How Decision Making Enables the Essential Connection Between Potential and Product

INCOSE Healthcare Working Group Webinar February 23, 2018

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Randall C. Iliff randall@eintllc.com



Eclectic Intellect, LLC

Today's Thought Menu

- Decisions in Development
- Real-World Decisions on IceCube
- Summary of Universal Insight

Development Decisions

- Who are the stakeholders?
- What do they actually need?
- How do those needs interact?
- How should the effort be structured?
- Where should attention be focused?
- Which decision methods should you use?

Please Note

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

So, What's an IceCube?

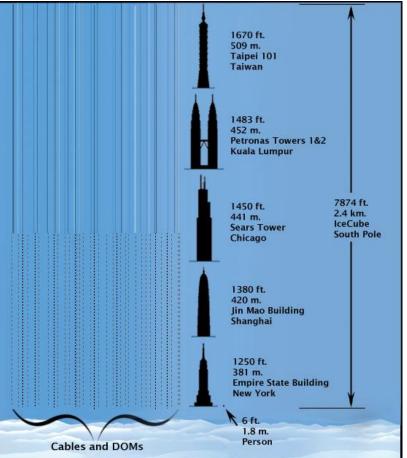
"IceCube" is a cubic kilometer scale "Discovery Class" research instrument now operating at the South Pole.

Funded by the National Science Foundation and collaboration partners in Germany and Sweden, the project is managed by the University of Wisconsin in Madison.

>5,000 Sensors, 1 kM³ Volume of Ice



DOMs are less accessible than spacecraft once they are deployed in deep ice...



IceCube

To Physicists:

- World's most powerful neutrino telescope
- Nearly unlimited potential for discovery
- A possible Nobel Prize

To Engineers:

- A massively complex effort
 - Little or no prior art
 - Anonymity if it works
 - Blame if it doesn't

Stakeholders

Constraint AUSTRALIA

BELGIUM

Université libre de Bruxelles Universiteit Gent Vrije Universiteit Brussel

SNOLAB

University of Alberta–Edmonton

DENMARK University of Copenhagen

GERMANY

FUNDING AGENCIES

(FWO-Vlaanderen

Deutsches Elektronen-Synchrotron ECAP, Universität Erlangen-Nürnberg Humboldt–Universität zu Berlin Ruhr-Universität Bochum RWTH Aachen University Technische Universität Dortmund Technische Universität München Universität Mainz Universität Wuppertal Westfälische Wilhelms-Universität Münster

Fonds de la Recherche Scientifique (FRS-FNRS)

Fonds Wetenschappelijk Onderzoek-Vlaanderen

THE ICECUBE COLLABORATION

• JAPAN Chiba University

NEW ZEALAND University of Canterbury

REPUBLIC OF KOREA Sungkyunkwan University

Stockholms Universitet Uppsala Universitet

SWITZERLAND Université de Genève

German Research Foundation (DFG)

Deutsches Elektronen-Synchrotron (DESY)

University of Oxford

UNITED STATES

Federal Ministry of Education and Research (BMBF) Japan Society for the Promotion of Science (JSPS) The Swedish Research Council (VR)

Knut and Alice Wallenberg Foundation

Swedish Polar Research Secretariat

Clark Atlanta University Drexel University Georgia Institute of Technology Lawrence Berkeley National Lab Marquette University Massachusetts Institute of Technology Michigan State University Ohio State University Pennsylvania State University South Dakota School of Mines and Technology Southern University and A&M College Stony Brook University University of Alabama University of Alabaka Anchorage University of California, Berkeley University of California, Irvine University of California, Los Angeles University of Delaware University of Delaware University of Mansas University of Mansas

University of Wisconsin Alumni Research Foundation (WARF)

US National Science Foundation (NSE)

University of Texas at Arlington University of Wisconsin–Madison University of Wisconsin–River Falls Yale University



What Did They Want?

