LA-UR-22-20431

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Title:	DARHT : Enduring Lessons from a Technical Project in a National Laboratory Context
Author(s):	Burns, Michael J Funk, David John
Intended for:	In support of Capstone Project for the Project Leadership Institute, a DOE Program
Issued:	2022-01-19

Los Alamos NATIONAL LABORATORY

DARHT : Enduring Lessons from a Technical Project in a National Laboratory Context

Michael J. Burns
DARHT CPM, 1994-2002, Los Alamos National Laboratory
and
David J. Funk, *Scorpius Project Director, Los Alamos National Laboratory*

January 28, 2002

DOE Project Leadership Institute
Stanford Center for Professional Development

REV 6 18JAN2022

U.S. DEPARTMENT OF ENERGY

PLI PROJECT LEADERSHIP INSTITUTE

Abstract

The Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility at Los Alamos National Laboratory (LANL) is the world's first flash x-ray facility able to take multiple high-resolution radiographs of the interior features of fast-moving dense objects during a single experiment. DARHT's radiography and complimentary diagnostics makes it an important diagnostic tool in support of the US Department of Energy's (DOE)/National Nuclear Security Administration (NNSA)'s stewardship of the US nuclear deterrent. The project to construct DARHT ran from 1988 through 2003. Initial Operating Capability along a single axis began in 1999. A technical issue delayed Critical Decision 4 for the full dual-axis capability until 2008. DARHT was characterized by several directed changes resulting from an environmental impact study, changes to the global security context resulting from the end of underground nuclear testing, and rapid evolution of applicable technology. Conventional building and lab-space construction were part of the project, but the project was dominated by Special Facility Equipment that, together with the mission to support the nuclear weapons program, required the project to be completed by national laboratories. Although the project pre-dated implementation of DOE Order 413.3, several important lessons for national laboratory projects remain applicable today and will be discussed here, including projects appropriate for the national laboratory environment, scope stability, risk acceptance and mitigation, communication, and collaboration. Finally, considerations for DOE contractor project managers are offered based upon the DARHT experience.

Disclaimer: The opinions, considerations, and selections of lessons learned presented here are due only to the author. These do not necessarily represent the positions, policies, principles, or practices of the US Government, the DOE, the NNSA, or any national laboratory.

Acknowledgements: Many thanks to David Funk, LANL ECSE Radiography and Integration Project Director, and Jonathan Morgan, LANL J-Division Leader, for their review and comments of this presentation and for the materials they provided.

Presenter biography

- 37 years in the DOE/NNSA complex
- Most recently Sandia Associate Laboratories Director for National Security (Division 5000), 2017 – 2021
- 30 years at Los Alamos national Laboratory
  - **DARHT Project Director 1994 – 2002**
  - J-Division (Integrated Weapons Experiments) Leader
  - Various management positions from Group Leader to Deputy Principal Associate Director
- Lawrence Livermore National Laboratory, 1984-1987, engineering Linear Induction Accelerators
- Special Assistant to President Bush and Senior Director on the Homeland Security Council staff
- Director of the Office of National Laboratories, US DHS, S&T Directorate
- International Atomic Energy Agency Iraq Nuclear Verification Office inspector

Purpose and Outline

- **Purpose:** To prepare for the 2022 PLI Capstone project, provide the PLI cohort an overview of the DARHT project, its principal challenges, and lessons learned from the project. This is <u>not</u> a DOE O 413.3B process presentation

- **Outline**
  1. What is DARHT?
  2. Project Evolution (Directed Changes and Impact)
  3. Transition to Operations (IOC, 2nd axis refurb, containment, investments)
  4. Important Lessons
     A. DOE/NNSA-sponsored Lessons Learned report
     B. Project execution should match the national laboratory context
     C. Scope stability is hard during periods of fast, fundamental change
     D. Management of threats and opportunities should consider risk, benefit, & mitigations
     E. Open communication is essential to manage risk and momentum
     F. Collaboration is essential for complex projects
  5. Things to consider motivated by the DARHT experience

We will pause after each section for questions and discussions

Recommended references included on many slides

BLUF
(Bottom Line Up Front)

- DARHT is an important tool to steward the US nuclear deterrent.
- The project was characterized by a significant number of directed changes and significant efforts were required during transition to operations to realize an effective facility. These led to criticism of the project, but DARHT has generated significant programmatic benefit, capability enhancements have been made, and more are being considered.
- The project began before DOE O 413.3 was implemented, but some of its formalism were put in place. It was found that project management processes alone, of whatever sort, are insufficient without substantive attention to important details in a high-risk/high pay-off environment
- Important lessons from DARHT merit consideration during the 2022 PLI capstone study, including:
  1. The national laboratory context for conduct of technical construction projects
  2. Scope instability requires exquisite leadership, communication, collaboration, and acumen
  3. Mgmt. of threats & opportunities should include consideration of benefit as well as risk and mitigation
  4. Communication (policy makers, project stakeholders, public, team, etc.)
  5. Collaboration

What is DARHT ?

