

Scope Management Plan for the IceCube Upgrade Project

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Change Log:

Version	Date	Author	Summary of changes
1.0	2022-01-03	V. O'Dell	1 st version
2.0	2022-02-25	V. O'Dell	Add in simulations for string reductions from Tom S.; scope opportunities from Erik B.
2.1	2022-03-11	A. Karle	Add in section on hole parameters
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3.1	2022-07-10	A. Karle	Add in paragraph about string / hole descopeing plan.

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1. Purpose

Scope Management is an integral part of project management. According to the NSF Research Infrastructure Guide (1), the Scope Management Plan not only describes the process by which the project maintains control of scope, but also documents scope changes that can be implemented depending on the project's cost and schedule forecasts. These scope changes can be either **downscopes**, if the project is over budget and/or behind schedule, or **upscopes**, if the project is under budget and performing well schedule-wise. This document complements the IceCube Upgrade's Project Execution Plan (2), describing the process followed to develop scoping options, a summary of the scope options, and the plans for managing them.

2. Baseline Scope

The baseline scope for the IceCube Upgrade is detailed in the “IceCube Upgrade Project Execution Plan” (2). An overview of the project is shown in Figure 1.

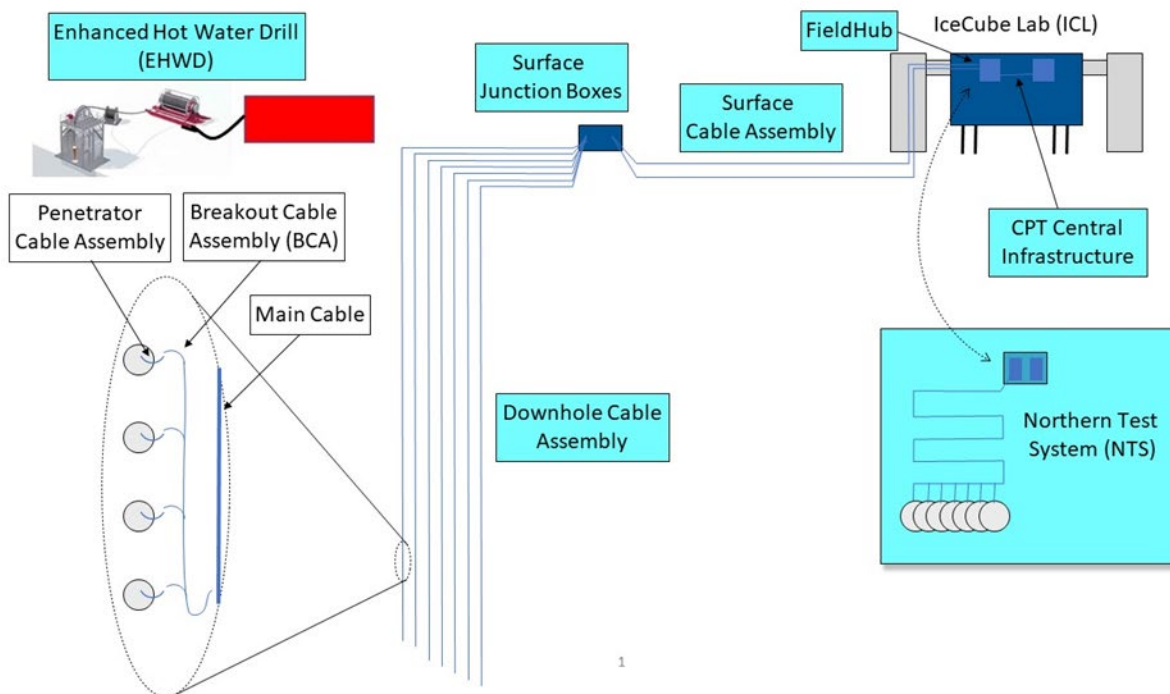


Figure 1 A high-level representation of the IceCube Upgrade.

