

## **IceCube Neutrino Observatory**

**Project Description:** IceCube will be the world's first high-energy neutrino observatory and will be located deep within the icecap under the South Pole Station in Antarctica. It represents a new window on the universe, providing unique data on the engines that power active galactic nuclei, the origin of high energy cosmic rays, the nature of gamma ray bursters, the activities surrounding supermassive black holes, and other violent and energetic astrophysical processes. IceCube construction is being carried out by the IceCube Consortium, led by the University of Wisconsin (UW). Approximately one cubic kilometer of ice is being instrumented with photomultiplier (PM) tubes to detect neutrino-induced, charged reaction products produced when a high energy neutrino interacts in the ice within or near the cubic kilometer fiducial volume. An array of Digital Optical Modules (DOMs), each containing a PM and associated electronics, will be distributed uniformly from 1.5 km to 2.5 km beneath the surface of the South Pole ice cap, a depth where the ice is highly transparent and bubble-free. When completed, IceCube will record the energy and arrival direction of high-energy neutrinos ranging in energy from 100 GeV ( $10^{11}$  electron Volts [eV]) to 10 PeV ( $10^{16}$  eV). The principal tasks in the IceCube project are: production of the needed DOMs and associated electronics and cables; production of an enhanced hot water drill and a DOM deployment system capable of drilling holes for and deploying DOM strings in the ice at the Pole; installation of a surface array of air shower detectors to both calibrate and eliminate background events from the IceCube DOM array; construction of a data acquisition and analysis system; and associated personnel and logistics support.



Pictured in the UW-Madison Physical Sciences Laboratory before being vacuum-sealed, each IceCube DOM is very much like a small computer. A total of 4,200 DOMs, designed to sample high-energy neutrino particles from deep space, are being deployed in 70 deep holes in the Antarctic ice.

**Principal Scientific Goals:** IceCube will be the world's first observatory capable of studying the universe with high-energy neutrinos. Measurement of the number, direction, timing, and energy spectrum of such neutrinos will provide unique new insights regarding the dynamics of active galactic nuclei, the acceleration mechanisms and locations of the sources of high energy cosmic rays, the properties and dynamics of gamma ray bursters, and the types of processes that take place near the event horizon of supermassive black holes at the centers of galaxies. Many of these phenomena take place at cosmological distances in regions shielded by matter and shrouded by radiation. Since neutrinos carry no charge and interact very weakly with matter, easily passing through the entire earth, they are unique messenger particles for understanding the astrophysics of such extreme phenomena and are capable of bringing us information about previously undiscovered cosmic objects, ones that are invisible to existing observatories that record electromagnetic signals or charged particles. IceCube data on sources will also complement data from existing astrophysical observatories in the optical, x-ray, and gamma ray regions of the electromagnetic spectrum, providing new tests of theories of the underlying dynamics of these objects.

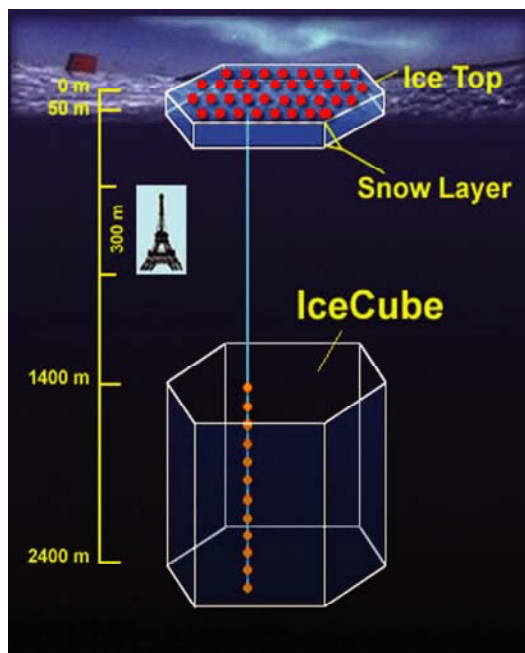
**Principal Education Goals:** IceCube provides a vehicle for helping to achieve national and NSF education and outreach goals based on the conduct of visionary science in the exciting South Pole environment. These goals include broadening the scientific workforce base in the U.S. and creating a technologically facile workforce with strong ties to fundamental research that is the core of a strong economy. Specific outcomes will include: the education and training of next generation leaders in astrophysics, including undergraduate students, graduate students, and postdoctoral research associates; K-12 teacher

