Rough Estimate	60%-80%	**Labor**: No experience available for reference. Activities, resource requirements, and schedule constraints are completely undeveloped. Technical requirements are beyond the state of the art.	5
			M&S/Equipment items that do not have a documented conceptual design, and have no documented costs from past projects. Use of this code for M&S should be minimized when completing the final estimate.	5

Table 6 Estimate Uncertainty ranges as a function of the maturity of the cost estimate.

- Cost estimate uncertainty (EU) contingency accounts for potential deviations in the actual cost compared to the base cost due to, for example, the level of design maturity, vendor price evolution or imprecision in estimates of labor hours.
  - Additional risk contingency is included in the project plan to account for discrete risk events, which are documented in the project risk register. Care is taken not to pad EU contingency to account for explicitly identified risks.
- EU contingency is included for all scope.
- EU contingency factors are implemented at each task, estimated considering the maturity of design and the confidence of the cost estimate, and documented in the Basis of Estimates. The EU contingency factor is generally the mid-point of the range in Table **6**. Any deviation from the midpoint must be documented in the Basis of Estimate.
- The EU contingency is summed over all elements to form a project wide EU contingency number.

5. Key Schedule Assumptions

5.1 General Scheduling Guidance

- Cost Account Managers should follow the scheduling guidance provided in the NSF Research Infrastructure Guide (5) and the GAO *"Schedule Assessment Guide"* (11) (and see Appendix B).
- Cost Account Managers are instructed by the Project Manager to provide their best estimate, consistent with this guidance, for resources and duration required for every task.
- There should be no contingency embedded in the activity duration estimates.
- Guidance for task durations are the following:

1) For ongoing LoE (i.e., management), the task durations may be as long as 1 year.
2) For individual tasks, the durations should be between 7-90 days. This is to ensure that monthly EV data is sensible. For tasks less than 7 days (especially e.g., on-ice tasking), we will implement them formally as steps in P6, allowing a method of both capturing the tasks and statusing the overall activity as tasks are completed.

5.2 Partner (in-Kind) Milestone Dates

- In-Kind deliverables are integrated into the Project schedule, and tracked using percent complete. The tasks and related milestones are connected to the NSF project milestones, so while they do not directly contribute to earned value, they do impact the NSF schedule and resulting NSF earned value and critical path.

5.3 NSF Milestone Dates

- The IceCube Upgrade Cooperative Agreement effective date was October 1, 2018.
- The initial panel review and onsite visit was in March 2019.
- Baseline project completion is June 2023.
- The effects of COVID19, both on the project and on the ability to deploy cargo and personnel to the South Pole, resulted in the project being delayed. A preliminary rebaselining review, exploring the project's sensitivity to several different logistics assumptions, was held March 2021.
- A logistics review to assess the Project estimating methods and needs for cargo and personnel at the SP was held in November 2021. A realistic schedule to align Project needs and AIL capabilities was produced in February to enable the project to make a new risk adjusted total project cost and project completion schedule. This then forms the new baseline.
- An NSF rebaselining review was held in May 2022, which reviewed the proposed new project baseline cost, schedule, risk, and technical progress.
- An Independent Cost Estimate Review will be held in August.
- The replanned / rebaselined project will start October 1, 2022.

5.4 Critical Path Analysis

- A complete Critical Path Analysis will be done in P6 before the rebaseline.
- In general, the on-ice activities, and the equipment-logistics chain, form the critical path. The Field Season dates are set, and the Project must be completed during FS3 (Nov 2025-Feb 2026). During this last Field Season, all drilling and deployment of modules is done.
- The Project Manager and Project Office use the on-ice milestone deadlines to understand the impact of delays to the Project and any additional resources that might be needed to ensure the overall success of the Project.

5.5 Shipping and Logistics Assumptions

The shipping and logistics assumptions are documented in (2) and are fully consistent with guidance from USAP (12) and (13). The Cost Managers for each piece of the upgrade that must be shipped to the South Pole are responsible for all packing and shipping costs to either Port Huaneme (PtH) or New Zealand (Christchurch or Lyttleton), where the cargo enters the US Antarctic Program logistics stream. The exact route that the item takes is decided by the logistics manager, based on cost and schedule information. Cost Managers are responsible for ensuring the shipping follows the procedure found in (2), and the Logistics Manager is responsible for liasoning with the USAP and the Antarctic Services Contractor to keep all information up to date.

Cost Managers are responsible for estimates of size and weight of items. These estimates are independently verified, as described in (2). The Project maintains a consistent cargo and personnel list ((1), (14)), based on these estimates. Further, all shipping to either PtH or NZ before entering the USAP cargo stream must have a minimum of one month schedule contingency. Given the current status of domestic and international shipping, more time may be needed as determined by the logistics manager. No explicit schedule contingency is given to the USAP cargo stream – this contingency is determined by the Antarctic Contractor.

The current status of South Pole logistics is severely impacted by the COVID19 pandemic. NSF is working with the project to reach a several year agreement on the amount of cargo and personnel that can be supported. An initial agreement was transmitted to the Project at the end of January, 2022 (13), which is reproduced in Appendix C, and the Project is using parameters from this agreement for the rebaselining plan.

