Written Testimony of Mr. James H. Yeck, IceCube Project Director
before the
UNITED STATES HOUSE OF REPRESENTATIVES
Committee on Science, Space, and Technology, Subcommittee on Research and Science Education hearing entitled "*NSF Major Research Equipment and Facilities Management: Ensuring Fiscal Responsibility and Accountability*",
March 08, 2012.

Chairman Brooks, Ranking member Lipinski, and distinguished members of the Subcommittee, thank you for the opportunity to testify. My name is Mr. Jim Yeck and I am the Project Director for IceCube, an NSF Major Research Equipment and Facilities (MREFC) Project that created the IceCube Neutrino Observatory. My testimony provides an overview of the IceCube MREFC Project from its beginning to its successful conclusion last year and its operations and responds to the questions from the Subcommittee.

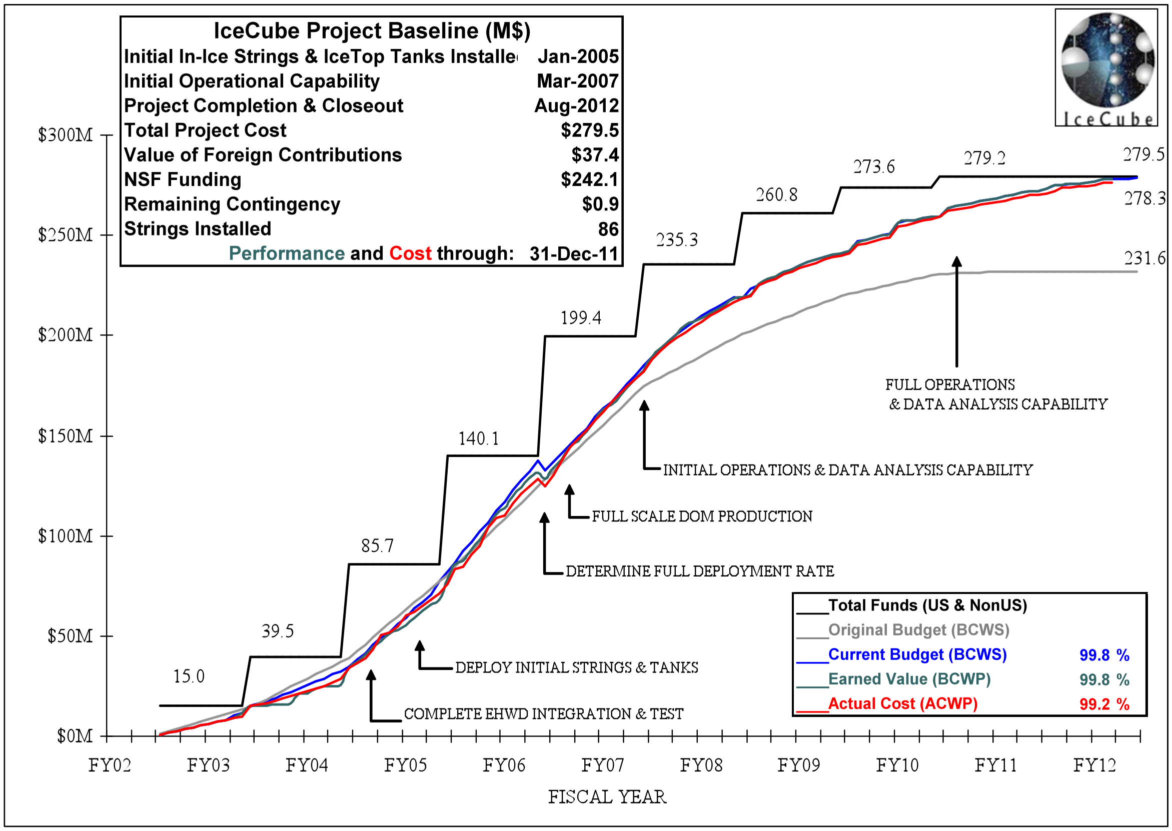
Overview of IceCube MREFC project, from inception to its operations today.

IceCube is a particle detector embedded in a cubic kilometer of deep, very transparent South Pole ice that was designed to detect high-energy neutrinos from nearby and across the Universe. The science capability of this observatory ranges from detecting neutrinos from dark matter annihilations that are predicted to take place in the sun to bursts of neutrinos from stellar explosions in our galaxy and other nearby galaxies to ultra-high energy neutrinos produced by violent astrophysical events at the centers of active galaxies across the Universe. The capability of IceCube greatly exceeds that of previous detectors and those currently under construction, and thus its capacity for transformational discovery is very significant.