- 300 Physicists agree on virtually nothing
- All had different research goals in mind
- We "binned" these into 8 primary groups

					SCIENCE OBJECTIVES -	THE ICECUBE "MISSION"					
		Search for sources of cosmic rays that generate neutrinos	Search for steady and variable sources of high energy neutrinos, e.g. Active Galactic Nuclei or Supernova Remnants	Search for high energy neutrinos from transient sources such as Gamma Ray Burst and Supernova bursts	Search for neutrinos from the decay of superheavy particles related to topological defects	Search for WIMPs which may constitute dark matter.	Search for magnetic monopoles and other exotic particles like strange quark matter	Monitor our Galaxy for MeV neutrinos from Supernova explosions and operation within SNEWS	Search for unexpected phenomena		
	ATTRIBUTE										
INTS	Event Energy Range	TeV to PeV	TeV	to 100 TeV	PeV to EeV	10 GeV to PeV	TBD eV	Me∨	TBD eV		
REQUIREMENTS	Expected Detectable Event Rate	TBD events/yr	TBD events/yr	"few" to 100 events/km2-yr	1 to 100 events/km ² -yr	TBD events/yr	TBD events/yr	TBD events/yr	TBD events/yr		
	Desired Angular Resolution	< 1 degree at TBD eV (D	riven by desire to resolve the spec	ific cosmological source.]	TBD Degrees [Do we care, o	other than just being able to have s reconstruction?	ufficient data for overall event	N/A	TBD degrees		
SCIENCE	Waveform		sufficient duration / resolution	1 to 3 ms?	TBD s						
PRIMARY S	Time Resolution	5 - 10 ns with initial degradation experienced at lower event energies 1 to 3 ms?									
PRIN	Operating Life			Fifteen year instrument	design life allows for 10 year fully	configured operational period plu:	s multi-year deployment.				

How do the Needs Interact?

- Some planning already had been done
- Science requirements for the instrument

Instrumented lce Volume 1 cubic kilometer (nominal) Array Shape CODE Effective Volume CODE Instrumented lce Volume CODE Instrumented lce Volume CODE Instrumented lce Volume CODE Effective Volume CODE Instrumented lce Volume CODE <th></th>	
Effective Volume TBD cubic kilometer at TBD eV and TBD arrival angle (varies with energy level and event orientation) Number of Strings 60 Digital Optical Modules (DOM) per String 60 Total Number of DOM 4800	
Number of Strings B0 Digital Optical Modules (DOM) per String 60 Total Number of DOM 4800	
Digital Optical Modules (DOM) per String 60 Total Number of DOM 4800	
Total Number of DOM 4800	
DOM Spacing - Horizontal 125 meters (efficient means to instrument the required volume of ice, provides good resolution for higher energy levels)	
DOM Specing - Vertical DOM Specing - Vertical 16.7 meters (provides highest resolution for vertical traveling particles)	
2 Detector Depth 1450 - 2450 meters (optical properties of ice improve with depth, limiting factor is boundary to surface shear effects)	
Total Station Count 1 LeeTop station at each hole location, nominally 80 station sets.	
Tanks per Station 2 tanks at each station provide operational redundancy, local veto capability.	
Tanks per Station 2 tanks at each station provide operational redundancy, local veto capability. Effective Tank Volume (TBD- simple look up and load entry) Digital Optical Modules (DOM) per Station / Tank Two DOM in each tank are used to provide greater dynamic range, resulting in a total of four DOM per LeoTop Station set.	
Digital Optical Modules (DOM) per Station / Tank Two DOM in each tank are used to provide greater dynamic range, resulting in a total of four DOM per IceTop Station set.	
Total Number of DOM 320 DOM Specing - Morizontal Within the tanker specing is 1 meter	
DOM Specing - Horizontal Within the tanks, spacing is 1 meter.	
DOM Spacing - Vertical IceTop array is positioned roughly 1,450 meters above the topmost In-Ice DOM.	
Detector Depth Tanks are installed to be flush with grade when covered, additional snow accumulation at roughly 1 foot per year thereafter.	
Sensitivity of DOM Single Photo Event (SPE)	
DOM Photon Event Dynamic Range SPE -> 200 PE / 15 ns (Note- two DOM are used in a high / low gain mode to support the iceTop Dynamic Range Requirement.)	
DOM Field of View Hemispherical with [TBD] four at [TBD] fail off	
Diplization Rate 300 mgasamples / second	
Digitization Rate 40 megasamples / second	
Absolue Amplitude Calibration Accuracy < 5 %	
Timing Accuracy < 5 ns	