5.6 Risks

The Project's management of risks is described in its Risk Management Plan (15) and individual risks are detailed in the Project's Risk Register (16). Some risks in the Risk Register are in areas that may be assumed by NSF (i.e., logistics stream risk could be covered by AIL / ASC), however as the impact of these risks affects the Project, the Project has captured all such risks. Risks and overall assumptions are described in the Risk Management Plan.

Appendix

A. Escalation

Figure 1 shows the average consumer price index from the US Bureau of Labor Statistics over the past 20 years (9). The average inflation rate is 2.09%, however we have chosen a more conservative 2.15% (shown as the central black line). The uncertainty is taken to be +-3% (see outer black lines) and is accounted for in the project's risk register.

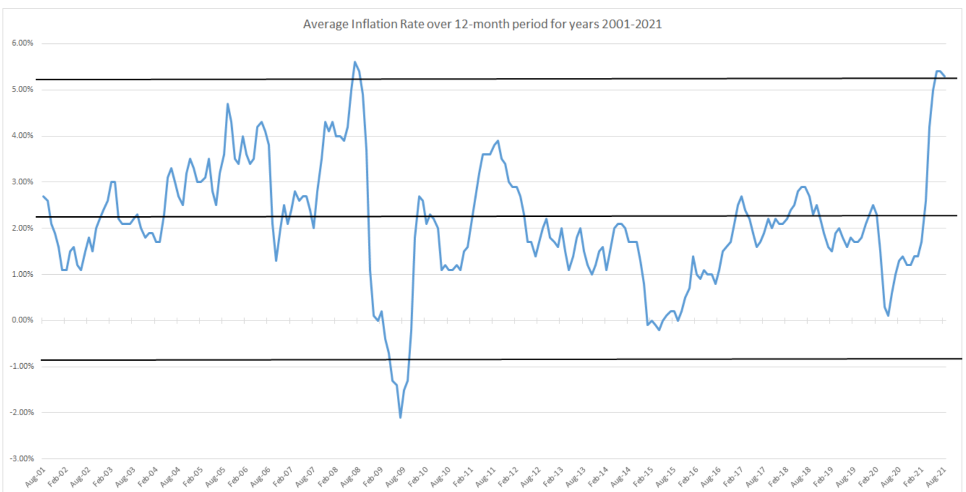

Figure 1 Average Inflation Rate for years 2001-2021 from the US Bureau of Labor Statistics. The central black line shows the 2.15% escalation rate used for the Upgrade project; the upper and lower black lines are +-3% respectively.

B. GAO 10 Best Practices for Schedules

Table 7 summarizes the GAO 10 Best Practices for Schedules, taken from the GAO Schedule Assessment Guide (11). The third column delineates the responsibility split between estimators (i.e. Cost Account Managers or Subject Matter Experts, WBS Level 2 Managers, and the Project Office). In most steps, all three will be engaged.

Practice	Definition / reasoning	Responsibility
Capture all activities	The schedule should reflect all activities as defined in the project's WBS, which defines in detail the work necessary to accomplish the project's objectives, including activities both the owner and the contractors are to perform.	Estimator / Cost Account Manager
Sequence all activities	Activities must be logically sequenced and linked—that is, listed in the order in which they are to be carried out and joined with logic. In particular, a predecessor activity must start or finish before its successor. Date constraints and lags should be minimized and justified.	Estimator / Cost Account Manager
Assign resources to all activities	The schedule should reflect the resources (labor, materials, travel, facilities, equipment, and the like) needed to do the work, whether they will be available when needed, and any constraints on funding or time	Estimator / Cost Account Manager
Establishing the duration of all activities	The schedule should realistically reflect how long each activity will take. When the duration of each activity is determined, the same rationale, historical data, and assumptions used for cost estimating should be used. Durations should be reasonably short and meaningful and should allow for discrete progress measurement. Schedules that contain planning and summary planning packages as activities will normally reflect longer durations until broken into work packages or specific activities.	Estimator / Cost Account Manager
Verify that the schedule can be traced horizontally and vertically	The schedule should be horizontally traceable, meaning that it should link products and outcomes associated with other sequenced activities. The schedule should also be vertically traceable—that is, data are consistent between different levels of a schedule. When schedules are vertically traceable, lower-level schedules are clearly consistent with upper-level schedule milestones, allowing for total schedule integrity and enabling different teams to work to the same schedule expectations.	Estimator / Cost Account Manager and Project Office
Confirm that the critical path is valid	The schedule should identify the project's critical path—the path of longest duration through the sequence of activities. Establishing a valid critical path is necessary for examining the effects of any activity's slipping along this path. The project's critical path determines the project's earliest completion date and focuses the team's energy and management's attention on the activities that will lead to the project's success.	Estimator / Cost Account Manager and Project Office
Ensure a reasonable total float	The schedule should identify reasonable total float (or slack)—the amount of time a predecessor activity can slip before the delay affects the project's estimated finish date—so that the schedule's flexibility can be determined. As a general rule, activities along the critical path have the least total float. An unreasonably high total float on an activity or path indicates that schedule logic might be missing or invalid.	Project Office
Conduct a schedule risk analysis	A schedule risk analysis starts with a good critical path method schedule. Data about project schedule risks are incorporated into a statistical simulation to predict the level of confidence in meeting a project's completion date; to determine necessary contingency; and to identify high-priority risks.	Project Office
Update the schedule using actual progress and logic	Progress updates and logic provide a realistic forecast of start and completion dates for project activities. Maintaining the integrity of the schedule logic is necessary to reflect the true status of the project. To ensure that the schedule is properly updated, the people responsible for the updating should be trained in critical path method scheduling.	L2 Managers, Project Office (Project Controls)
Maintain a baseline schedule	A baseline schedule is the basis for managing the project scope, schedule, and resources. The baseline schedule is designated the target schedule and is subjected to a configuration management control process. Project performance is measured, monitored, and reported against the baseline schedule. The schedule should be continually monitored so as to reveal when forecasted completion dates differ from baseline dates and whether schedule variances affect downstream work.	Project Office