DARHT Project Summary

- **Dual Axis Radiographic Hydrodynamics Test (DARHT)** Facility at Los Alamos
- **Purpose:**

Provide “enhanced high-resolution radiography capability for the purpose of performing hydrodynamic tests and dynamic experiments in support of the Department’s historical mission and near-term stewardship of the nuclear weapons stockpile”

Final Environmental Impact Statement, DOE/EIS-0228, August 1995

- **Scope (including directed changes):**
  - 21,000 ft^2 Radiographic Support Laboratory
  - 150-lb HE load Hydrotest Firing Site
  - 6,000 ft^2 Vessel Clean-out Facility
  - Special Facility Equipment including
    > 2 accelerator-based x-ray sources
    > hydrotest diagnostics and controls
    > 6-ft dia. high-explosive containment vessels
    > vessel clean-out process equipment

Aerial view of the DARHT Hydrotest Firing as of 2021

- **Duration:** 1988 – 2003
- **Initial Operating Capability (first tests)**
  - 1999 (one x-ray machine)
  - 2009 (add 4-pulse 2nd machine after refurbishment)
- Construction project Total Project Cost: $275,880K

DARHT Project Organization

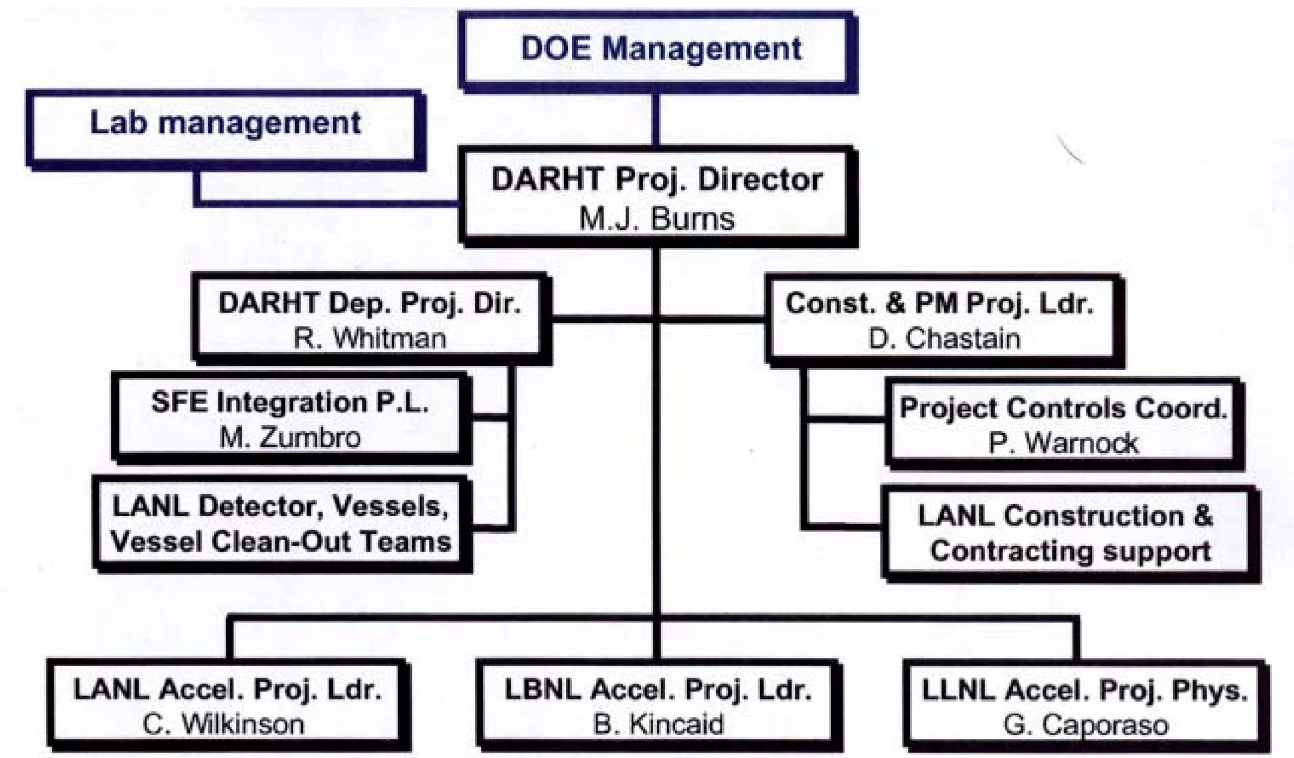


Figure from C. Wilkinson, "The DARHT Project", LIGO-G030500-00-M, Sept. 2003, https://dcc.ligo.org/public/0035/G030500/000/G030500-00.pdf

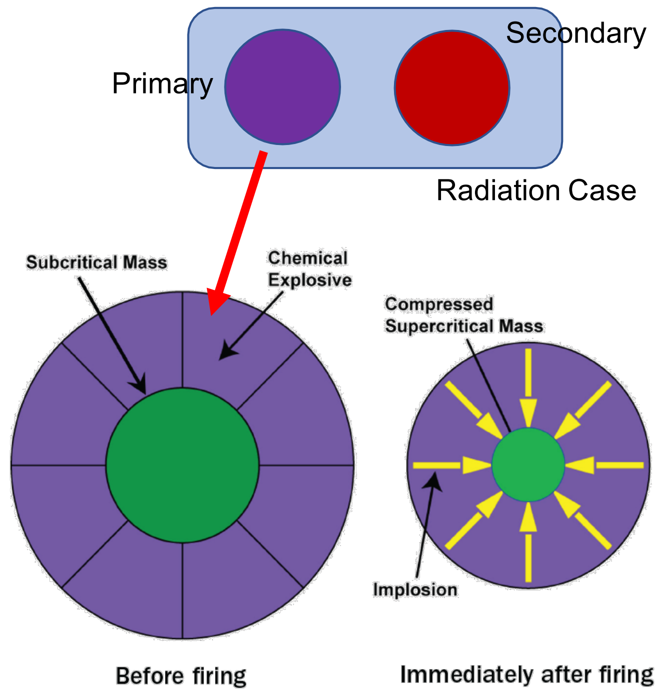
- This org. chart was during Phase 2 when the full LANL/LBNL/LLNL/MIT-LL collaboration was underway
  - MIT-LL was part of the Detector team and reported to the LANL Detector project leader (P.L.)
  - Otherwise, the leaders for collaborating labs reported to the DARHT Project Director
- "DOE Management" was led by Dr. Robert DeWitt (DOE Defense Programs, later NNSA/NA-10).
  - The equivalent of the Federal Project Director today

What is DARHT ?

Radiographic hydrodynamic testing is a key tool to ensure safe and effective nuclear weapons

Hydrodynamics Test – "A dynamic, integrated systems test of a mock-up nuclear package during which the high explosives are detonated, and the resulting motions and reactions of materials and components are observed and measured. The explosively generated high pressures and temperatures cause some of the materials to behave hydraulically (like a fluid)."