The IceCube MREFC project was proposed in 1999 and final approvals for construction were given in April 2004. Detector installation started in January 2005 and was completed in December of 2010. A special hot water drill was used to embed the detector instrumentation in the South Pole ice (the ice melted was almost three times the volume of the Capitol dome). Once the holes were drilled in the ice, deployment specialists carefully connected digital optical modules to cables and lowered them into the drill holes to a depth of 2.5 kilometers. Each cable has 60 modules attached to it, and there are 86 cables in total. IceCube has a surface component called IceTop that serves as a cosmic air shower array. The construction effort required almost ten million pounds of cargo and over 30,000 person-days of work at South Pole. The total MREFC Project cost of IceCube is $279.5 million. The National Science Foundation provided $242.1 million and funding partners in Belgium, Germany, and Sweden provided support valued at $37.4 million. The IceCube detector exceeds its original performance and sensitivity goals.

The IceCube Collaboration of scientists and professionals includes about 250 people from 39 institutions in 11 countries.

The technical, cost, and schedule performance of the IceCube MREFC Project was consistent with the original project baseline and the NSF funding plan approved in 2004. The following chart highlights the cost and schedule plan and performance.



How and why was IceCube identified and selected as a worthy large facilities construction project?

A series of reviews organized by NSF, DOE, and the National Academy Sciences concluded that the proposed IceCube detector would open a new window on the Universe by detecting very high energy neutrinos from objects across the Universe. The scientific and technical review committees found the science to be well motivated and exciting and the detection technique proven. Construction plans matured and eventually committees advised that the IceCube MREFC project was ready for construction.

The process of identifying IceCube as worthy and ready for construction included robust peer and management review organized by NSF and eventually an assessment by the National Academy. This six-year process started with the submission of a Letter of Intent in February 1998 and concluded with approval by the National Science Board in April 2004.

IceCube Scientific and Construction Readiness Review Timeline

Feb 1998	Letter of Intent submitted to the NSF by Professor Francis Halzen, University of Wisconsin-Madison
May 1999	Astroparticle Physics with High Energy Neutrinos – Open Meeting for the scientific community organized by Francis Halzen
Nov 1999	**IceCube Proposal submitted to the NSF** on behalf of the U.S. IceCube Collaboration; separate proposals submitted to the German (DESY and Ministry), Sweden, and Belgium (Flemish and Walloon) funding agencies
Early 2000	NSF Peer Review of the IceCube Proposal
Apr 2000	DOE-NSF Science Advisory Group for Experiments in Non-Accelerator Physics (SAGENAP) Review of the IceCube Proposal
June 2000	NSF Readiness Assessment by a External Panel
Oct 2000	National Science Board Approval to Submit IceCube in a Future Budget Request.
Fall 2001	Endorsement of IceCube by the High Energy Physics Advisory Panel's Subpanel on the Future of Particle Physics in the U.S
Oct 2001	NSF Readiness Review by an External Panel
Nov 2001	NSF Review by an External Panel of the IceCube Enhanced Hot Water Drill Final Design
Sept 2002	International Workshop on Neutrinos and Subterranean Science – Community Input
Sept 2002	NSF Review of IceCube Drilling Plans
Early 2003	National Academy Neutrino Facilities Assessment Committee Review: Neutrinos and Beyond: New Windows on Nature
Sept 2003	NSF External Panel Annual Review
Feb 2004	NSF Review by External Committee of the proposed IceCube MREFC Project Baseline
Apr 2004	**NSB Approval to Proceed with IceCube Construction**

A National Academy Sciences study reaffirmed the scientific merit of IceCube in 2003, noting that the capability of IceCube greatly exceeds that of previous detectors and those currently under construction, and thus its capacity for transformational discovery was very significant.

What were the strengths and weaknesses of the process?

The primary strengths of the approval process for IceCube were the quality of the external review; the close and effective coordination between NSF's Office of Polar Programs and the Division of Physics; strong institutional commitment and engagement by the University of Wisconsin–Madison; and the international scientific interest and support of the NSF approval process. It was extremely valuable to be able to defend scientific goals and project plans in front of the highest quality external committees. The breadth and depth of the experience of those assembled for these reviews resulted in better implementation plans and higher confidence that the IceCube MREFC Project would be successful. The shared commitment to achieving successful approval helped the partners to work constructively together during the approval process. NSF's Office of Polar Programs and the Division of Physics, working with the Large Facilities Office, interacted constructively with UW–Madison and the international partners.

