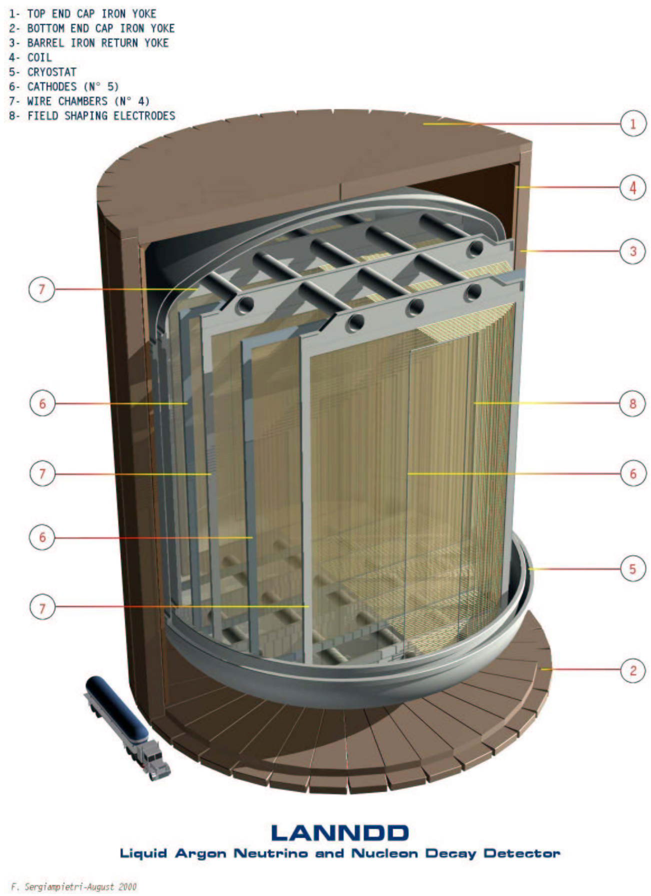
Large Underground Space for Neutrino Detectors



Kirk T. McDonald

Princeton University

June 26, 2001

Meeting with Brierley Associates

Ithaca, NY

http://puhep1.princeton.edu/~mcdonald/nufact/

Neutrinos

- Recent evidence indicates that neutrinos have mass.

  The total mass of neutrinos in the universe is likely large than that of ordinary matter.

- Neutrinos are much like electrons – but without electric charge.

- The heaviest neutrino weighs about 1/10,000,000 of an electron.

  ⇒ Neutrinos produced on Earth or in the Sun move at very close to the speed of light.

- Most neutrinos pass through the Earth without interacting.

- Go underground to avoid cosmic rays.

- To detect low-energy neutrinos, natural radioactivity must be low.

- ⇒ Need **large underground space for neutrino detectors**.

(At Least) Three Kinds of Neutrinos

- There are 3 kinds of electrons: e, μ, and τ.

  The main difference is their mass: $m_\mu \approx 200 m_e$, $m_\tau \approx 3700 m_e$.

- For each type of electron, there is a type of neutrino:

  ν_e, ν_μ, and ν_τ.

  The neutrinos differ mainly in their masses – but these are not well known yet.

- Apparently, neutrinos can change their type:

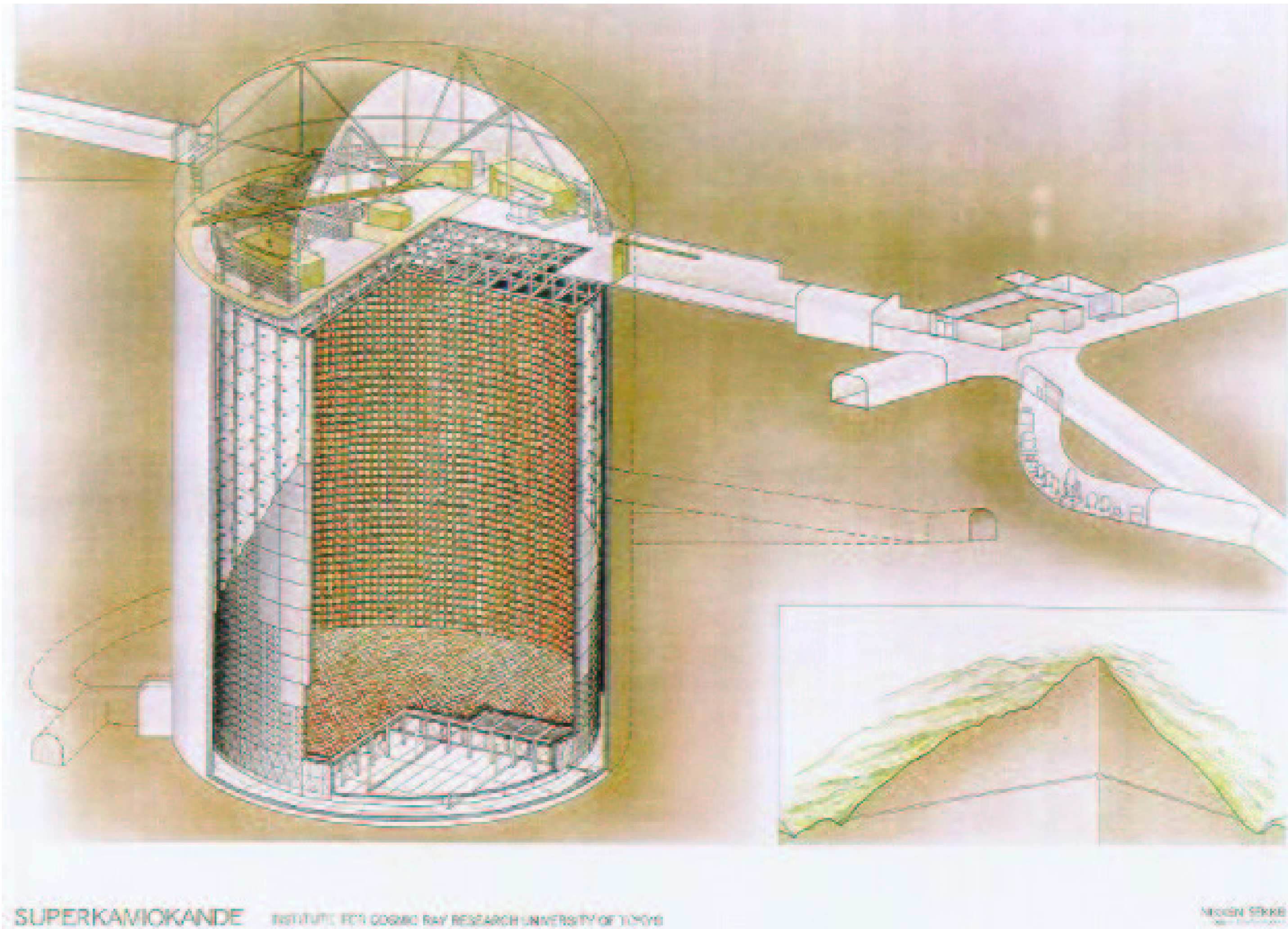
  "neutrino oscillation".

- The distance over which a neutrino changes its type depends on its energy.

- For the most probable type of oscillation, the best distance for observation is 400 km $\times E_\nu$ in GeV.

- Example: Ithaca to Brookhaven Lab is 360 km $\Rightarrow$ best for $E_\nu \approx 0.9$ GeV – which is a good energy for neutrino beams at BNL.