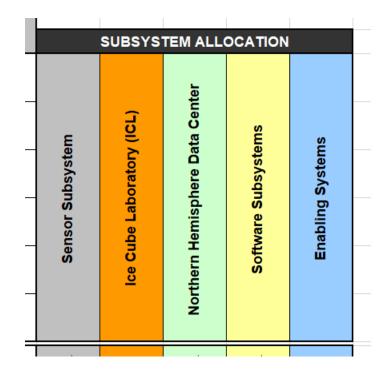
How do the Needs Interact?

- Some derived requirements were obvious
- Most required complex decisions and trades

s B	Establish DOM Physical Location	Determine x, y, z coordinates to within .5 Meter (TBR)
ation	Establish optical characteristics of Ice along all inter-DOM paths	Primarily path loss, although scattering and other effects may also be noted.
alibri	Establish operating characteristics of each DOM	Gain, noise rate, FOV, pedestal characteristics, others.
ပဒိ	String Commissioning	Determine that newly deployed string is acceptable to add to the body of operational instrument.
P 7	DOM Noise Rate	< 850 hits / second
groui ation	DOM Data Processing	Initial waveform capture and digitization in DOM, context sensitive compression of data prior to transfer
back Timin Radi	Local Coincidence Function	User selectable, three modes: Off, Soft - Reduced data set for marginal probability events; Hard - Discriminator function requiring "m of n" confirmation from vertically adjacent DOM.
S ent / Disc	Event Trigger Function	String and Global trigger logic to package event data and discriminate noise
	Veto Function	Surface Array (IceTop) allows identification and discrimination of downgoing background
age age	Incoming Data Stream from Sensor Array	150 Gig / day
d Stor	Non-Volatile Storage at South Pole	TBD Buffer / Archive Capacity & Redundancy Requirements
EM F	South Pole High Priority Communications	At all times, it must be possible to complete a minimum 10KB transfer to the Northern Hemisphere within 10 minute period. (SNEWS and GRB Reporting)
SYST Inspo	South Pole Medium Priority Communications	500 Meg / day
/ED S	South Pole High Volume Data Transfer	31 Gig / day
Dat	Northern Hemisphere Data Warehouse	TBD Buffer / Archive Capacity & Redundancy Requirements
	Power	Essential to minimize South Pole power consumption wherever practical.
2	Master Time Reference	Internal reference consistent with overall < 5ns timing error budget allocation, conversion to UTC based on GPS reference.
itenar	Experiment Monitoring	Built in monitoring capabilities are essential for managing inaccessible devices (such as the DOMs) but also help minimize South Pole headcount needs.
Main	Experiment Control	Experiment control is needed to managed the state of individual system elements as well as closely establish and control operational parameters during a given data taking session.
on &	Personnel Safety	Safety is a universal design consideration, but particularly for operations that must be conducted under difficult working conditions at the South Pole.
perati	Instrument Security	On site and remote access controls, user account management, and general IT safeguards to ensure undisturbed operation.
ō	Data Integrity	"Chain of custody" confidence in data from first capture through analysis and publication.
	System Growth Provisions	As a discovery instrument, there is a greater than normal responsibility to provide future flexibility for expansion or reconfiguration.

How to Organize the Effort?

- At the highest level this choice was simple
- IceCube has five major subsystems