scientific/professional development, including development of new inquiry-based learning materials; increased diversity in science through partnerships with minority institutions; and enhanced public understanding of science through broadcast media and museum exhibits (one is currently under construction). Some of these outcomes will result from separate R&RA grants to universities and other organizations for work associated with IceCube, selected following the standard NSF merit review process.

**Partnerships and Connections to Industry:** The IceCube Collaboration consists of 12 U.S. institutions and institutions in three other countries: Belgium, Germany, and Sweden. The Department of Energy, through its Lawrence Berkeley National Laboratory, is also participating.

**Management and Oversight:** The strong project management structure at UW, which includes international participation, provided the framework for the Start-up Project funded in FY 2002 and FY 2003, and the initiation of full construction with FY 2004 funding. UW has in place an external Scientific Advisory Committee, an external Project Advisory Panel, and a high-level Board of Directors (including the Chancellor) providing oversight of the project. IceCube is externally managed by a Project Director and a Project Manager. Internally, NSF has appointed a Project Coordinator to manage and oversee the NSF award. A comprehensive external baseline review of the entire project (including cost, schedule, technical, and management) was carried out in February 2004. There was a follow-up external cost review in Fall 2004, and comprehensive annual external reviews are planned for each subsequent spring following the annual deployment season. The first such annual review was held in May 2005. Besides annual progress reviews and other specialized reviews, the project provides written monthly progress reports and quarterly reports. NSF conducts site visits, weekly teleconferences with the project managers, and weekly internal NSF project oversight and management meetings. Oversight responsibility for IceCube construction is the responsibility of OPP; support for operations, research, education, and outreach will be shared by OPP and MPS as well as other organizations and international partners.

**Current Project Status:** The primary IceCube project tasks carried out to date are: (1) completion, testing, and shipment to the South Pole of the Enhanced Hot Water Drill (EHWD) system for drilling the required deep-ice holes into which the strings of DOMs will be placed; (2) completion and commissioning of the three planned DOM production and low temperature ( $-80^{\circ}\text{C}$ ) testing facilities in the U.S., Germany, and Sweden; (3) production, testing, shipment to the Pole, and subsequent re-testing of the DOMs and cables needed for deployment of DOM strings in the 2004/2005 and 2005/2006 austral summer seasons (November to mid-February); (4) design, construction, and installation of the initial data acquisition system at the Pole; (5) completion of plans for commissioning and verification of the initial DOM strings; (6) placement at the Pole of the building that will serve as the IceCube



IceCube will occupy a volume of one cubic kilometer. Here we depict one of the strings of optical modules (number and size not to scale). IceTop, located at the surface, comprises an array of sensors to detect air showers. It will be used to calibrate IceCube and to conduct research on high-energy cosmic rays. Credit: NSF/University of Wisconsin and Darwin Rianto, University of Wisconsin.

permanent counting house in the 2005/2006 season; (7) during the 2004/2005 season, successful drilling of the first deep hole at the Pole and the deployment of the first IceCube string (60 DOMs), which is now connected to the data acquisition system, fully operational, and functioning well, as well as successful deployment and operation at the Pole of eight surface cosmic ray air shower detector modules (2 DOMs/module); and (8) during the 2005/2006 season, the first test of the production capability of the EHWD and DOM deployment systems, with plans for deployment of up to ten additional strings (as of this writing (January 15, 2006) four additional detector strings have been installed).