Superkamiokande Sets The Standard

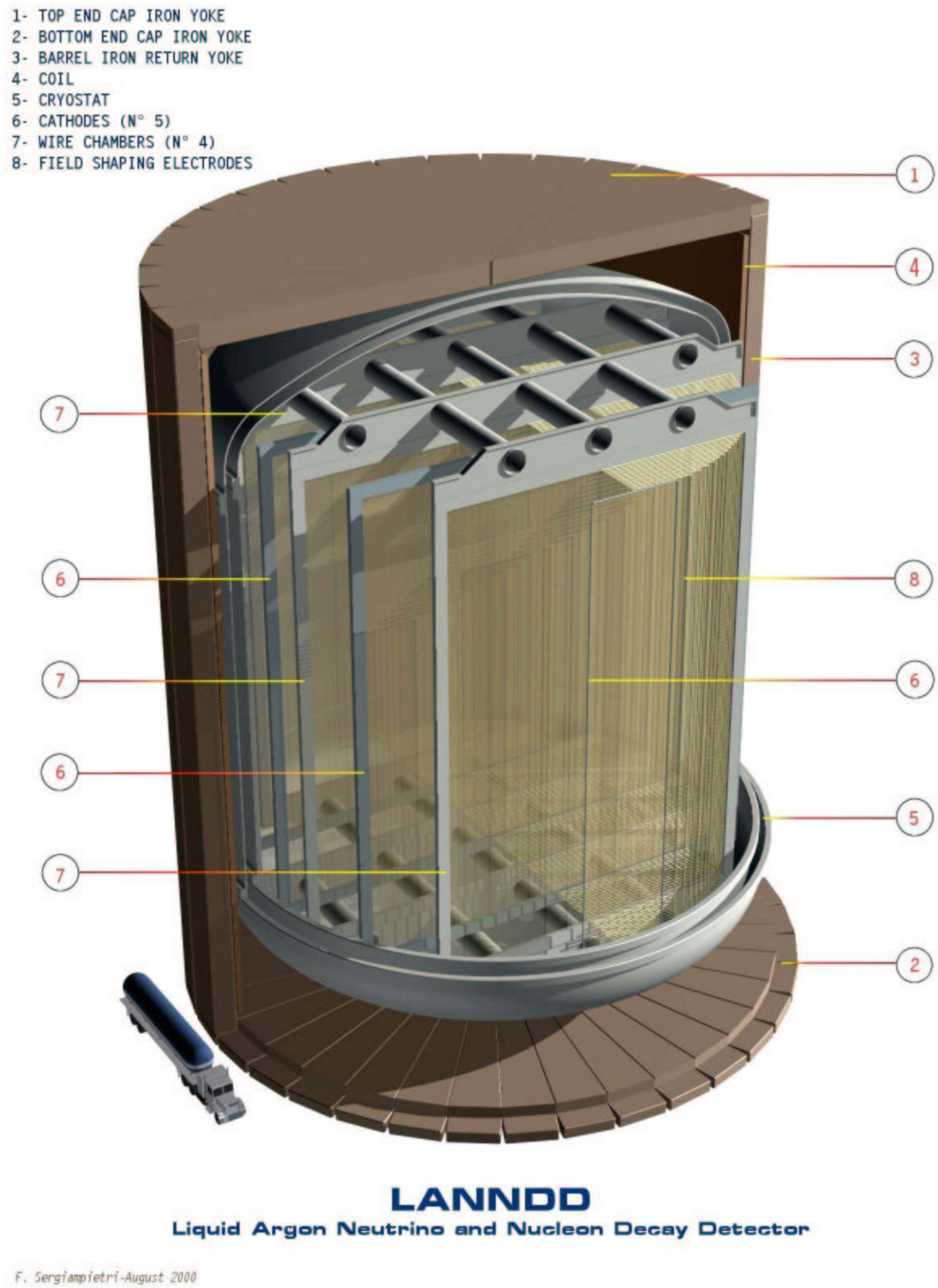


SuperK is a water tank, 40 m diameter, 50 m tall.