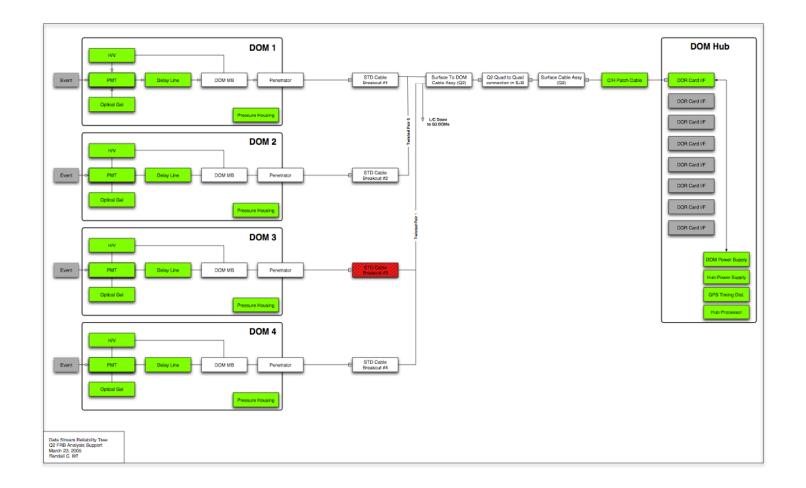
Needs, Requirements, Structure

					SCIENCE OBJECTIVES	THE ICECUDE THIS NON?									
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	ATTRIBUTE										SUBSYS	TEM ALLO	DCATION		
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ENCE	Waveform		sufficient duration / resol	ution to distinguish event signature	l is (TBD ns duration, TBD dynamic	c range, TBD sample rate)		1 to 3 ms?	TBD s	or Sub	29	nispte	vare Subsyst	s guile	
	Time Resolution			5 - 10 ns with initial decradation e				110.3 ms?	TED	Stas	Cube	T Hat	Offeren	Enst	
PRIMARY						-		110.3 ms/	160		ŝ	lorthe			
-	Operating Life			Fiteen year instrument		configured operational period plu	is multi-year deployment.					-			
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1	Array Shape Effective Volume					I lower planes with hexagonal cros inde (varies with energy level and				*	~	4	4		
	Effective volume Number of Strings			ING CADIC KIDI		ingle (varies with energy level and				×	V	4	4	×	
8	Digital Optical Modules (DOM) per String					60				*	N.	4	4	4	
Ŷ.	Total Number of DOM				4	800				4		4	*	4	
	DOM Specing - Horizontal			125 meters (efficient met	ens to instrument the required volu	me of ice, provides good resolutio	on for higher energy levels)			4	V	4	4		
с ° .	DOM Specing - Vertical				16.7 meters (provides highest reso	slution for vertical traveling particle	25)			~		4	4		
	Detector Depth			1450 - 2450 meters (opt	ical properties of ice improve with	depth, limiting factor is boundary	to surface shear effects)			1		4	4	4	
	Total Station Court				1 IceTop station at each hole is	scation, nominally 80 station sets.				×		4	4	4	
	Tarks per Station			2 ta	nics at each station provide operat	tional redundancy, local velo capa	bity.			1		4	4		
	Effective Tank Volume					(up and load entry)				×		4	4		
ų,	Digital Optical Modules (DOM) per Station / Tank			Two DOM in each tank are		range, resulting in a total of four I	DOM per loeTop Station set.			1		4	1		
5	Total Number of DOM					20				~	V	4	4	4	
	DOM Specing - Horizontal					spacing is 1 meter.				*		4	4		
	DOtil Specing - Vertical Detector Depth					50 meters above the topmost in-loa itional snow accumulation at rough				4	~	4	4		
				Tanks are installed to be hu		n Event (SPE)	tox per year thereafter.			*				V .	
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alibe	Establish operating characteristics of each DOM					lestal characteristics, others.				×		4	4		
× 3	String Commissioning			Determine the		able to add to the body of operatio	onal instrument.			1			4		
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	South Pole High Priority Communications		At all tim	es, it must be possible to complete			inute period. (SNEWS and GRB R	eporting)			V		4		
- T	South Pole Medium Priority Communications		7000			ieg / day							4		
	South Pole High Volume Data Transfer				31 G	ig / day					V		4		
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	Master Time Reference			Internal reference consiste	nt with overall < Sns timing error b	sudget allocation, conversion to UT	FC based on GPS reference.						4		
	Experiment Monitoring						help minimize South Pole headcour			×			4		
	Experiment Control						perational parameters during a give			1	V.	4	4		
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	Instrument Security					nt, and general IT safeguards to e				×		4	4		
	Data Integrity System Growth Provisions					first capture through analysis and sibility to provide future flexibility (*	4	4	*	4	
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Focus on Science Data Stream