Major milestones for IceCube are below:

**FY 2004 and FY 2005 Milestones:**

- Completed production of digital optical modules and data acquisition and handling system (DAQ)
- Delivered EHWD system and DOM deployment system to the South Pole
- Delivered initial DOM strings, IceTop modules, and initial elements of the DAQ to South Pole
- Assembled the EHWD and DOM deployment systems
- Established drill camp and move new counting house building into place
- Drilled, deployed, and tested initial DOM strings and corresponding IceTop modules

**FY 2006 Milestones:**

- Ramp up to near-full DOM production at all facilities and IceTop module production
- Drill, deploy and test up to 10 additional DOM strings and corresponding IceTop modules, including installing and testing the associated DAQ elements

Projected outyear milestones (FY 2007-2010) are based on current project planning and represent a general outline of anticipated activities. These activities are also dependent on weather conditions and the Antarctic logistics schedule.

**FY 2007-10 Milestones:**

- Complete and commission new counting house at the Pole
- Continue DOM and IceTop module production
- Continue to drill, deploy, test, and commission DOM strings (up to 18 strings per season) and the corresponding IceTop modules (two for each DOM string), including installing and testing of the associated DAQ elements
- Begin initial operations of IceCube with strings available in FY 2007
- Complete installation and commissioning

**FY 2011 Milestones:**

- Commence full operations of IceCube for science

**Funding Profile:** Startup activities were funded with FY 2002-03 appropriations. Construction was initiated with FY 2004 appropriations. The total project cost for IceCube is \$271.77 million. Of this amount, \$242.07 million will be from the U.S. and \$29.70 million will come from foreign contributions.

**Appropriated and Requested MREFC Funds for IceCube**  
(Dollars in Millions)

	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007 Request	FY 2008	FY 2009	FY 2010	Total
IceCube	\$15.00	\$24.54	\$41.75	\$47.62	\$46.25	\$28.65	\$22.38	\$11.33	\$0.95	\$238.47
Unobligated Balance from FY 2005					\$3.60					\$3.60
<b>Total</b>	<b>\$15.00</b>	<b>\$24.54</b>	<b>\$41.75</b>	<b>\$47.62</b>	<b>\$49.85</b>	<b>\$28.65</b>	<b>\$22.38</b>	<b>\$11.33</b>	<b>\$0.95</b>	<b>\$242.07</b>

The funding profile table below reflects actual obligations for past years and anticipated obligations for future years. The differences between these two tables are due to funds appropriated in FY 2002 and FY 2003 but not spent until later years. In addition to the \$3.60 million shown in the table above, \$6.59 million has been carried over from prior year appropriations into FY 2006 and will be obligated in FY 2006 and later years.

**IceCube Funding Profile**  
(Obligated Dollars and Estimates in Millions)

	Concept/ Development		Implementation		Operations & Maintenance		Totals		Grand Total
	R&RA	MREFC	R&RA	MREFC	R&RA	MREFC	R&RA	MREFC	
FY 2001	0.50						\$0.50	-	<b>\$0.50</b>
FY 2002				10.12			-	\$10.12	<b>\$10.12</b>
FY 2003				25.75			-	\$25.75	<b>\$25.75</b>
FY 2004				38.36			-	\$38.36	<b>\$38.36</b>
FY 2005				48.10			-	\$48.10	<b>\$48.10</b>
FY 2006 Current Plan				49.85			-	\$49.85	<b>\$49.85</b>
FY 2007 Request				35.71	0.50		\$0.50	\$35.71	<b>\$36.21</b>
FY 2008 Estimate				22.38	1.75		\$1.75	\$22.38	<b>\$24.13</b>
FY 2009 Estimate				11.33	2.25		\$2.25	\$11.33	<b>\$13.58</b>
FY 2010 Estimate				0.47	3.75		\$3.75	\$0.47	<b>\$4.22</b>
FY 2011 Estimate					4.00		\$4.00	-	<b>\$4.00</b>
FY 2012 Estimate					4.00		\$4.00	-	<b>\$4.00</b>
Subtotal, R&RA	\$0.50		-		\$16.25		\$16.75		
Subtotal, MREFC		-		\$242.07		-		\$242.07	
<b>Total, Each Stage</b>		<b>\$0.50</b>		<b>\$242.07</b>		<b>\$16.25</b>			<b>\$258.82</b>