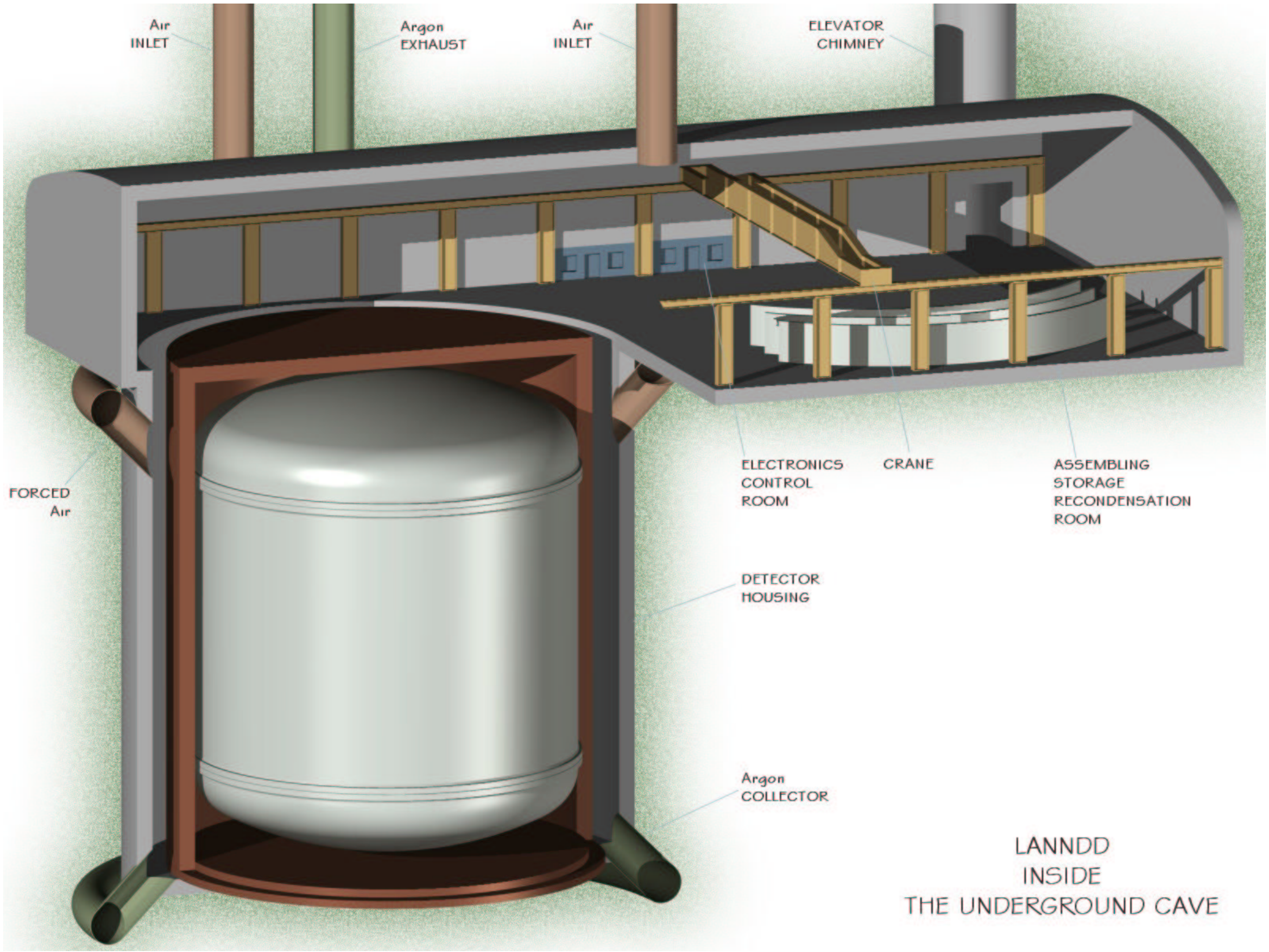
It is located about 2000 m underground in a zinc mine in western Japan.

