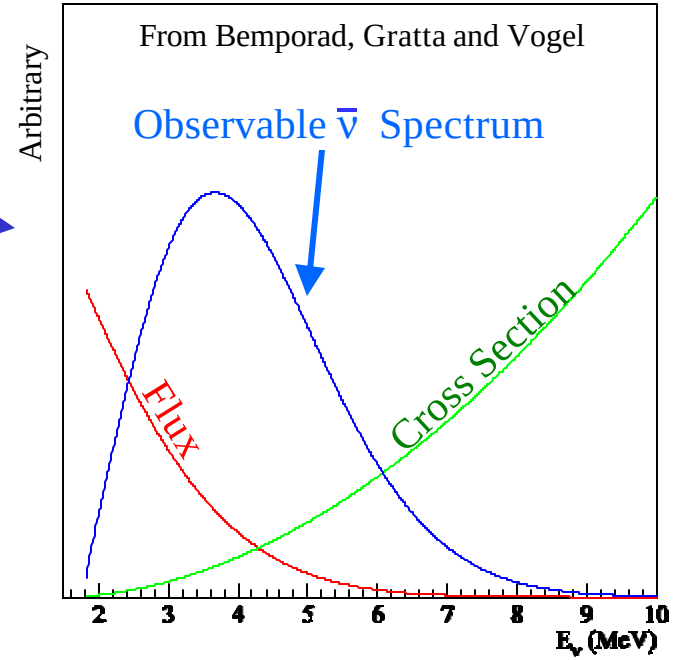
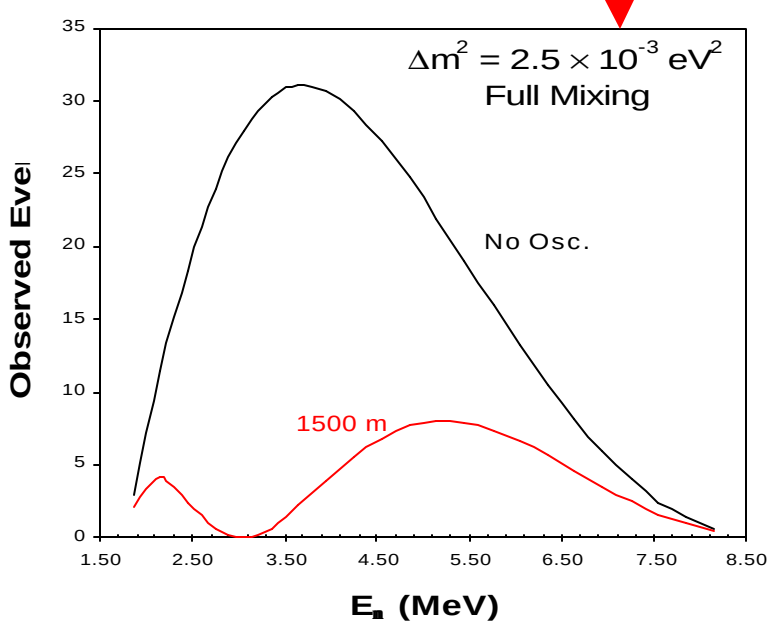
Neutrino Overview (by a non-expert)

- **Long Range Plan** (HEPAP 1/02): Neutrinos listed 3rd after ILC and LHC
- **Long Range Plan** (NSAC 4/02): Recommendation #3 – NUSEL: ββ-decay and solar neutrinos
- **Quarks and Cosmos** (NRC 4/02): Recommendation #3 - Neutrinos, Dark Matter and Proton Decay
- **Facilities for Future** (OS 3/03): ββ-decay #18, ν-superbeam #21
- **Neutrinos and Beyond** (NRC 03): endorsed Icecube and DUSEL
- **Quantum Universe** (HEPAP 04): Question #7 off-axis, reactor, superbeam, neutrino factory, NUSEL, ββ-decay
- **Physics of Universe** (OSTP 2/04): Priority #2 Neutrinos, Dark Matter and Proton Decay. NSF to lead NUSEL and NSF/DOE to develop program
- **SAGENAP** (HEPAP 12/04): Reactor θ_{13} should proceed quickly, coalesce to one experiment
- **Neutrino Matrix** (APS 11/04): one of two high priority recommendations - Reactor θ_{13}, off-axis, superbeam, ν-factory, NUSEL
- **NuSAG** (HEPAP 9/05?): recommendations on reactor $\theta_{13,}$ ββ-decay, off-axis
- **EPP2010** (NAS 06?):