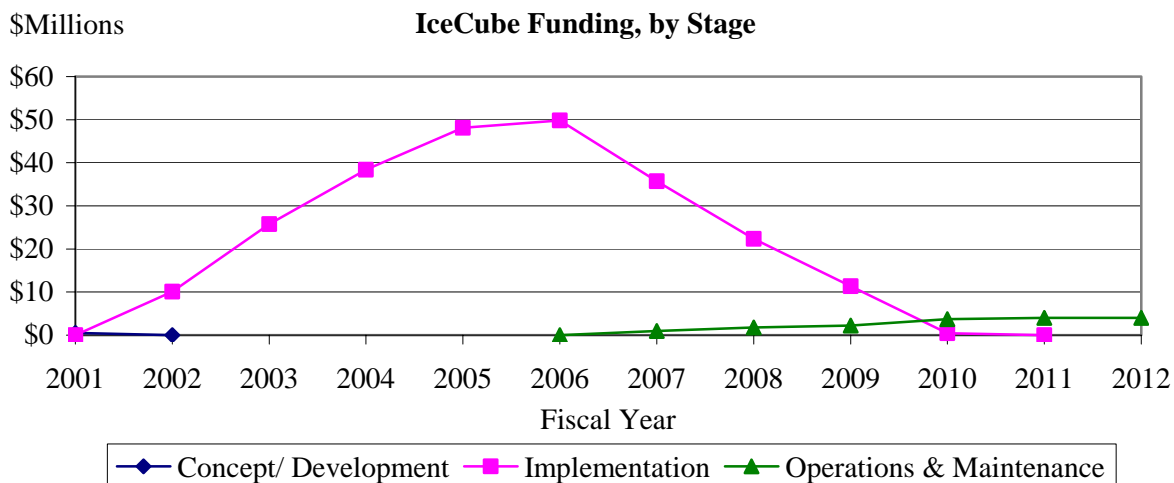
NOTE: The expected operational lifespan of this project is 25 years after construction is complete in FY 2010. Operations support is planned to begin in FY 2007. Corresponding support for conduct of research also must be provided. Current planning calls for international partners to provide a share of the costs. The estimates shown above are for operations and maintenance and have been developed for planning purposes. Efforts are underway to further develop these cost estimates; they will be updated as new information becomes available.

Information pertaining to the data in the table is provided below.

- Concept/Development: \$500,000 was provided in FY 2001 through the R&RA account to support drill conceptual development and design, R&D on advanced data acquisition and analysis techniques,

and development of interface electronics and associated software for digital detector electronics readout. IceCube builds on the work of the Antarctic Muon and Neutrino Detector (AMANDA), which demonstrated proof-of-principle. Those investments focused on state-of-the art drill and electronics development and acquisition.