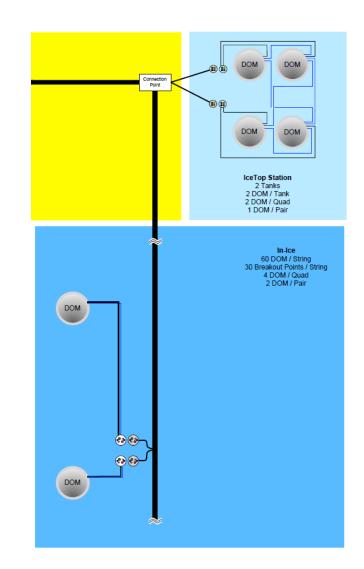


Science Data Stream FMEA

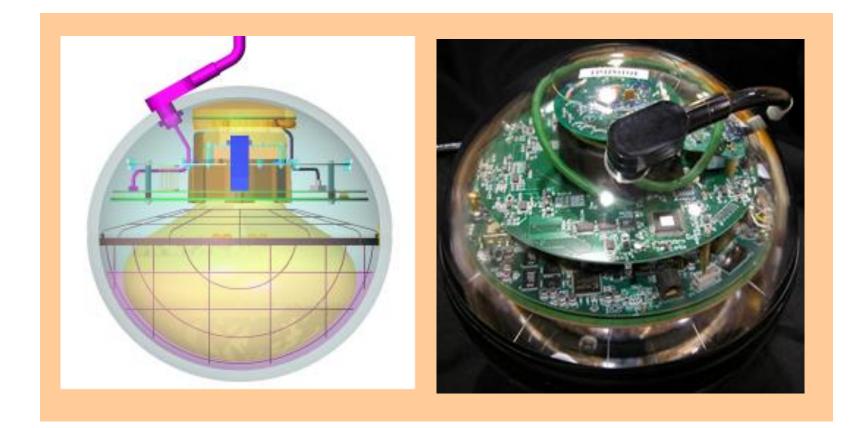
Functional Role	Key System Elements	Accessible?	Failure Effect	Criticality
Science Data Stream - Sensor Subsystem	In-Ice and Ice-Top DOMs, cables, connections	No	Permananent Loss of Science Data due to failed Channel(s) for the remainder of the instrument operational life.	Very High
			Permananent Loss of Science Data due to induced failure of Channel(s) for the remainder of the instrument operational life.	Very High
			Permananent Loss of Science Data from Channel(s) due to wear out, performance drift, or end of service life degradation effects in excess of user defined thresholds.	High
			Degraded Science Data from Channel(s) compared with specifications, but still deemed useful for scientific purposes such as Supernova detection and reporting.	Moderate
Science Data Stream - DOM Hub	DOM Hub, DOR Card, DOM Power Supply, Master Clock Distribution System	Yes	Permanent Loss of Science Data from unavailable channel(s) / string(s) during the interval between failure and system restoration following maintenance.	Moderate
Buffer Limited Trigger and Event Processing	Raw Data Storage, Raw Data Buffer, String Processor, Trigger, Event Buffer, Event Data Storage, Communications Buffer	Yes	Permanent Loss of Science Data from effected channel(s) / string(s) during the interval between buffer overflow and system restoration following maintenance.	Moderate
Off-Line Data Processing	All other system elements	Yes	User inconvenience prior to restoration, no loss of science data.	Low

Sensor Subsystem

- Cables
- Connections
- Digital Optical Modules



Digital Optical Module



Key DOM Decisions

- Pressure Sphere Specification and Margin
 - Life-cycle analysis to identify max / min pressure
 - Hydrostatic Pressure from 2,400 meters of water
 - Peak "re-freeze" dynamic pressure during install
 - Minimum pressure during transport
- Interior environment pressure and fill gas
 - Finite set of options to select from
 - Simple trade study analysis effort