Reactor Measurements of θ_{13}

- Nuclear reactors are very intense sources of $\bar{\nu}_e$ with a well understood spectrum
  - 3 GW 6×10^{20} $\bar{\nu}_e$/s
    700 events / yr / ton at 1500 m away
  - Reactor spectrum peaks at ~3.7 MeV
  - Oscillation Max. for $\Delta m^2=2.5\times10^{-3}$ eV^2 at L near 1500 m





- Disappearance Measurement:

  Look for small rate deviation from $1/r^2$ measured at near and far baselines

  - Counting Experiment
    - Compare events in near and far detector
  - Energy Shape Experiment
    - Compare energy spectrum in near and far detector

Experimental Setup

- The reaction process is inverse -decay (IBD) followed by neutron capture
  - Two part coincidence signal is crucial for background reduction.

$$\bar{n}_e p \rightarrow e^+ n$$

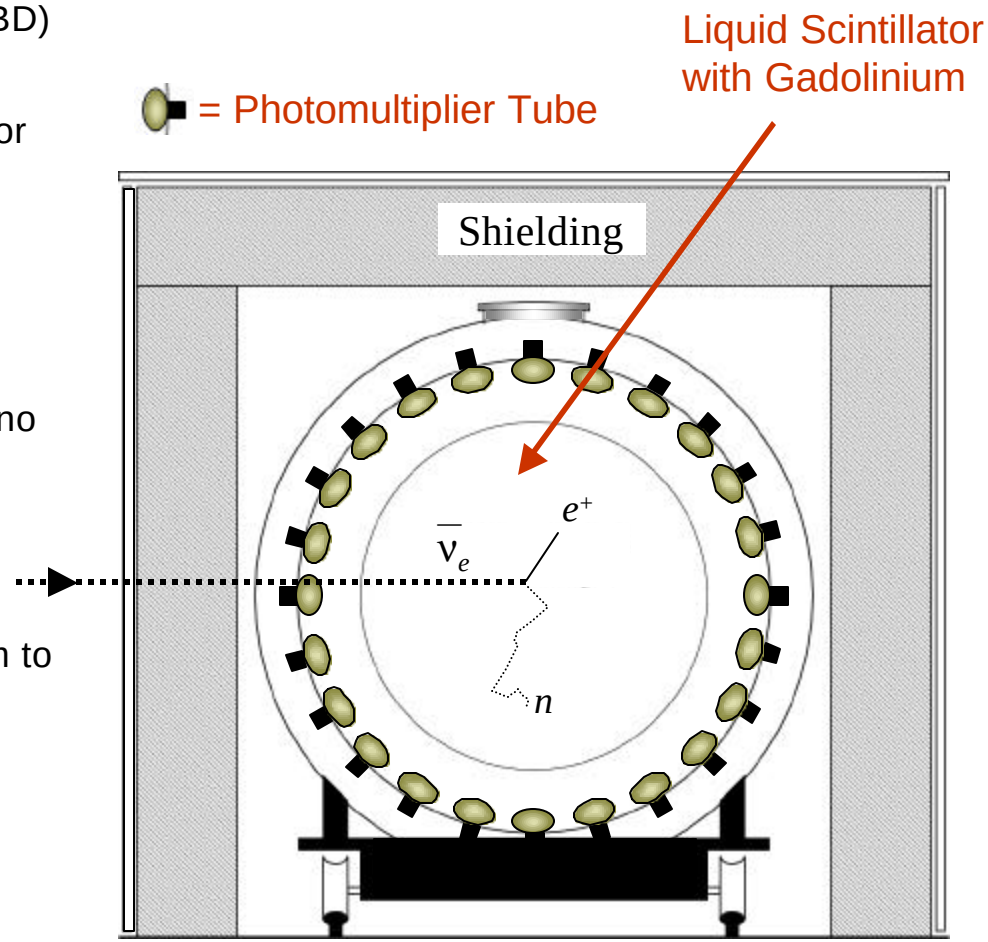
$$\hookrightarrow n \text{ capture}$$

- Positron energy spectrum implies the neutrino spectrum

$$E_{\acute{\imath}} = E_{vis} + 1.8 \text{ MeV} - 2m_e$$

- The scintillator will be doped with gadolinium to enhance capture

$$n \; {}^{m}\text{Gd} \qquad {}^{m+1}\text{Gd} \; \gamma\text{'s (8 MeV)}$$



Signal = Positron signal + Neutron signal within 100 msec (5 capture times)

Braidwood Neutrino Collaboration

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14 Institutions

70 Collaborators

Braidwood Neutrino Experiment

Braidwood Setup:

- Two 3.6 GW reactors
- Two 65 ton (fid vol) near detectors at 270 m
- Two 65 ton (fid vol) far detectors at 1510 m
- 180m shafts and detector halls at 450 mwe depth