In brief, the upgrade consists of an Enhanced Hot Water Drill designed to drill holes to 2600 meters, optical module “strings”, each instrumented with 38 dual PMT modules (D-Eggs) and 52 multiple PMTs (mDOMs) in the physics region between 2150-2425M, as well as calibration devices, D-Eggs,

and mDOMs above and below the physics region (see Figure 2). The backbone of the strings are the downhole cables.

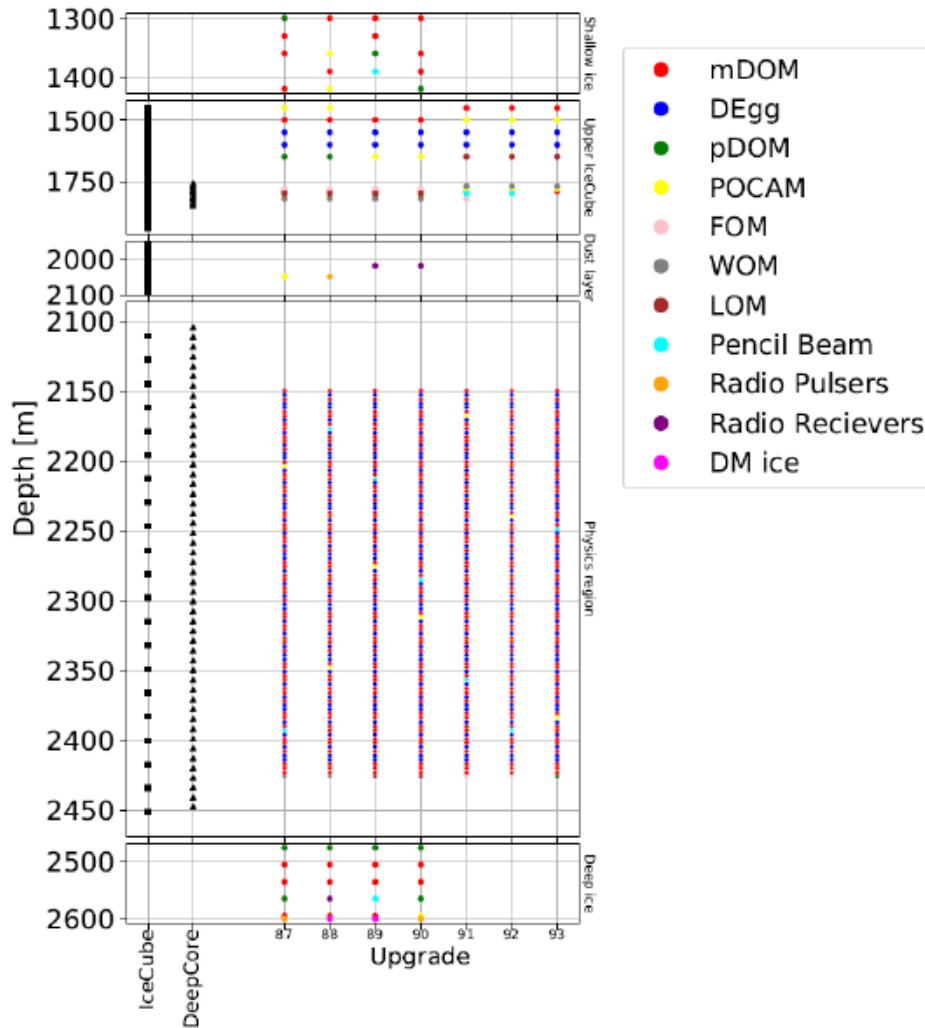


Figure 2 Configuration of the 7 Upgrade Strings, in comparison with IceCube Gen1 and IceCube DeepCore.

Additionally, the project consists of surface cables, junction boxes, and computing necessary to readout and calibrate the deployed strings. The project also supports a “Northern Test System” mainly used for firmware and software development needed to validate hardware and software/firmware as well as support any necessary updates to software and/or firmware.

The detector is installed and commissioned by the Upgrade Project, and is handed off to the ongoing IceCube Neutrino Observatory Maintenance and Operations. For details of the configuration of the detector and software at handoff see (2).