Table 7 GAO 10 Best Practices for Scheduling (see (11) for more details).

C. Planning Capacities for IceCube (AIL-OPP)

Figure 2 summarizes the logistics capacities accorded to IceCube Upgrade by OPP-AIL.

ICU Planning Capacities
OPP-AIL, 1/31/2022

Year	FY23	FY24	FY25	FY26	FY27
Vessel South (TEUs)	18*	as needed	as needed	n/a	n/a
Vessel North (TEUs)	n/a	17	50	17	50
LC-130: Hours/Flights^	12/2	114/19	60/10	42/7	36/6
SPoT-1 (Sleds/Weight, lbs)	3/180,000	3/180,000	3/180,000	3/180,000	3/180,000
SPoT-2 (Sleds/Weight, lbs)	3/180,000	3/180,000	3/180,000	3/180,000	3/180,000
SPoT-3 (Sleds/Weight, lbs)	3/180,000	3/180,000	3/180,000	3/180,000	3/180,000
Pole Population (Nov-Jan)	0	11	21	46~	4

*If ICU needs more space to move things ahead, we will find a way to make more TEUs available.
^This does not fully meet the goal to have all fuel required on site prior to the FY26 main drilling season. AIL will continue to look at ways to mitigate that risk as planning moves forward.
~This is a hard maximum and needs to be reviewed again for ways to bring it down if at all possible.

In general:
1. Our supportability is dependent on moving as much cargo to Pole as possible in FY24. This means getting as much cargo on the FY23 vessl or, if needed, getting it to MCM via commercial surface shipment/C17 no later than Nov. 2024.
2. FY27 info is provided in advance of IPT discussion/clarification on retro requirements.
3. Temperature controlled storage (at MCM and Pole) is likely still an issue that needs to be resolved with this capacity.

Figure 2 Logistics Capacities reserved for IceCube Upgrade

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References

1. **IceCube Upgrade.** *IceCube Upgrade (ICU) Master Cargo Spreadsheet.* 2021.
2. **IceCube Upgrade Project.** *IceCube Upgrade Logistics - Cargo Estimation and Shipment Planning.*

3. **IceCube Neutrino Observatory.** *IceCube Neutrino Observatory Divestment Plan.* December 2021.
4. **U.S. Government Accountability Office.** *Cost Estimate and Assessment Guide: Best Practices for Developing and Managing Program Costs.* 2020.
5. **National Science Foundation.** Research Infrastructure Guide. [Online] December 2021. https://nsf.gov/publications/pub_summ.jsp?ods_key=nsf21107.
6. **IceCube Upgrade Project.** *Cost Estimating Plan for the IceCube Upgrade Project.* 2021.
7. **Smartsheet®.** *https://www.smartsheet.com/.* [Online]
8. **IceCube Project.** *Travel estimate analysis from historical data.*
9. **US Bureau of Labor Statistics.** [Online] tps://www.bls.gov/charts/consumer-price-index/consumer-price-index-by-category-line-chart.htm.
10. **AACEI.** AACE International. [Online] https://web.aacei.org/.
11. **U. S. Government Accounting Office.** *Schedule Assessment Guide.* [Online] December 2015. https://www.gao.gov/products/gao-16-89g.
12. **Antarctic Support Contractor for the National Science Foundation Office of Polar Programs.** *Packing and Shipping Instructions.* 2020. TL-MAN-002.
13. **OPP-AIL.** *ICU Planning Capacities.* January 31, 2022.
14. **IceCube Upgrade.** *IceCube Upgrade (ICU) Population Master Spreadsheet.*
15. **IceCube Upgrade Project.** *The IceCube Upgrade Risk Management Plan.*
16. **IceCube Upgrade.** *The IceCube Upgrade Risk Register.*

IceCubeGen2_KeyAssumptionsv-Upgrade_v1_14

Final Audit Report 2022-07-05

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