DOM Fill Gas Trade Study

- Baseline plus 4 options
- Emphasis on info – not scores

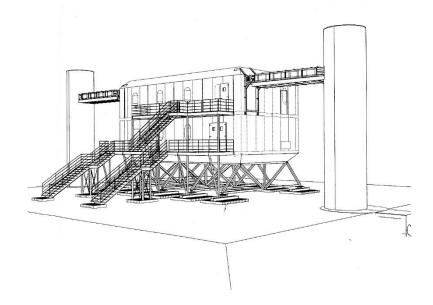
	Current Baseline			e Concepts	-	į – – – – – – – – – – – – – – – – – – –	
	Current Baseline	1	2	3	4		
	Seal DOM in partial vacuum of ambient atmosphere.	Clean Dry Air via in house compressor system	Compressed gas cylinder	Commercially available dry nitrogen.	Sulfur Hexafluoride	Comments	
Convert Description	n No special steps taken to control and monitor	House compressed air will have been filtered to	For an and the build of all off have a builder.	Purity and dev point requirements can be	Sultur hexaflucride is an excellent dielectric		
	the product response to the control of the state of the particulates, trace passes, and daw point of the atmosphere sealed in the DOM.	remove large particulates, and the deve point reduced by 22.C from ambient by use of a refrigerated dryer.	controlled dew point, and lower concentration of particulates.	pany and the part requirements can be specified to supplier.	material for high voltage electronic applications.		
Atmospheric Content	Reactive Chemical Species Average	Reactive Chemical Species Average	Purity ranges from 99% to 99.998%, water	99.999+% Nitrogen dew point < -100C.	99.99% Sulfur Hexafluoride	[
	Divione 0.001 ppm* hydrogae Sulfide 0.01 ppm* Suffur Divisite 0.05 ppm* Nitrogae Toxide 0.05 ppm* hydrocarbons 0.24 mgm/m3- Particulate Centamination 50 mgm/m3-24h *Measured by volume at 25 C and 760 mm pressure.	Chlorine 0.001 ppm* trydrogen Solfide 0.21 ppm* Suffur Cloxide 0.25 ppm* Nithrogen Oxide 0.25 ppm* Nythrogen Oxide 0.25 ppm* Nythroden 0.24 mpm/m3 Particulate Contamination < 50 mgm/m3-24h *Measured by volume at 25 C and 760 mm pressure.	Pointy ranges into or the derivative system contant range must spon for Yoshing parity product to unspecified for welding grade product. Parity class were not called out on supplier's spec, sheets.				
Risk of corrosion on DOM PW assemble	B Extremely High a	Very High	Very High	Very Low	Very Low	Baseline and alternate approach 1	
Corrosion Mechanian	Condensation due to high dew point, reactive atmospheric gases, corresive particulates, Coone due to combination of oxygen and high voltage (corona discharge). Ozone will also attack and degrade organic materials such as wirn insulation.	Condensation due to high dew point, reactive atmospheric gases, comsive particulates, Ozone due to combination of oxygen and high voltage (corona discharge). Ozone will also attack and degrade organic materials such as wire insulation.	Possible reactive atmospheric gases, reduced confernation concerns due to the lowering of the dew point in the "high puthy" product, coron due to combination of oxygen and high voltage (corona discharge). Conce will also attack and degrade organic materials such as usine insulation.	As long as the atmosphere in the DOM has been purped prior to nitrogen backfit, there will be no atmospheric contribution to controlion reactions. Ozne will not from because no suygen is present inside of DOM.	As long as the atmosphere in the DOM has been purged prior to suffur hexafluoride backfill, there will be no atmospheric contribution to corrosion reactions. Ozone will not form because no oxygen is	not capable of delivering reliabl performance throughout the 15 y project life. Alternatives #2 and #3 are most li to provide a nencorrosive atmospi throughout the 15 year project il	
Possible trace radioactive gase	ns Radon	Radon	wire insulation.	present inside of DOM.	present inside of DOM.		
Reliability Impai	t Very Poor Reliability Extremely high probability of corrosion effects on the PWBs, internal connectors, and coone attack on base metals, electrical insulating	Poor Reliability High probability of corrosion effects on the PWIDs, internal connectors, and ozone attack on base metals, electrical insulating materials, and	Poor Reliability High probability of corrosion effects on the PWBs, internal connectors, and coone attack on base metals, electrical insulating materials, and	Highly Reliable Only physics of failure mechanism (other than manufacturing defects) is metallic whisker crowth.	Highly Reliable Only physics of failure mechanism (other than manufacturing defects) is metallic whister crowth.		
	materials, and possibly the optical gel.	possibly the optical gel.	possibly the optical gel.	Consistent dielectric performance due to controlled purity and dew point.	Consistent dielectric performance due to controlled purity and dew point.		
DOM Performance Impai	t None	None	None	None	None	[
				Nore			
Possible trace radioactive gase	Radon	Rædon	Radon	None Nitrogen is processed through molecular sieve and cryogenic separators in order to purify the gas. This process will all minate contamination from other gases.	None	No Impact	
Safety Impa	t Low Safety Risk	Low Safety Risk	Low Safety Risk	Moderate Safety Risk	Moderate Safety Risk		