-Final Environmental Impact Statement, DOE/EIS-0228, August 1995

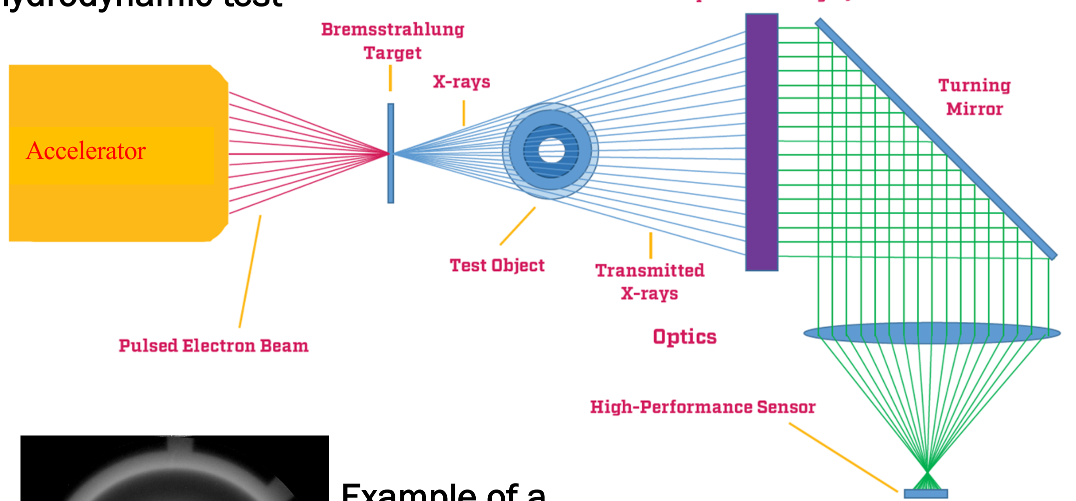


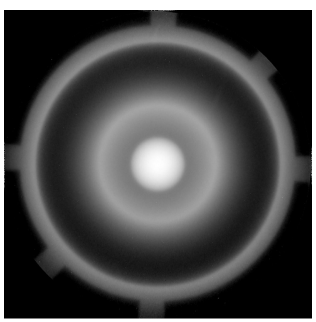
Text and figures from Crawford, Baraza, & Ekdahl, "SCORPIUS Update: Progress Towards a New, Multi-Pulse Radiographic System", ***2021 Pulsed Power Conf.,*** *Dec. 14, 2021*

What is DARHT ?

Modern radiographic hydrodynamic test systems use intense, short bursts of x-rays to image very dense, fast-moving features