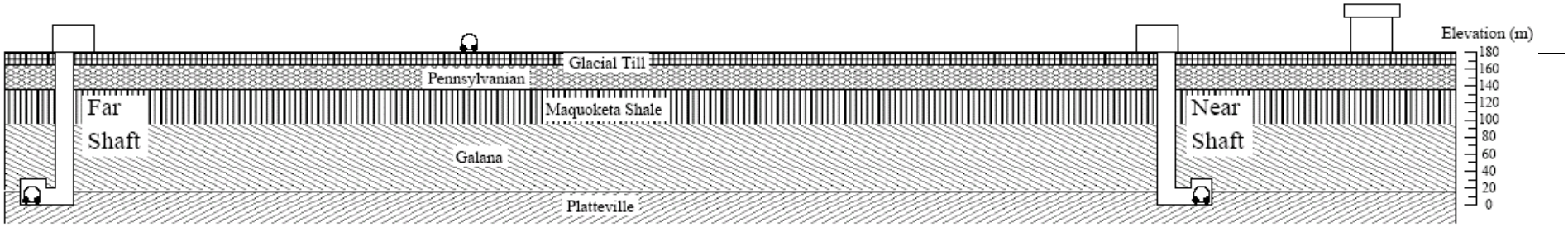
Project Summary:

- Overview
- Civil Construction
- Detector Design
- Backgrounds and Veto System
- Physics Capability

Civil Construction

- Two detector locations at 200 m and 1500 m from the reactors
  - A 10 m diameter shaft allows access to the detector caverns at 183 m below the surface
  - Caverns are 12m x 14m x 32m and house two detectors with their veto systems
- Detailed cost estimates were done by the Hilton and Associates engineering firm.
  - Total cost = $29M + $5M (EDIA) + $8.5M (Contingency)

(Shafts: 2@$9.8M, Caverns: 2@$2.4M, Tunnels: $1.7M, and $3.2M mobilization)



Detector Cost Estimate

- $4.2 M /detector with veto system + $1.3M (Cont.)
- Other detector related items $1M with cont.

Total for 4 detectors: $23M with cont.

Description	Est. Cost (thousands of dollars)
Spherical Detectors	
Steel tank	340
Acrylic vessel	500
Oil	89
Gd-loaded Scintillator	640
Oil plumbing system	100
Temp regulation system, N2 purge	40
PMTs	870
PMT supports	100
Cable system	7
Tank support system	50
Detector electronics	150
DAQ	50
Assembly Labor	65
Radioactive Source Scanning System	100
Muon System	1,100
Subtotal per Detector and Veto	4,201
Contingency (30%)	1,260
Total for one Detector System with cont.	5,461
Total for four Detector Systems with cont.	21,844
Items independent of number of detectors	Est. Cost
Attenuation Length Tester	29
Storage Tank Farm on Site	750
Subtotal of above items	779
Contingency (30%)	234
Subtotal of above items with contingency	1,013
Overall Total with contingency	22,857