A New Large Detector Concept: LANNDD

Liquid Argon Neutrino and Nucleon Decay Detector



LANNDD is 50 m Diameter, 60 m High



http://xxx.lanl.gov/abs/astro-ph/0105442

LANNDD Physical Parameters

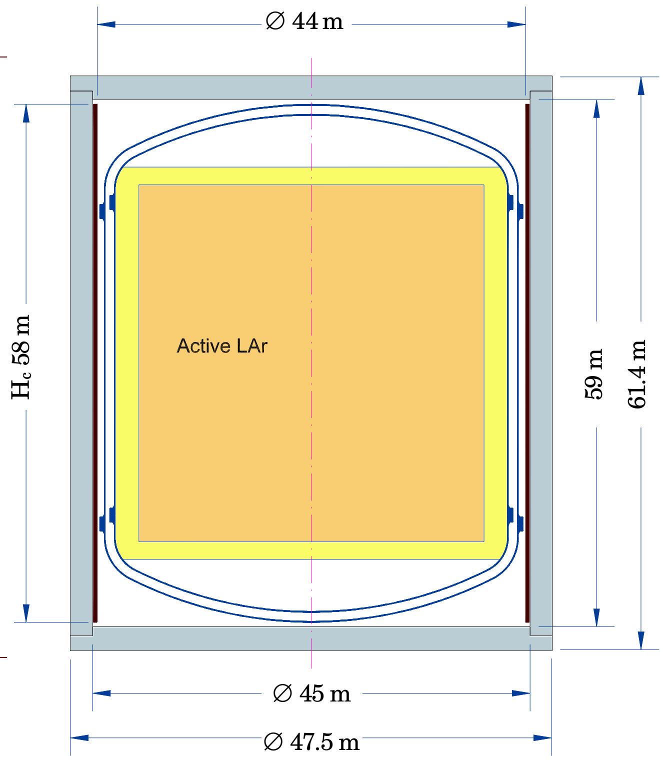
The magnet

Solenoid

Magnetic flux intensity	$B = 0.2\,(0.4,\ 1.0)$ T	
Ampere turns/m	$nI = B/\mu_o$	= 318.3 A/m
Current density in Cu	$J = 0.8$ A/mm^2	
Coil inner diameter	$D_c = 44$ m	
Coil height	$H_c = 58$ m	
Total current	$I_T = 18.5$ MA	
Cu density	$d = 8.96$ g/cm^3	
Cu resistivity at 273 (90)°K	$\rho = 1.55\,(0.29)$ μΩ·cm	
Coil thickness	$T_c = nI/J$	= 0.2 m
Power	$W \approx \frac{\rho \cdot J}{\mu_o} \cdot B \cdot \pi \cdot D_c \cdot H_c$	= 17 (37, 79) MW
Coil mass	$M \approx \frac{d}{\mu_o \cdot J} \cdot B \cdot \pi \cdot D_c \cdot H_c$	= 16 (33, 71) kT

Iron yoke

LAr-to-Iron field ratio	$\alpha = B/1.8$ T	= 0.11 (0.22, 0.55)
End cap yoke thickness	$h_{Fe} \approx \alpha \cdot D_c/4$	= 1.2 m
Barrel yoke thickness	$T_{Fe} \approx D_c \cdot (\sqrt{1+\alpha} - 1)/4$	= 1.2 m
Mass of the return yoke	$M_{Fe} = 120\,(247,\ 677)$ kT	