The primary weaknesses of the IceCube MREFC Project approval process were the general environment of uncertainty, the potential for discontinuities in financial support, and the fact that both NSF and UW–Madison were still maturing in terms of their large project processes and general capabilities.

The most cost effective projects are those where there is an early commitment to move the project forward on a schedule that is only limited by the ability to make technical progress. An approval process that is stretched out or unclear in its outcome creates an environment of uncertainty that is extremely difficult to manage at the facility level where day-to-day activities include hiring, placing contracts, and paying bills. The most influential factor in the ability of a project to succeed is acquiring experienced and capable staff. Discontinuities in funding and uncertainty can make this challenging, if not impossible. UW–Madison became heavily vested in the success of IceCube and used local resources to bridge funding delays and gaps. This was manageable but not desirable.

NSF large facilities management continues to improve and the guidance and rules are stabilizing. Around 2000, when IceCube was getting started, the NSF large facility guidance was still evolving; e.g., when IceCube was approved it was not permissible to include Education & Outreach in an MREFC Project, now it is. As NSF builds a history of successful MREFC projects there is higher confidence in its management practices. The situation at UW–Madison was similar, and the support arrangements for IceCube evolved in the beginning from a project initially supported out of the Physics Department to an autonomous center within the Graduate School.

How is IceCube currently managed?

IceCube is managed through contracts and memoranda of understanding between the participating legal entities; partnerships between the stakeholders; and line management arrangements that ensures top-to-bottom accountability and open communication.

Management and Contractual Arrangements

NSF and the UW–Madison. The IceCube Construction Project and the Maintenance and Operations (M&O) Program of the IceCube Neutrino Observatory are managed under the terms of Cooperative Agreements between the NSF and UW–Madison. A Project Management Plan details the management arrangements for the Construction Project and an Operations Plan covers the M&O Program. UW–Madison executes subawards to U.S. universities and laboratories for both the Construction Project and Operations Program.

IceCube Collaboration. The group of scientists motivated by the IceCube scientific goals and their institutions form the IceCube Collaboration. The Collaboration Governance Document describes the organizational matters of the collaboration including the election procedure for the Spokesperson [icecube.wisc.edu/collaboration/governance.php]. As described in the Cooperative Agreements and in the Collaboration Governance Document, UW–Madison executes a Memorandum of Understanding (MOU) that defines the institutional responsibilities for all constituent institutions. The Construction Project MOUs defined each institution's construction "deliverables" and the Maintenance & Operations MOU addresses the responsibilities of each institution in support of successful operations.

Antarctic Support. The Office of Polar Programs (OPP) has lead responsibility for the IceCube program within NSF. OPP tasks their Antarctic support contractor, Raytheon Polar Services Company (RPSC), and the Air National Guard, to provide the logistics and field support required for IceCube construction and operations. During the construction phase UW–Madison defined the IceCube construction project support requirements and OPP provided IceCube MREFC funding to RPSC via their contracts. This three-party arrangement was initially challenging but worked well as the project matured.

International Oversight and Finance Group (IOFG). NSF and representatives of the foreign funding agencies typically meet on an annual basis to review IceCube progress. The foreign funding agencies made significant contributions to the construction project and operations program. The foreign collaborating institutions are accountable to their respective funding agencies to deliver on their construction project and operations support commitments. In addition to in-kind contributions of hardware and labor there is a cash contribution to a "common fund" to support the computing and software necessary for the large IceCube data volumes.

Management Partnerships

IceCube Collaboration and UW–Madison. IceCube management is based on effective partnerships between stakeholders that share ownership in the success of the entire IceCube program. There is close partnership between the IceCube Collaboration (over 250 scientists and professionals from 39 institutions and 11 countries) and UW–Madison, which serves as both a collaborating institution and as host institution for both the construction project and the operations program. The IceCube Collaboration worked on every aspect of the detector. A remarkable aspect of the construction phase was the wide distribution of the hardware development across the collaboration. Production and testing of digital optical modules was completed in Sweden, Germany, and the U.S. (UW–Madison).