Braidwood Status and Schedule

- Engineering / R&D Proposal ($1M) submitted in Nov. 2004
  - Need this funding to complete the engineering for a proposal
    - Develop a “Design and Build” package for civil construction
    - Complete detector design at the bid package level
    - Complete and set up management plan and project oversight
    - Complete the development of the Gd-Scint and provide test batches for prototypes
- Baseline Cost Estimate:
  - Civil Costs: $34M + $8.5M (Cont.)
  - 4 Detectors and Veto Systems: $18M + $5M (Cont.)
- Schedule:
  - 2004: R&D proposal submission.
  - 2004: Bore hole project completed on Braidwood site.
  - 2005: First NuSAG review
  - 2006: Full proposal submission
  - 2007: Project approval; start construction
  - 2010: Start data collection

Experiment Setup and Rates

Component	Parameter	Value
Reactors	Power	3.59 GW
	Number	2
	Up Time	92%
Running Time		3 years
Near Detectors	Mass	65 tons
	Number	2
	Distance	270 m
	Shielding	450 mwe
	Events/Detector	3,800,000
Far Detectors	Mass	65 tons
	Number	2
	Distanace	1510 m
	Shielding	450 mwe
	Events/Detector	123,000
Detector Eff.		75%
Background Rates	^{9}Li	1045 evts/det.
	^{8}He	131 evts/det.
	Flat	785 evts/det.
	Exponential	212 evts/det.

Daya Bay Collaboration

Some 70 scientists from China, Russia, US

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RUSSIA
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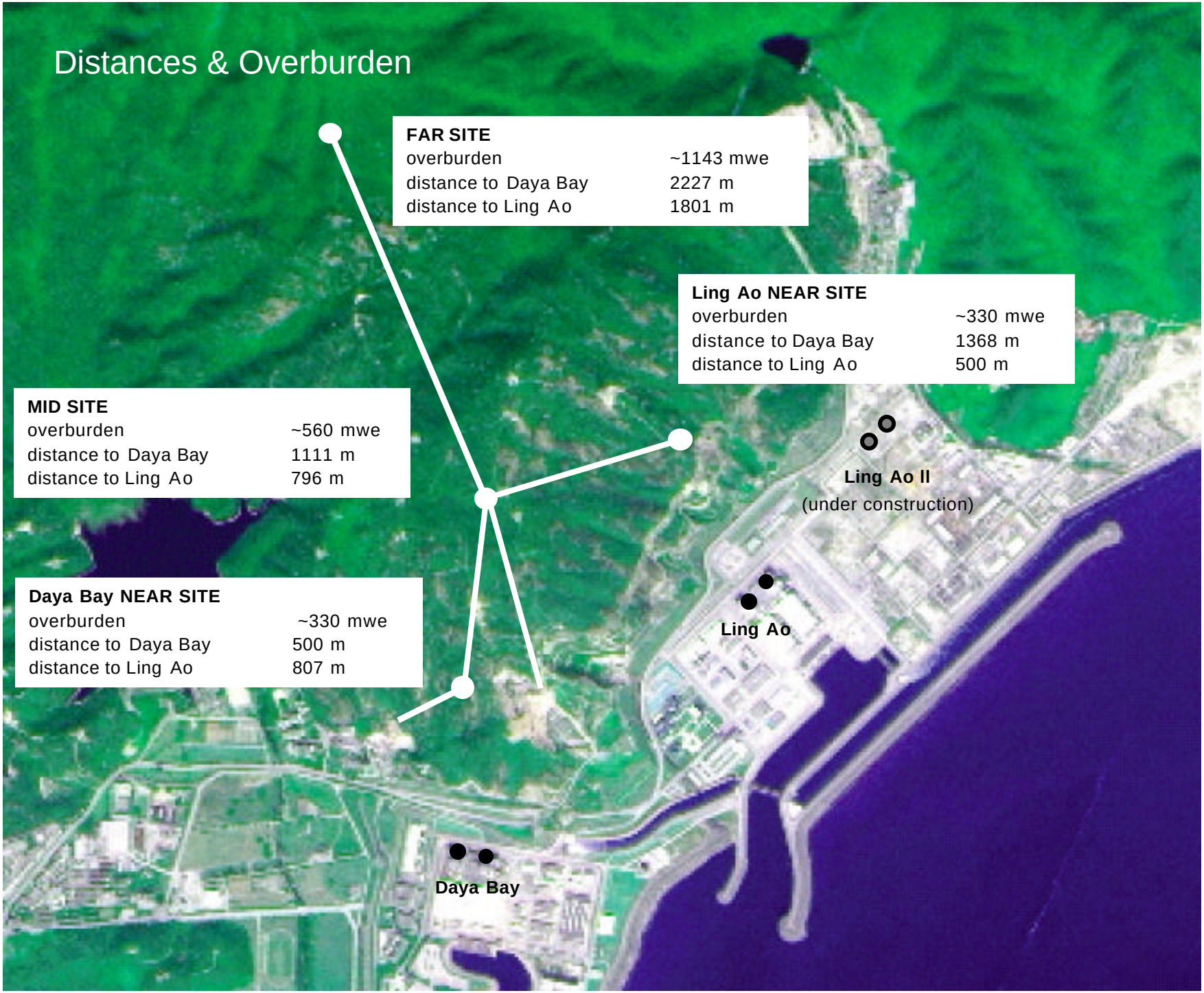
Daya Bay
Niudipu
Longhua
Buji
Henggang
Kuiyong
Dapeng
Yantian
Shenzhen
Sha Tau Kok
Shatoujiao
Tai Pang Wan
Tong O
Tung Wan
Pak Shek Au
Man Uk Pin
Fanling
Lai Tau Shek
Cheung Wo
22°
Tin San Wai
Ting Kok
Shuen Wan
Kau Lau Wan
Yung Shue Au
Tai Po
Wu Lei Kiu
XIAOSANMEN DAO
Lin Fa Tei
Wu Kwai Sha
HONG KONG SAR (CHINA)
Wong Yi Chau
Tsuen Wan
Sai Kung
Sha Tsiu
Pak A
Pik Uk
Fu Tau Pun Chau
Cheung Sha Wan
Kai Tak International Airport
Tau Kwu
Kowloon
Yau Tong
KENNEDY TOWN
HAPPY VALLEY
Victoria Peak 554 m (1818 ft)
Hong Kong
Mount Collinson
Stanley Mount
South China Sea
Fa Peng