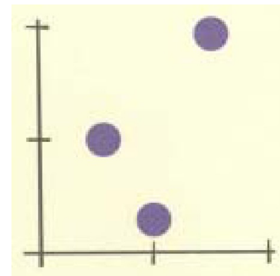
Schematic of a radiographic hydrodynamic test



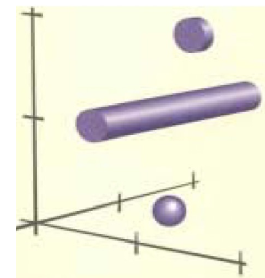


Example of a Radiographic Image

*Figures from Crawford, Baraza, & Ekdahl, "SCORPIUS Update: Progress Towards a New, Multi-Pulse Radiographic System", **2021 Pulsed Power Conf.**, Dec. 14, 2021*



Different objects in a single view (2D) appear identical



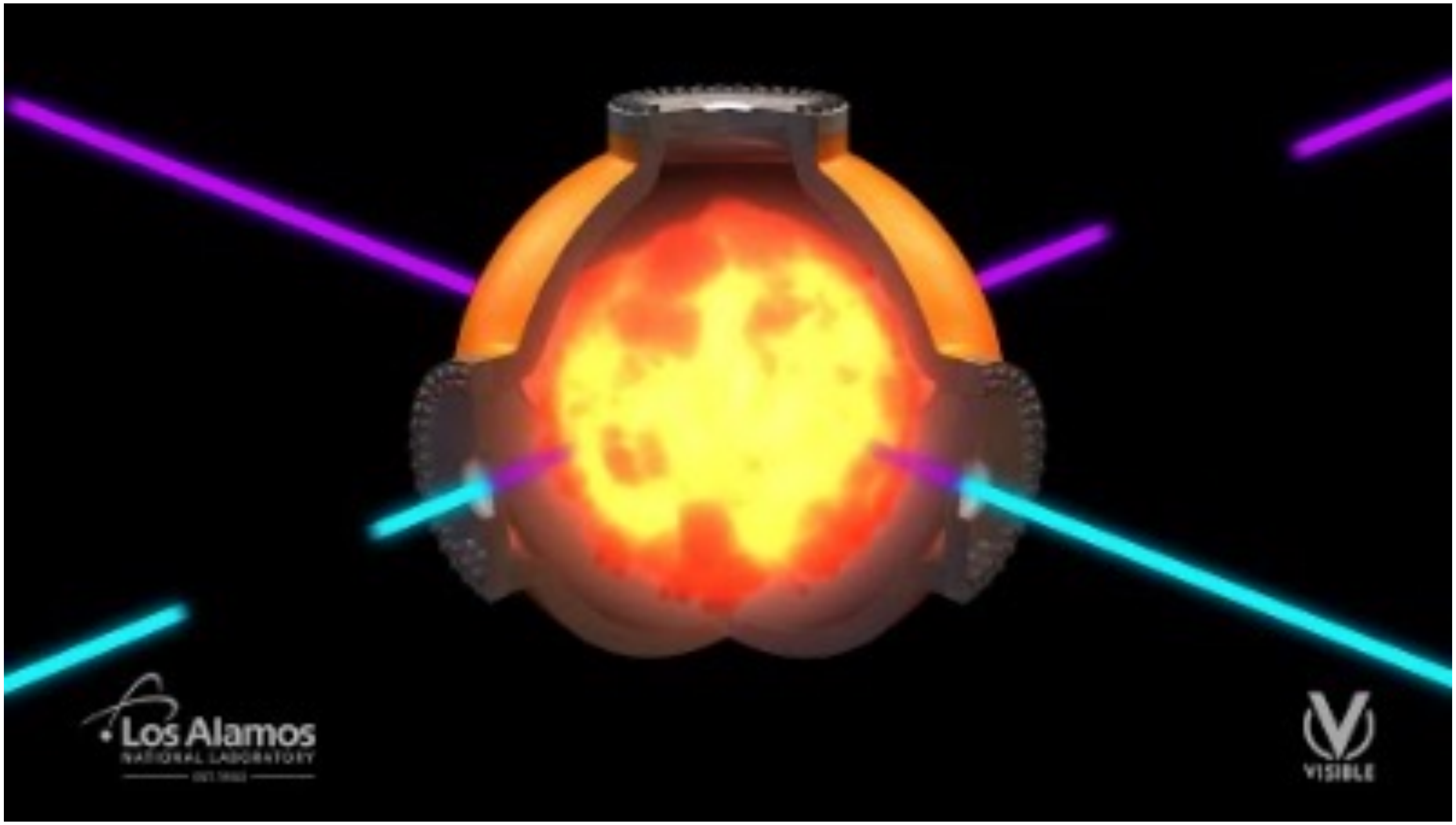
Two-views returning basic 3D info shows they are not