NSF and UW–Madison. The partnership between NSF and UW–Madison provides the management accountability necessary to ensure that resources are used efficiently and that construction and operations goals are consistently achieved. NSF is the primary funding agency for IceCube having provided about 85% of the construction project funding and providing 63% of the annual M&O support. Over 80% of the NSF MREFC funding was allocated directly to, and managed by UW–Madison, with the remainder allocated to RPSC and the Air National Guard.

NSF/UW–Madison and Foreign Funding Agencies. The direct engagement of the NSF program managers and the UW–Madison IceCube leadership with the primary foreign funding agencies is a partnership demanded by the international nature of the support for the scientific collaboration. Representatives of the foreign funding agencies are invited to review project plans, participate in external reviews, evaluate reports, and provide general oversight to the IceCube program.

Key Management Arrangements

The key management arrangements used to manage IceCube include: 1) clear lines of accountability and authority from NSF to UW–Madison and to the IceCube construction project and operations program, 2) detailed scope, schedule, and budget definition, 3) explicit cost and schedule contingency derived from risk assessment, 4) regular reviews by external committees, 5) tracking and progress reporting against established milestones, budgets, and performance metrics, and 6) routine oversight by NSF, UW–Madison, and foreign funding agencies. It is important to emphasize the IceCube approach used for contingency management, external reviews, and project oversight.

Contingency Management. An essential tool of project management is to define an explicit contingency budget within the total project cost baseline that is derived from an assessment of risk. The IceCube MREFC project performance baseline was approved in April 2004 and included a 22% contingency budget. In order to create this contingency budget the project scope was reduced from 80 deep ice cables to 70. The built-in incentive for all parties was to control costs in order to restore the original project scope. The management flexibility enabled by the project contingency budget allowed significant efficiencies to be gained in the deep ice drilling and instrumentation production and testing program. Schedule performance made possible by contingency expenditures resulted in cost savings and full scope restoration to 80 cables plus an additional six cables made possible by additional foreign contributions.

External Reviews. Peer reviews organized by NSF were absolutely essential to IceCube success. These reviews were typically carried out on an annual basis beginning after the submission of the initial proposal and continuing throughout the duration of the MREFC Project. The review committee membership was tailored to the needs of the project and the committee recommendations and advice were always constructive and helpful. It is a great strength of the scientific community that its members embrace the opportunity to help each other through service work on these types of committees. The UW–Madison IceCube Project Office established a standing Project Advisory Panel, Science Advisory Committee, and Software & Computing Advisory Panel. These advisory bodies met annually and provided input directly to the project. The combination of the NSF organized reviews and the IceCube project advisory bodies ensured that critical issues were identified early and that project plans included input from experts.

Project Oversight. NSF provided effective oversight of IceCube. The NSF Program Manager during the approval and construction phase was a senior and experienced NSF program manager. There was a high level of engagement with UW–Madison and the IceCube Project

Office. IceCube, like all large complex projects, encountered significant challenges during each project phase and the NSF Program Manager coordinated input within NSF and provided clear guidance to the IceCube Project Director. The NSF Program Manager and the IceCube Project Director had an open approach to communicating project information while respecting their distinct roles. The UW–Madison IceCube Leadership Team, chaired by the UW–Madison Chancellor, met on a quarterly basis and provided consistent oversight of the IceCube MREFC Project. This maintained a high level of institutional commitment throughout the construction project and the transition into operations.

Construction and Transition to Operations Strategies

The main project strategy was to maximize the installation of instrumentation each South Pole summer by ensuring that installation was not limited by the availability of instrumentation. This placed a priority on the critical activity—safely drilling holes in the South Pole ice sheet. Major constraints included the limited construction season of three months during the Antarctic summer, limited transport flights for cargo and fuel, and available bed space at the McMurdo and South Pole stations for people. The U.S. Antarctic Program infrastructure, including the bases, supply chain, and experience, was critical to project success.

What are the roles and responsibilities of the facility staff and the roles and responsibilities of NSF in the management and oversight of IceCube?

As noted earlier in this testimony there was a close partnership between the NSF and UW–Madison. One of the main reasons that this partnership worked extremely well was the clear and common understanding of the distinct roles and responsibilities of the two parties and an environment of mutual respect and trust. Respect and trust developed during the startup phase of this relationship enabled effective management of critical challenges as the two parties worked efficiently together.