	The atmosphere presents no safety issues, the evacuation equipment will require special operator training to ensure operator safety.	The atmosphere presents no safety issues, the evacuation equipment will require special operator training to ensure operator attefy. The use of pressurized gases will again require special operator training to ensure operator safety.	The atmosphere presents no safety issues, the evacuation equipment will require special operator training to ensure operator training to ensure operator special operator training to ensure operator safety.	Nitrogen gas is inert and will not support life, therefore special proclutions and operator training will be required. Training will also be required for operators to handle pressurized gases.	Suffur hexeffuoride is inset and will not support life, therefore special precessions and operator training will be required. Training will also be required for operators to handle pressurted gases. Under normal conditions suffur hexeffuoride is stable, but will decompose is an electric are to form gasessue hypotoluts which	II safety issues are manageable. Soft hexaflueride is the most significant issue	
					efective arc to form gasecus byproducts which includes fluorine gas. Fluorine gas, in the presence of molisture is very corrolive as it will form hydrogen fluoride. If an archig even has exercised when generalist. The use of standard safety equipment, including chemical resistant gloves and a face shelid should be vero when any DDM is opened.	herafueride is the most significa hexafueride is the most significa issue	
DOM Manufacturing Impar	t Least complicated production operation	Moderately complicated production	Moderately complicated production	Moderately complicated production	Includes full-file gill, including gill, in the presence of metalian is very combine as it will fam hydrogen fluoride. If an arcing even has exercised when portrol BThe use of transder anthy equipment, including chemical ensittent gloves and a face shell should be worn when any DOM is opened. Moderately complicated enduction	ni early excel at an angeta. A	
	The use of a glove box and vacuum chamber to control the atmosphere surrounding the DOM hemispheres during final assembly is assumed in all concepts.	Moderately complicated production specifican The use of the given be of vacuum chamber is still assumed. The need for a class, dry set based advante by any approximent to a still compressor with a stiftpartial drys and filter.	Mederatily complicated production operation The use of the given be and vocum character is till assumed. The need for a class, dry ar source after the requirement of as a site or or operation of compressed ar a long with pressum regulators to action the full pressum of the site of	Medinatory complicated production operation The use of the given to division chamber is still aurum. The need for a division status drives the most of the division according to the product for splitable of modulators to control the final pressure and flow	Includes fusions gas, Historie gas, in the presence of motistary is very control as at Will form hydrogen fluoride. If an ancing even has occurred in a DOM, caudios will need to be exercised when opening it. The use of standard afety sequencemi, including chemical resistant gloves and a face shelid should be vom when any DOM is opened.	All controlled environment alternat	
DOM Manufacturing Impas Report / Rework Impas	The use of a glove box and vacuum chamber to control the atmosphere surrounding the DOM hemispheres during final assembly is assumed in all concepts.	operation The use of the glove box and vacuum chamber is still assumed. The need for a clean, dry air	operation The use of the glove box and vacuum chamber is still assumed. The need for a clean, dry air source drives the negutierement for an air compressor with a retrigerated dryver and filter, or cylinders of compressed air along with	operation The use of the glove box and vacuum chamber is still assumed. The need for a dry nitrogen	Records Hubbrid gale, Indone gale, it is an inform hydrogen function. If an ancing even that accorded in a DOR cauchow all meets to be accorded in a DOR cauchow all meets to be address experiment. Including chemical measured globes and a face isoliaid should be warn when any DOR is equival. Including the second should be warn when a set is assumed to be an autor is set its assumed for the read for a suffar headlende source drives the requirement the sould be address drives the requirement the sould be address to be address provided headlender source drives the requirement the regiment of address to be address provided to be regimented address to be address to be address headlender source drives the requirement the regimented address to be address to be address to regimented address to be address to be address to be address to be address to be address to be address headlender source drives the requirement the address to be address to be address to be address to be address to be address to regiment of address to be address to be address to be address to be address to be address to be address to be address to the address to address to be address to be address to be address to the address to address to be address to be address to be address to the address to address to be address to be address to be address to the address to address to be ad	headfuoride is the most significations in the set of th	
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DOM Fill Gas Trade Study