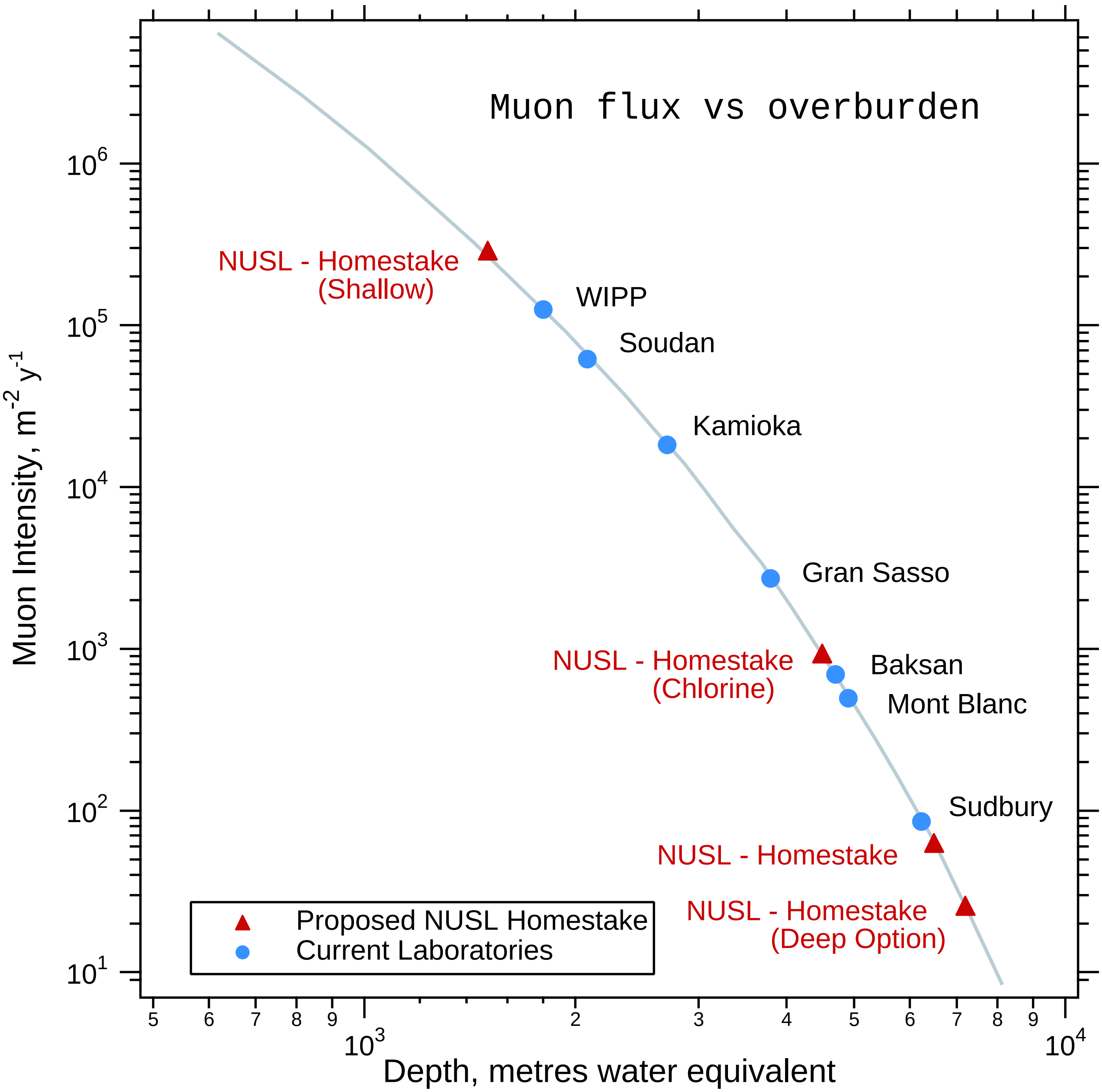


NuFact'01 – March 24-30, 2001   F. Sergiampietri   LANNDD 26

http://www.hep.princeton.edu/~mcdonald/nufact/sergiampietri_nufact01.pdf

Where to Put a Large Neutrino Detector?

Previous (smaller) neutrino detectors are in existing mines.



Is a New Site Affordable?

- For an accelerator-based neutrino experiment,
  Physics output $\propto$ neutrino flux $\times$ detector mass.
- $\Rightarrow$ Physics/dollar optimized when accelerator costs are similar to detector/site costs.
- Accelerator upgrades to a 4-MW proton source to drive the neutrino beam will cost $\approx$ \$400M.
- A 50-100 kton neutrino detector will cost \$100-200M.
- In this context, a site cost of \$100-200M is justifiable.

- A recent prosposal seeks \$200M to upgrade the Homestake Mine site – but only for small detectors.
  http://www.sns.ias.edu/ jnb/Laboratory/NSFproposal.pdf
- Can a new, large site be commissioned for a similar cost?

Appendix C.3: Comparison of Select Characteristics and Costs of Four Principal Candidate Sites