Distances & Overburden



Detector parameters under study

Description	20T	40T	60T
S. Steel Outer Vessel Dia.(mm)		5000.	
S. Steel Vessel Thickness (mm)		6.	
S. Steel Vessel Length (mm)	5500.	9000.	13000.
S. Steel Tank Weight (T)(no ribs)	5.96	8.46	11.54
Acrylic Vessel Thickness (mm)		25.	
Target Vessel O. Radius (mm)		1519.	
Target Vessel O. Length (mm)	3638.	7138.	11138.
Target Mass w/o Vessel(T)	20.0	39.51	61.81
(density = 0.795)			
Target Vessel Mass (T)	1.72	2.89	4.32
(density = 1.4)			
Catcher Vessel O. Radius(mm)		1994.	
Catcher Vessel O. Length (mm)	4588.	8088.	12088.
Catcher Mass w/o Vessel (T)	22.81	46.1	52.0
(density =0.79) Catcher Vessel Mass (T)	2.89	4.42	6.17
(density =1.4) Buffer Weight w/o Vessel (T)	38.94	58.19	80.2
(density =0.78) Total Detector Weight (T)	92.3	150.1	216.0
Total PMT's, 15% Coverage	380	631	919

Another Possibility: Simultaneous near/mid/far

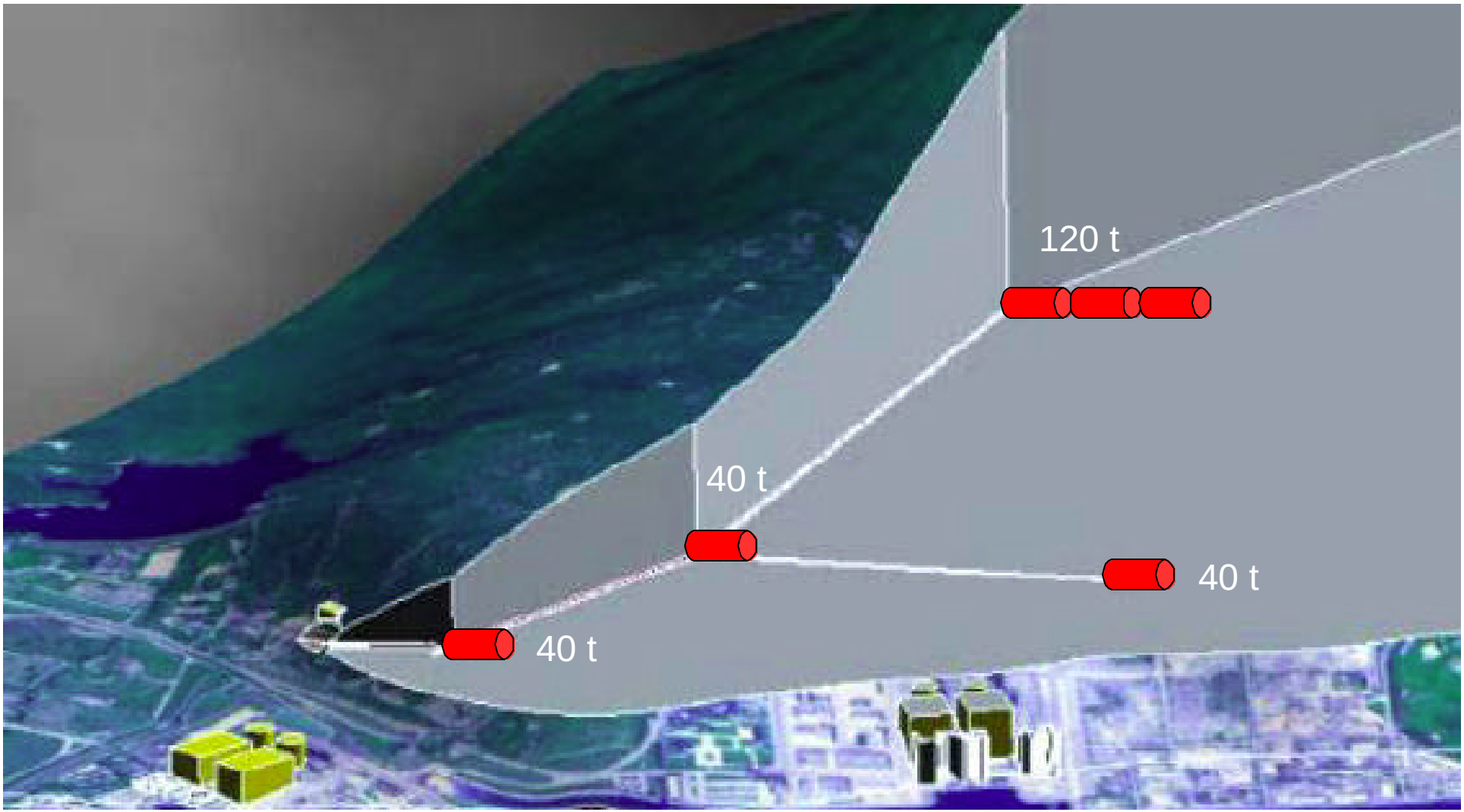


Illustration K. Chow

Cost

Diablo Canyon

Civil Construction $23,038,454.04

Total Estimated Cost $65M with contingency of 30% on civil construction and 50% on the detectors and remaining infrastructure (150 tons total).

Daya Bay

BINE estimate for civil construction US $8.5

IHEP total estimate for civil plus infrastructure US $12.5

Estimate for the equipment being developed

The Diablo cost without contingency was $25M

Organization

Collaboration now operating under a joint R&D agreement between LBNL and IHEP.