NSF Roles and Responsibilities

The NSF is responsible for seeing that the IceCube MREFC Project meets its baseline requirements of cost, schedule, scope, and technical performance. The NSF has a special role in IceCube because of its responsibilities in managing operation of the Amundsen-Scott South Pole Station. These responsibilities include: safety; physical qualification of project staff; environmental protection; transport of personnel, fuel and equipment; and the provision of housing, food service, support personnel, logistical support, IT support, and general infrastructure support.

Within the NSF the Office of Polar Programs (OPP) is the lead organizational unit responsible for the conduct of scientific, technical, cost, schedule and management reviews, general progress reviews, and agency guidance regarding the IceCube Project. OPP designates a Program Officer (PO) who provides continuous oversight and guidance through direct communication with the UW–Madison IceCube Project Director and site visits to UW and other project sites, including the South Pole Station. The IceCube Program Officer is the Project Director's point of contact at the NSF.

UW–Madison Roles and Responsibilities

The UW–Madison is the host institution for the IceCube Project Office and the home university of the Principal Investigator. The responsibilities of the host institution include:

- Providing internal oversight for the project.
- Appointing the Project Director (subject to concurrence by the NSF, and the IceCube Collaboration Board).
- Ensuring that the Project Office has adequate staff and support.
- Ensuring that an adequate management structure is established for managing the project and monitoring progress.
- Ensuring that accurate and timely reports are provided to the NSF, IOFG, and the IceCube Collaboration.
- Developing subawards with other U.S. collaborating institutions and providing appropriate funding.
- Establishing MOUs between the UW and non-U.S. collaborators defining the non-U.S. collaborators' deliverables.

IceCube Principal Investigator

The Principal Investigator is responsible to the Vice Chancellor for Research and the NSF for the overall scientific direction of the IceCube Project. The Principal Investigator is Co-Spokesperson for the IceCube Collaboration during the construction phase and an ex-officio member of the IceCube Collaboration Board. The Principal Investigator communicates to the Project Director the scientific goals established by the IceCube Collaboration and concurs on the project implementation plan established by the Project Director.

Project Director

The IceCube Project Director (PD) is appointed by the Vice Chancellor for Research, subject to concurrence by the IceCube Collaboration Board and the NSF. The UW holds the Project Director (PD) responsible for execution of the construction project. The PD serves as the primary point of contact for the IceCube Collaboration and the NSF on all construction matters. The PD establishes the detailed Project Execution Plan that supports the IceCube scientific goals as described in the IceCube Proposal and in the Cooperative Agreement. The PD executes and controls project activities to ensure that project objectives, including cost and schedule baselines are met. The PD also serves as Co-Principal Investigator on the Project, and advises the Principal Investigator and the Collaboration Spokesperson on all issues that affect the IceCube scientific goals.

Other responsibilities of the Project Director include:

- Development of project scope and integrated cost and schedule baseline plans that are consistent with funding plans.
- Approval of annual budgets and funding allocations for institutions receiving NSF funding and MOUs with non-U.S. collaborating institutions.

- Ensuring that adequate project management control and reporting systems are implemented.
- Establishment of the IceCube Change Control Board and approval of baseline changes at Change Control Level 1.
- Chairing monthly project status reviews involving the Level 2 managers and selected Project Office staff.

How do you work with NSF to ensure that the American taxpayer is getting a return on this investment?

The IceCube MREFC investment is carefully managed as addressed earlier in this testimony. Performance metrics were developed for the Operations Program that help to ensure that this continuing investment is also an efficient use of American taxpayer. Over 5,000 digital optical modules (DOMs) instrument one billion tons of ice (cubic kilometer) a mile and a half below the South Pole surface.

Early operational results with the IceCube instrumentation are good:

- A total of 98.5% of the 5,484 DOMs installed and frozen into the deep ice at the South Pole are currently taking data and reliability analysis indicates that 98.0% of these DOMs will still be taking data in ten years.
- Detector uptime is approximately 99.0%.
- Every hour the IceCube Neutrino Observatory detects over 10 million downward-going cosmic particles and about 5 upward-going neutrinos.

The international IceCube Collaboration carries out the scientific program and shares responsibility for the M&O program including service work by research groups to manage the large data volumes and direct financial support. The details of these contributions are managed and tracked at a very detailed level.