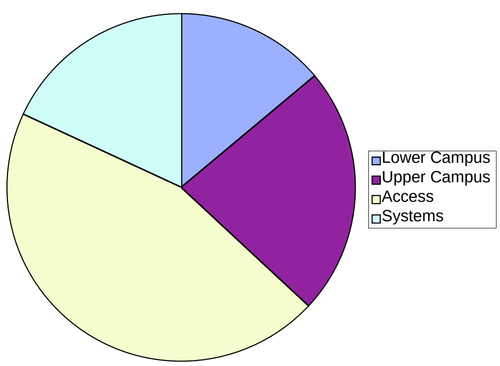
	CUNL	Homestake	San Jacinto	Soudan
mwe[a]	1600[h] 1840[l] 3172[j] (3524)[k]	6156[j] (6700)[k] 6656[j] (7100)[k]	A: 5000[l] B: 6000[l] C: 6510[l] D: 7000[l]	2200[m]
Depth (m)	655 1300	2255 2438	See note u	710
Depth (ft)	2150 4265	7400 8000	See note u	2300
Density	2.44	2.73	2.73	3.1
Figure of Merit[b]	[n]\$11/ton [o]\$23/m^3 [p]\$25/m^2	\$140/m^3 [q]\$50/ton	[r]\$73/m^3	
LII Factor[c]	1.1	1.05- 1.1	1	1.2
Halls	$5.9M [o] 3 halls of 15m x 10m x 100m	$40M[s] for 3 halls of 18m x 18m x 100m	$33M[t] 3 halls of 20m x 20m x 100m	
Cavern D[d]	See note u	See note u	$81.8M[v]	$70M [w]
Cost of Operations	($0M) $2- 10M/year[x] ($0M) $40M- $200M over 20 year lifetime	$3.8M/year[y] $76M over 20 year lifetime	$2.3M/year[y] $46M over 20 year lifetime	$1M/year[w] $20M over 20year lifetime
Cost of Access[e]	[z]$43.6M +($14.2)	$43M[aa]	$51M [bb] $65M[bb] $82M[bb]	$21M[w]
Declared Contingency	25%		25%	
Surface Building Costs[f]	25kft^2 = \$6M +\$10M	3 bldg = \$53M 32kft^2; 175kft^2; 41kft^2	\$18kft^2 warehouse + 12k ft^2 lab + \$30kft^2 Admin = \$6.6M	
Total[g]	$63.7M ($104M)	$83M ($159M)	$115M ($161M)[cc]	

Table 3—Summary of Major Development Tasks for NUSL at Homestake

Task	Location/Type	Estimated Cost[1]
Laboratory excavations and finishes	Lower Campus	$12,130,000
Control and scientist support facilities	Lower Campus	$3,980,000
Facilities for Detector Mechanical Support Systems	Lower Campus	$1,110,000
Ultra-low background counting facility and equipment	Lower Campus	$2,900,000
Refuge Room and Sump	Lower Campus	$400,000
Cosmogenic Decay Storage Areas	Lower Campus	$250,000
Total for Lower Campus		**$20,770,000**
Demolish and clear existing structures	Upper Campus	$5,000,000
Renovate existing structures for science, administration	Upper Campus	$5,000,000
New building for science, administration	Upper Campus	$6,125,000
New near-underground space for outreach	Upper Campus	$14,000,000
Receiving and warehousing space	Upper Campus	$3,750,000
Total for Upper Campus		**$33,875,000**
Road Improvements and Parking	Access	$3,000,000
Immediate Shaft and Cage Improvements	Access	$8,500,000
Drifts at 7400 level	Access	$20,210,000
Ramp system improvements	Access	$1,500,000
Yates shaft improvements	Access	$30,710,000
Underground materials handling and transport systems	Access	$1,625,000
Total for Access		**$65,545,000**
Lower Campus System Upgrades	Systems	$22,110,000
Upper Campus System Upgrades	Systems	$3,250,000
Lower Campus Isolation Systems	Systems	$500,000
Sealing Unused Underground Areas	Systems	$400,000
Total Systems		**$26,260,000**
Sub-Total Laboratory Development		**$146,450,000**
EDIA (12%)		**$17,574,000**
Contingency (25%)		**$36,612,500**
Total for Laboratory Development		**$200,636,500**

[1]Estimated costs are in FY2003 dollars.