- 4 components of an experiment:
  1. Test Object and measurement task
  2. Test geometry
  3. X-ray source parameters
  4. Detector parameters
- Performance parameters for each component can be adjusted to optimize system performance

What is DARHT ?

An overall video description of DARHT

(https://www.youtube.com/watch?v=FOCJCsC8gl4&list=RDCMUCbWmiA_pHk9DE62BaSUFFRw 4min, 31 sec)



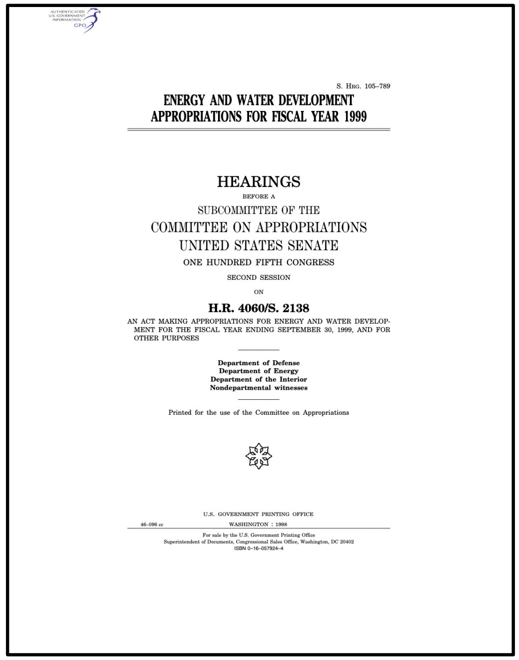
Project Evolution

The DARHT project began in 1988 and soon underwent several directed changes

- DARHT began as a $53.4M Total Estimated Cost (TEC) component of a complex-wide refurbishment project (88-D-106) with two 16-MeV Linear Induction Accelerators (LIAs)

- 88-D-106 scope:
  - Radiographic Support Lab
  - Hydrotest Firing Site
  - 2, 16-MeV accelerators

- Then a stand-alone project (97-D-102)



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S. Hrg. 105–789

ENERGY AND WATER DEVELOPMENT APPROPRIATIONS FOR FISCAL YEAR 1999

HEARINGS

BEFORE A

SUBCOMMITTEE OF THE

COMMITTEE ON APPROPRIATIONS

UNITED STATES SENATE

ONE HUNDRED FIFTH CONGRESS

SECOND SESSION

ON

H.R. 4060/S. 2138

AN ACT MAKING APPROPRIATIONS FOR ENERGY AND WATER DEVELOPMENT FOR THE FISCAL YEAR ENDING SEPTEMBER 30, 1999, AND FOR OTHER PURPOSES

Department of Defense
Department of Energy
Department of the Interior
Nondepartmental witnesses