IceCube M&O Support for Fiscal Year 2011 ($'000)

Total Required M&O Support	NSF M&O Core Support	U.S. Base Grant Support	U.S. Institutional Support	Non-U.S. Support
15,888	6,900	1,512	1,628	5,847
100%	43%	10%	10%	37%
100%	**U.S. = 63%**			**Non-U.S. = 37%**

The return on the IceCube investment is primarily measured by the quality of the scientific output. This is measured by the scientific publications [icecube.wisc.edu/pubs] and regular peer review of IceCube research proposals routinely submitted by Principal Investigators from the collaborating institutions. IceCube is unique in its discovery potential given the large instrumented detector volume in the Southern Hemisphere. The merit of the investment in IceCube is broadly acknowledged and there are plans to construct a detector of similar scale (KM3NET) in the Mediterranean Sea. This is largely a European initiative and would result in a Northern Hemisphere neutrino observatory that is complementary to IceCube.

How was the entire life cycle of the project, including management and operations after construction, taken into account in the management and oversight of IceCube?

The biggest challenges with MREFC projects are often the transition phases: 1) R&D, project definition and planning, and the transition into a construction start, 2) ramp up into full construction, 3) efficient ramp down of the construction effort, and 4) the transition into operations. MREFC funding does not cover R&D, operations, or research and therefore these transitions and the full program of support require multiple proposals and an integrated funding plan by the NSF. These transition phases were also difficult for IceCube but managed successfully by the collaborating parties. Discontinuities in funding and support can be detrimental as the facility managers strive to maintain a team of talented and motivated people, which is essential to the program's success. The NSF MREFC program has matured over the last decade and there is now substantial institutional experience that benefits the current generation of MREFC projects.

IceCube R&D and Construction Start
NSF and other parties supported AMANDA, essentially a prototype of the IceCube detector. AMANDA operated prior to and then concurrently with the initial IceCube construction and provided valuable experience regarding relevant hardware, software, and data management and helped to develop the scientific, engineering, and institutional experience within the IceCube Collaboration needed to propose IceCube. The IceCube proposal was based on the success of AMANDA, although the scale-up to IceCube was significant.

Transition to Operations
The initial IceCube proposal and the reviews that followed provided opportunities to present and critique the life cycle requirements of the facility. For example, the IceCube proposal submitted in 1999 included an estimate of the annual operating requirements; the project baseline reviews in 2004 assessed the plan for transitioning into operations; the NSF and foreign funding agencies began meeting to discuss operations plans in 2005; and, initial operations funding was provided in 2007.

Research
The development of the IceCube scientific goals and exploitation of the scientific potential of the facility requires continuing support to the collaborating groups. Collaborating university groups in the U.S submit proposals to the NSF on a three-year cycle and these proposals undergo peer review. This foundation of research support enables the return on the MREFC investment.

What have been the biggest challenges you have faced with the project thus far and how were they rectified?

The biggest challenges encountered include the scale-up from AMANDA to IceCube; establishing management capability and support arrangements at UW–Madison; ensuring the safety of the deep ice drilling operation; and, the limited NSF experience in the stewardship of large facilities during the late 1990's. A major challenge was a potential hold on IceCube when a policy of no new construction starts was imposed following a change in administration. This uncertainty was resolved once it was clarified that the National Science Board had already approved IceCube for inclusion in future NSF budget requests, thus building on the ongoing success of the AMANDA project.

The success of the AMANDA detector was essential but still not sufficient to move forward with IceCube. The scientific collaboration needed to grow in depth and capability. Deep ice drilling and instrumentation fabrication needed to transform from R&D scale into large-scale production. A substantial engineering effort was made to design detector systems for high reliability since the sensors, once frozen in the ice, are not physically accessible and cannot be repaired. The design was also optimized for ease of maintenance and operation. For example automatic calibration systems were a design goal to limit ongoing operations efforts at the South Pole. The time between the IceCube proposal submission and the start of construction in 2004 allowed the transformation and the scale-up that was needed.

Establishing an effective Project Office at UW–Madison required the active engagement of the university leadership. The business, administrative, and human resource systems that are effective for typical university business are not well suited for a schedule driven large project like IceCube. UW–Madison moved to establish IceCube as a center within the Graduate School with direct control over support personnel and resources. Experienced managers and engineers were hired from outside the university and the dialogue between the project personnel and the university leadership was focused on what was needed to succeed and the actions to be taken for that success.