3. Scope Options

3.1 Project Downscope

Project downscales are considered that save project money or schedule. Note that much of the instrumentation is “in-kind”, that is delivered by partners outside of the NSF Upgrade Project budget, thus descopeing instrumentation is not a cost saver.

3.1.1 Reducing the number of strings deployed

The optical sensors are built in the U.S., Germany, and Japan, and are funded by our foreign partners. The downhole cables are also in-kind, funded through the Michigan State University. Hence removing strings saves only a modest amount of money but could potentially mitigate schedule risk. The cables are currently planned to be purchased in approximately June 2022, and cost roughly \$300k apiece. If we decide to descope in the next few months, it is possible, although not certain, to recoup the cost of the cables and apply the money elsewhere in the project. The surface cables have already been bought; thus, descopeing in the next few months would not save the cost of these cables.

The real potential of descopeing the number of strings deployed is in the schedule savings during the main drilling season (FS3 in FY26). Each hole takes approximately 3 days to drill and deploy (where we are including setup and breakdown in the time estimate), thus drilling two less holes, for example, would save about 1 week of on-ice time during Field Season 3.

3.1.1.1 Scientific Impact of descopeing strings

IceCube has run simulations to determine the scientific impact of descopeing strings. The simulation assumes that the last two holes are not drilled and compares the 5-string configuration with the nominal 7 string configuration. Figure 3(a) compares event distributions for the 5-string and 7-string case in the Upgrade Volume as a function of energy. At energies > 10 GeV, the distributions are consistent; however, at low energies, which are sensitive to the neutrino mass hierarchy, the 5-string detector shows a reduction of neutrino rate of about 15-20%. Figure 3(b) compares the zenith angle of the distributions and shows that the degradation of neutrino rates is roughly flat as a function of zenith angle.

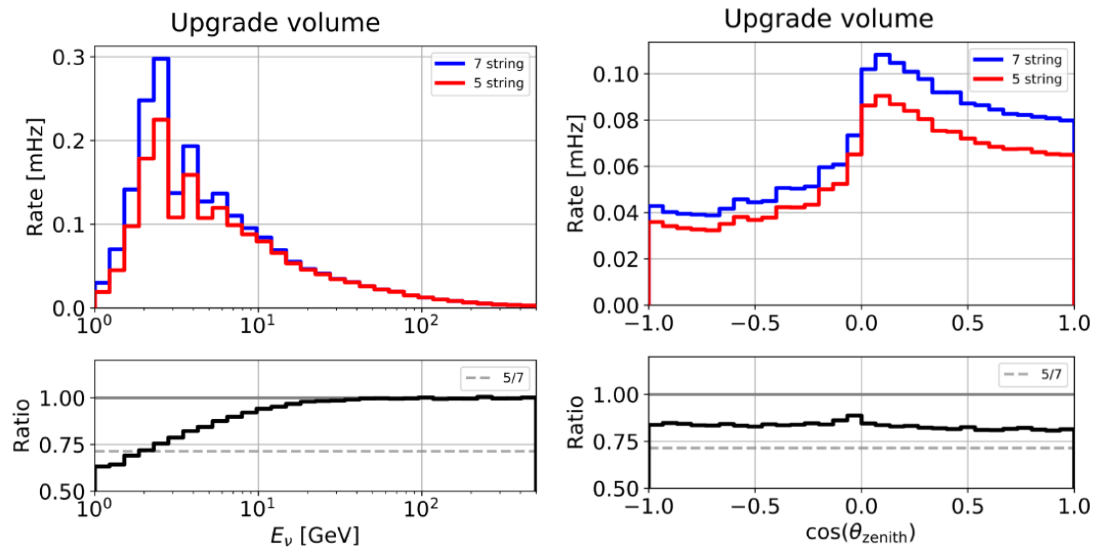


Figure 3 Comparison of neutrino event distributions between 5 string and 7 string Upgrade detector as a function of (a) neutrino energy and (b) $\cos(\theta_{zenith})$.