- Yielded decision plus database of options
- Sample of Trade Study content

Low Safety Risk	Moderate Safety Risk	Moderate Safety Risk
The atmosphere presents no safety issues, the evacuation equipment will require special operator training to ensure operator safety. The use of pressurized gases will again require special operator training to ensure operator safety.	Nitrogen gas is inert and will not support life, therefore special precautions and operator training will be required. Training will also be required for operators to handle pressurized gases.	Sulfur hexafluoride is inert and will not support life, therefore special precautions and operator training will be required. Training will also be required for operators to handle pressurized gases. Under normal conditions sulfur hexafluoride is stable, but will decompose in an electric arc to form gaseous byproducts which includes fluorine gas. Fluorine gas, in the presence of moisture is very corrosive as it will form hydrogen fluoride. If an arcing event has occurred in a DOM, caution will need to be exercised when opening it. The use of standard safety equipment, including chemical resistant gloves and a face shield should be worn when any DOM is opened.

IceCube Laboratory





It Snows at the South Pole

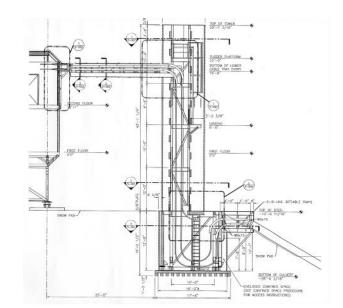
- Not much (1 ft/yr) but builds up over time
- Snow blows and drifts in very nasty ways
- Decisions:
 - How to keep the IceCube Laboratory useable?
 - How to manage over 80 huge cables?

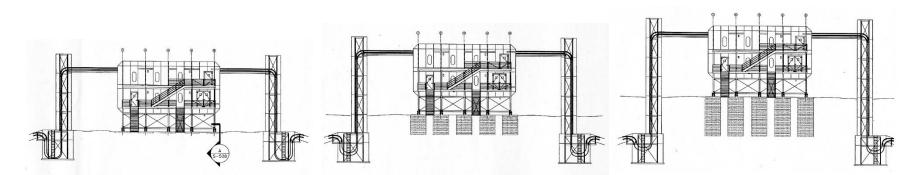
IceCube Laboratory

- Building Lift Operation
 - Applied proven South Pole Station precedent
 - CFD modeling to minimize vortices and deposition
- Cable Management
 - No prior precedent (80+ huge, very stiff cables)
 - Installed over multiple seasons
 - Wanted single entry panel, settled for two
 - Accepted complex logistical constraints
 - Accepted complex personnel task / training effort

IceCube Laboratory

- Snow and Cable Solution
 - Stilts for the building
 - Towers for the cables
 - Periodic lift operation





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Many Thousands of Decisions

- Data collection throughout multi-year build
- Component selection for extreme cold / hi-rel
- Extreme task simplification for installers
- Minimizing peak and total power consumption
- Logistics impacts (LC-130 load limits)
- International collaboration coordination
- Documentation and training support

Summary of Universal Insight

- The most critical decisions were those regarding stakeholders and needs
- Next was a system / sub-system / interface view that enabled simultaneous development
- Mission-level FMEA guided decision priority
- Decision method driven by available data, type of choice, need to communicate result
- Data is valuable, mere scores are dangerous



Thanks!

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