The IceCube production drilling operation required the drill to operate 24 hours a day for 7 or more continuous days. This required three shifts that needed to operate in a seamless manner with each new shift picking up where the last shift left off. In the first year of IceCube deep ice drilling there was a serious accident requiring immediate medical evacuation from the South Pole and recovery in New Zealand. This accident provided a serious wake up call to all the parties and many improvements in training, staffing, and equipment were implemented before the second drilling season. Examples of improvements include retention of experienced drillers and additional shifts. An additional 85 holes were drilled over the next five years without another serious injury and with an exemplary safety record.

The stewardship of a large facility requires engagement, problem solving, and support over decades. The needs of a large facility are quite different than those of a research grant. Facility stewardship requires an active role by the funding agency that goes beyond the mantra of "NSF responds to proposals" and is more of a joint ownership and partnership. The MREFC program has matured significantly over the last decade since IceCube was originally proposed. There is excellent sharing of experience, lessons-learned, and ingredients to success. A brief distillation of these points is provided below.

Lessons Learned from the IceCube MREFC Project Experience

Set realistic goals for the MREFC Project baseline

- Scope reduced to 70 cables (86 final total)
- Operations ramp up when detector ready to start science program

NSF support and oversight

- NSF collaborated with UW–Madison to best support the project
    - Dedicated and experienced IceCube Project Officer
    - Annual peer reviews of project performance and recommendation tracking
- MREFC Project funding secure and predictable
- Start-up, operations, and research funding requires advance planning

UW–Madison commitment and support

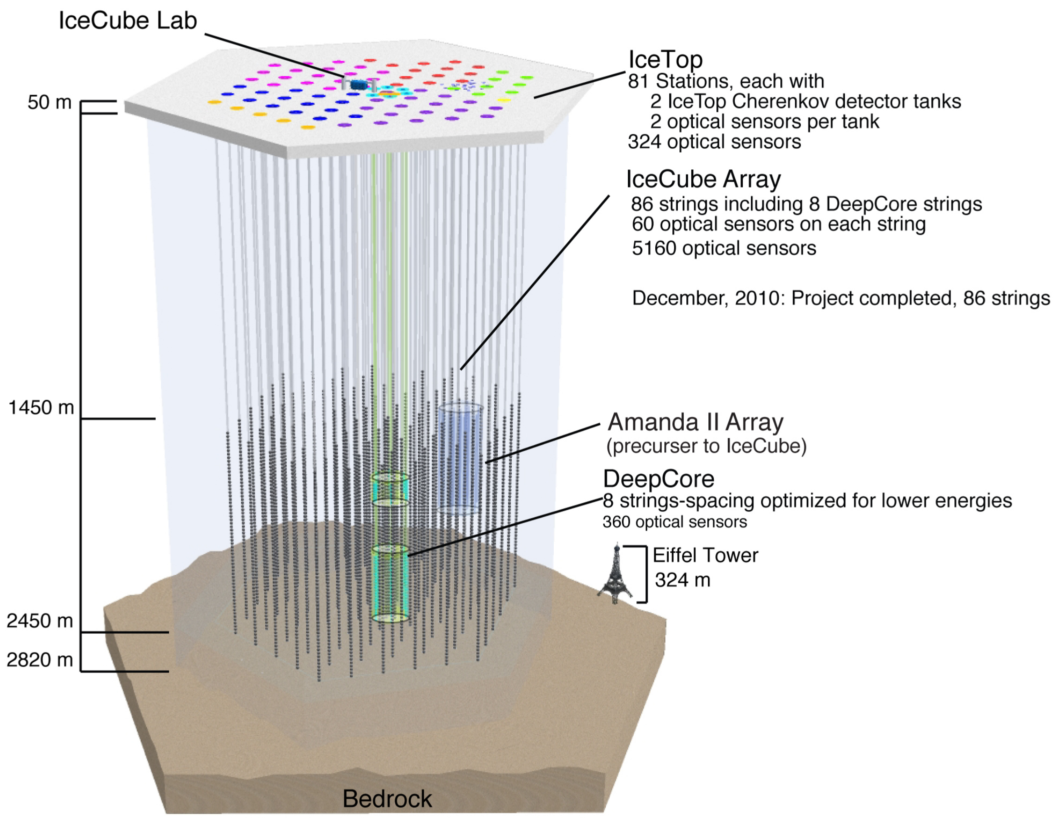
- University leadership involvement critical at key junctures
- Recruiting experienced personnel essential to project success
- Establishing expert advisory committees to inform project plans