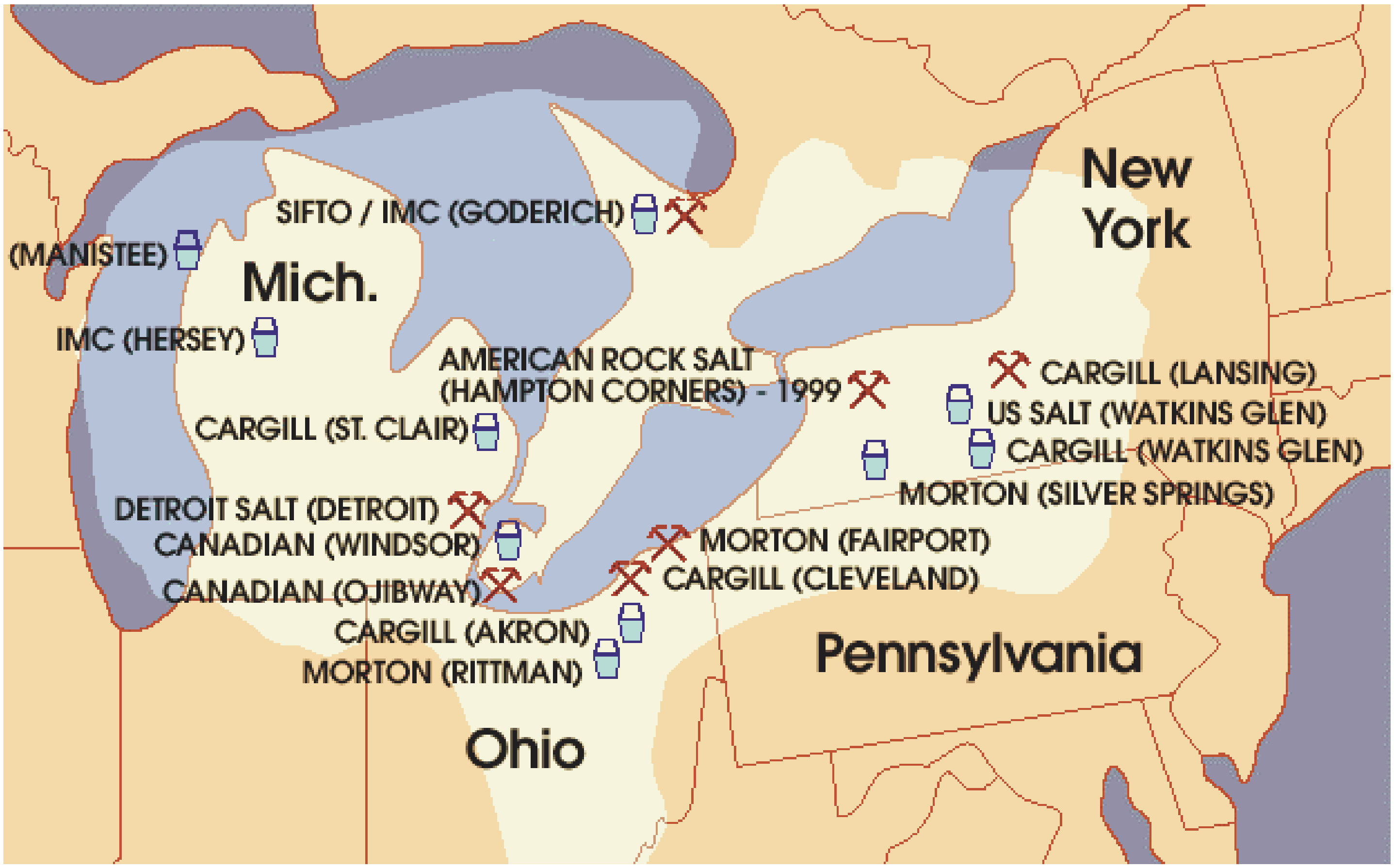
Figure 3—Distribution of Development Costs for the National Underground Science Laboratory at Homestake



Siting Criteria for a Large Neutrino Detector

- Good access so can construct a large underground facility.
  $\Rightarrow$ Horizontal tunnel preferable to vertical shaft.
- Deeper is better – but a large neutrino detector does not need to be as deep as a small one.
  At least $2000'$ underground.
- A dry site is preferable.
- Low natural radioactivity is preferable.
  This and the previous item tend to favor sites in salt beds – if big caverns are viable there.
- The site should be near suitable academic, cultural and industrial infrastructure.

Extensive Salt Beds in the Great Lakes Area



How deep?

Vertical access only?

Horizontal Access Sites Along the Hudson and in the White Mountains

High Peak near Catskill, NY is 3650′ high and 170 km from BNL.

Possible access: $L = 2.6$ mi, $\Delta h = 3050'$, or

$L = 4.0$ mi, $\Delta h = 3300'$.

Mt. Washington, NH is 6288′ high and 390 km from BNL.

Possible access: $L = 2.8$ mi, $\Delta h = 4300'$.

Mt. Adams, NH is 5774′ high and 390 km from BNL.

Possible access: $L = 3.0$ mi, $\Delta h = 4400'$.

Water, radioactivity...?