Figure 4 compares the reconstructed energy and zenith angle resolutions as a function of energy. For energies up to 10 GeV, the energy resolution degrades by about 10-20%. The degradation of the resolution of $\cos(\theta_{zenith})$ is also on the order of 10-20%, with the lower energy neutrinos being affected less.

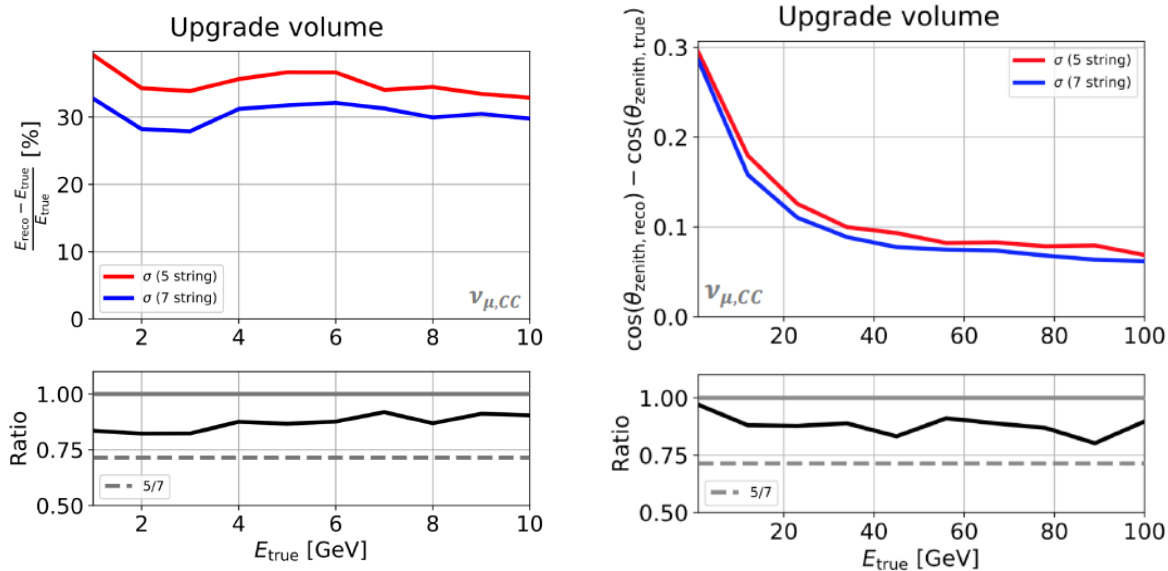


Figure 4 Comparison of reconstructed neutrino event resolutions between 5 string and 7 string Upgrade detector as a function of neutrino energy for (a) neutrino energy and (b) $\cos(\theta_{zenith})$.

3.1.1.2 Conclusions on reducing the number of strings

In general, for the neutrino rate at low energies, the 5 string detector has a 15-20% drop in rate, with up to about 30% drop in rate for energies < 10 GeV. One way to make up for the overall loss of events is to run longer. More concerning is the resolution degradation which would fundamentally limit the performance of the detector. Studies show that the energy resolution, for energies < 10 GeV, are affected at the 10-20% level, and the zenith angle resolution degrades by 10-20% for higher energy neutrinos.

While the collaboration would clearly prefer to deploy the full 7 string detector, these studies show that even the 5-string detector would have a substantial measurement and discovery potential.

In case of a descope, the sequencing of the strings will not change by default. The sequencing has been carefully analyzed with respect to positioning and relocating drill and deployment equipment. Which strings would be eliminated would depend on the reason and the time when the decision is made. An analysis will be performed as part of the field season preparation. Technically, any one or two of the seven strings (numbers 87, 88, 89, 90, 91, 92 and 93) may be omitted. If the decision happens during the field season, it will be by default the last two strings that get omitted. If the decision happens early in the season, or yet earlier, for example on grounds of availability of string hardware, scientific criteria and instrument configuration can also enter the selection. A decision matrix with criteria and scenarios will be developed as part of preparation of field season 3.