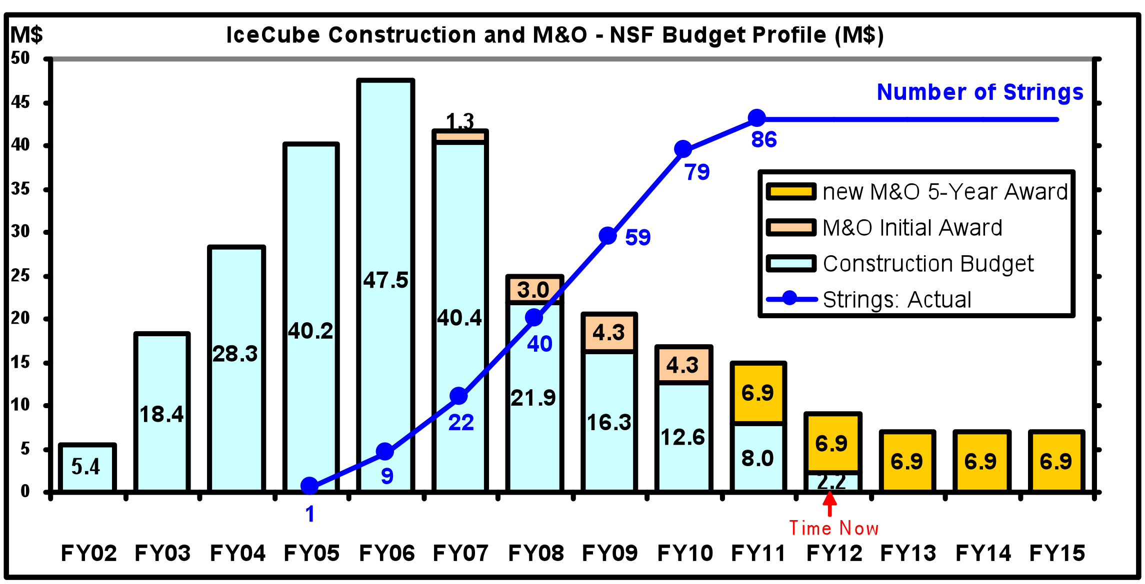
Project management

- Create partnerships—share information, integrate efforts, and jointly share successes and failures
- Integrate the physics and engineering efforts; creating a single line of accountability promotes teaming and shared ownership of results
- Recruit production expertise—achieves higher quality and lower production costs
- Openly communicate issues and ensure transparency—shifts approach from ignore and hope to open responsibility and action (no surprises)
- Invest in safety—goal is shared responsibility and excellence
- Automate project tracking tools—reduces the time and effort from performance measurement to corrective responses
- Overarching goal is to eliminate uncertainty and risk—resolution is better than perfection
- Facility management of the contingency budget with full transparency on decisions

Ingredients to IceCube and MREFC Program Success

- Funding agency (NSF and European Partners) commitment with clear roles
- Strong facility/host role (UW–Madison) as an equal partner with NSF
- Project organization populated with high quality people - recruit experience
- Project & Collaboration leaders
    - Made timely decisions
    - Served as an umbrella for the distributed team so they could do their jobs
    - Managed expectations and communicated plans and results
- Understood the project including characteristics that were common to other large projects and those that were unique, e.g., Antarctic support and environment
- Established realistic project goals, developing a track record of success
- Maintained credibility with stakeholders
- Sought collective ownership of problems and solutions


IceCube Lab
IceTop
81 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
324 optical sensors
IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors
December, 2010: Project completed, 86 strings
50 m
1450 m
2450 m
2820 m
Amanda II Array
(precurser to IceCube)
DeepCore
8 strings-spacing optimized for lower energies
360 optical sensors
Eiffel Tower
324 m
Bedrock


IceCube Construction and M&O - NSF Budget Profile (M$)
M$
Number of Strings
new M&O 5-Year Award
M&O Initial Award
Construction Budget
Strings: Actual
FY02 FY03 FY04 FY05 FY06 FY07 FY08 FY09 FY10 FY11 FY12 FY13 FY14 FY15
5.4
18.4
28.3
40.2
47.5
40.4
1.3
21.9
3.0
16.3
4.3
12.6
4.3
8.0
6.9
2.2
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6.9
1
9
22
40
59
79
86
Time Now