- **Implementation:** The total project cost of the IceCube construction project is currently estimated at \$271.77 million. Of this amount \$242.07 million will be from NSF, and \$29.70 million from foreign partners. Construction is planned to extend through FY 2010. A comprehensive baseline review of the IceCube project was conducted in February 2004 to provide a solid project baseline scope, cost, and schedule. The plan is to drill holes and deploy strings of DOMs in each austral summer season (November through mid-February). This began with the successful deployment of the first IceCube string in the FY 2005 austral summer season (2004/2005) and, in FY 2006, the first test of the production capability of the drilling and deployment system. With good EHWD drill performance, and barring weather-induced complications of logistics support, the full complement of DOMs should be in place by about the end of FY 2010.
- **Operations and Maintenance:** Full operation of the IceCube Neutrino Observatory is planned to commence in FY 2011 following completion of drilling and DOM deployment and full detector commissioning planned for FY 2010. Initial operations will begin in FY 2007, ramping up in subsequent years to full science operations in FY 2011. These costs will be shared by the collaborating institutions, domestic and foreign. Of the amounts shown in the table for operations, approximately half are for data analysis that will be carried out by the collaborating U.S. and foreign IceCube institutions, the other half are for direct operations and maintenance support (IceCube-specific logistics, system engineering, operation and maintenance of the data acquisition and data handling systems, data quality monitoring, IT upgrades, and calibrations). The general operations of South Pole Station, reported in a separate section, also contribute to supporting IceCube. Costs included for IceCube here include only those that are project-specific and incremental to general operations. The expected operational lifespan of this project is 25 years beginning in FY 2011.



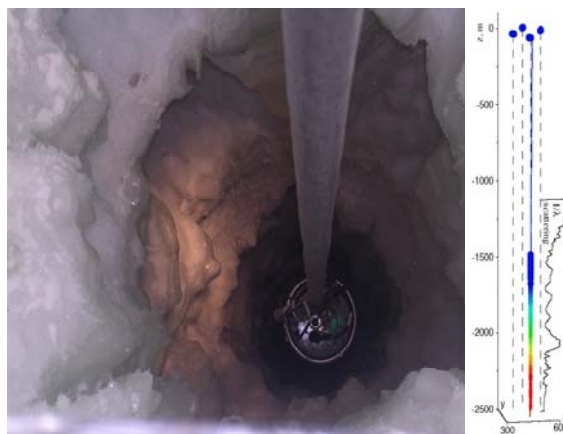
**Future Science Support:** NSF will support activities at U.S. institutions working on more refined and specific data analyses, data interpretation (theory support), and instrumentation upgrades, through ongoing research and education programs. The annual support for such activities is estimated at \$3.0 million once the facility reaches full operations.

Associated Research and Education Activities: Besides the training of next-generation astrophysicists, IceCube will encourage the creation of new links to K-12 teachers for the purpose of scientific/professional development of secondary school teachers, reaching into the classroom with new inquiry-based IceCube learning materials, as well as using the unique South Pole environment to convey the excitement of astrophysics, and science generally, to K-12 students. Extra measures will be undertaken to interest underrepresented groups in science. The plan includes partnership with two largely minority institutions (Clark-Atlanta University, Atlanta, GA, and Southern University, Baton Rouge, LA). Public outreach will be carried out through broadcast media and museum exhibits based on the IceCube science and the South Pole environment. Funding for Education and Outreach (E&O) activities will come from the R&RA account. Annual E&O budgets are estimated at \$400,000.

### Recent Research Highlight

► **IceCube, a New Kind of ‘Telescope’ at the South Pole:** A sub-surface observatory that tracks elusive cosmic messengers called neutrinos is now under construction beneath the South Pole. When completed, the IceCube detector array will comprise as many as 80 separate “strings,” each containing 60 sensors, that descend vertically more than a mile deep into ancient ice that has been compressed so hard that it is clear as glass. In January 2005, the first string was lowered into a narrow shaft produced by a novel hot-water “drill.” When tested, the string met or exceeded its design requirements, and began taking data.

IceCube, so called because it will eventually extend to a square kilometer of sensors buried between 1,450 and 2,450m below the surface, will observe the arrival of high-energy neutrinos (subatomic particles generated in violent astronomical events in our galaxy or others, such as stellar explosions), record their characteristics, and determine their point of origin in space within 1/2 of a degree.



Strings of instruments such as this one will detect the arrival and trajectory of neutrinos, producing data of the sort seen in the diagram on the right. The size of the circle is proportional to the strength of the signal, and the color (from blue to red) indicates relative times of the “hits” recorded by the string’s sensors. *Credit: University of Wisconsin*