3.1.2 Modifying drill hole parameters

An additional descope option is available in modifying the hole specifications. The current plan foresees that 5 of the 7 holes will be drilled with a modified drill sequence that has the intent to eliminate air bubbles. This procedure requires drilling a slightly larger hole and an additional circulation of water. The possibility exists to drill most or all holes in the standard procedure, as was done in IceCube Gen1. Dropping this degas-procedure reduces the fuel usage per hole by 10% and reduces the drill time per hole by 10 hours. Thus, dropping 3 (or 5) degassing procedures saves 30 (50) hours of drilling time and 2400 (4,000) gal of fuel.

In addition to this measure, a smaller descope option eliminates the deepest segment of one (or two) out of four strings that are configured for a depth of 2620m reducing the depth to 2450m. This is a minor modification that would save another 4 (8) hours of drill time.

These combined measures could save up to 60 hours of drill time, and at least that amount of work time on ice, as well as 4000 gallons of fuel in the process. The decision to take these measures would be taken on the ice once it is determined that the drill schedule is compressed beyond a critical value, either before drilling starts, or during drilling.

The science impact of these measures is relatively small. Removing air bubbles would allow a comparison of holes with and without air bubbles. However, all IceCube holes have the mentioned bubble column in the center of the hole. In the past 4 years, since the Upgrade was proposed, substantial progress has been made in simulation and analyzing the effect of the central bubble column. Once these effects are correctly simulated, they become a feature and are no longer a systematic error. The degassing of at least one or 2 holes would demonstrate that we understand the causality of the feature. However, no adverse science impact is expected for the neutrino physics goals by introducing these measures. Similarly, reducing the number of full depth strings from 4 to 2 would have only marginal impact in the ice calibration of the ice in that region.

3.2 Project Upscopes

The project upscopes considered are ones that can be exercised late in the project, as the Field Seasons define the critical path for the overall project and carry inherent risks. The Upgrade project, and its eventual integration in the overall operating IceCube detector, relies heavily on the ongoing IceCube Maintenance and Operations (M&O) program for the collection, storage, and analysis of data from the newly deployed sensors and calibration devices. The project upscope options are listed below, and facilitate the fully integrated Upgrade detector in: storage and analysis of Upgrade data; reduction of time needed to perform analyses with the fully integrated detector; and reduction of the time to physics results.

The additional cyberinfrastructure needed to realize the additional support for facilitating data handling and analysis of the upgraded detector are:

1. ~1-2 PB storage for data and simulation (\$70-100/TB, \$140-200k per storage element)
2. ~10 GPU data analysis and photon simulation servers (\$33k/server, \$330k)
3. 1 Machine Learning server for algorithm training and testing (\$200-300k)

The sum of all these scope options is approximately \$800k. The exact configuration of upscales we would exercise will depend on the money available and will be decided at the time of the third field season, and exercised as soon as the success of this final field season is assured.

4. Scope Option Management

Managing the scope options involves:

- Updating the scope options on a routine basis
- Monitoring the decision points for executing down- or up-scopes and reviewing the need for executing a scope option in a timely manner.
- Prioritizing the scope options.

The scope options are updated regularly if there are changes to schedule or cost that would impact the descope options available to the project. At least once a year a more comprehensive review of the (available) scope options will be performed.

The available contingency for the NSF funded project compared to the risk exposure and projected draws on contingency is evaluated on a routine basis as part of Earned Value Management. If the available contingency is considered to be insufficient for completing the project, steps will be taken to select and exercise descope options to bring the contingency up to an acceptable level.

When descopeing is necessary, the project will consider the ranking of the descope options to decide which option(s) to execute. Selection of the proposed descopes will be coordinated with the IceCube collaboration.

References

1. **National Science Foundation.** Research Infrastructure Guide. [Online] 2021.
https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf211107.
2. **IceCube Upgrade Project.** Project Execution Plan for the IceCube Upgrade Project. [Online] 2022.