Printed for the use of the Committee on Appropriations

U.S. GOVERNMENT PRINTING OFFICE

46–096 cc WASHINGTON : 1998

For sale by the U.S. Government Printing Office
Superintendent of Documents, Congressional Sales Office, Washington, DC 20402
ISBN 0–16–057924–4

See testimonty above for history
https://www.govinfo.gov/content/pkg/CHRG-105shrg4376096/pdf/CHRG-105shrg46096.pdf, pp 34-37

"The DARHT project has changed significantly over the past ten years due to many factors including the increased scientific demands placed upon hydrodynamic testing following the cessation of underground nuclear testing, the emergence of new radiographic technology, and an increased sensitivity to environmental impacts"
- Asst. Sec. V.H. Reis

Project Evolution

The Special Facility Equipment (SFE) Work Breakdown Structure (WBS) components for Phase 1 (1st axis) of DARHT

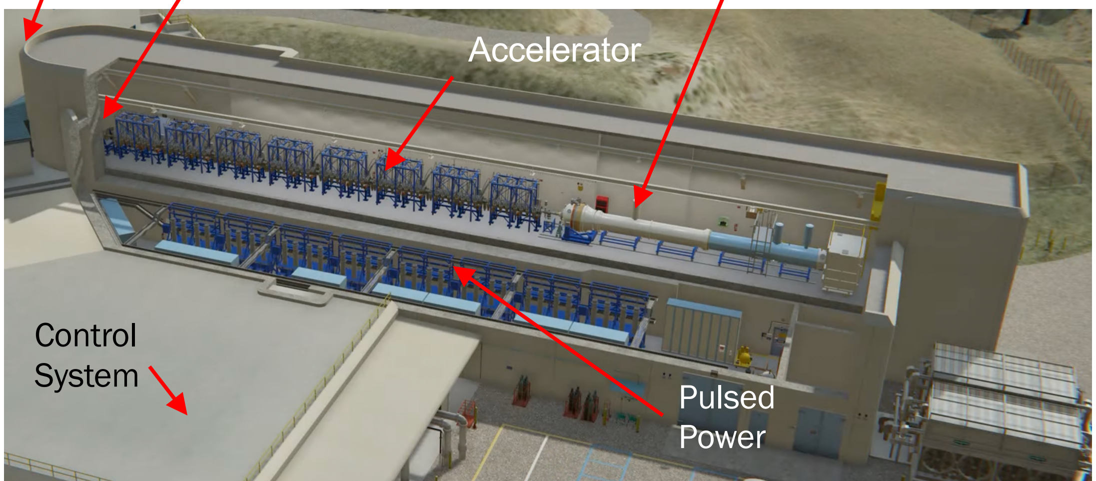
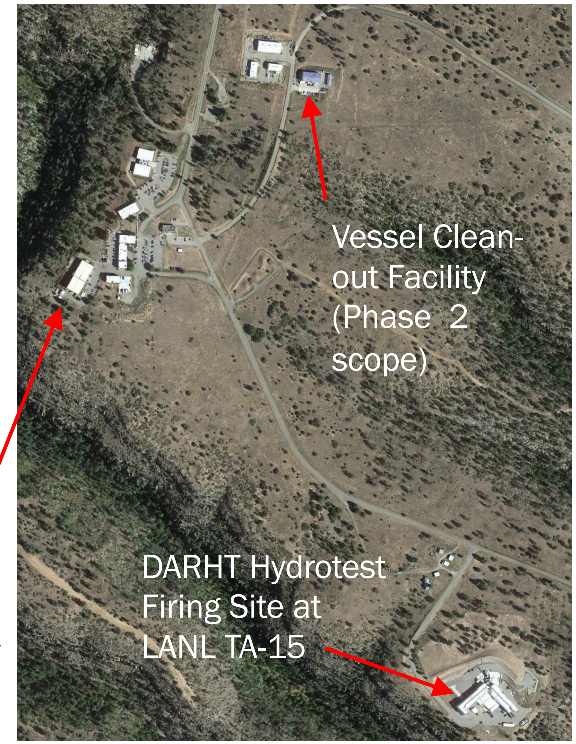


Figure from
https://www.youtube.com/watch?v=FOCJCsC8gI4&list=RDCMUCbWmiA_pHk9DE62BaSUFFRw

Photo from https://earth.google.com/web/search/Los+Alamos,+NM/@35.83885143,-106.30396687,2192.67022191a,2645.4338959d,35y,0h,0t,0r/data=CigiJgokCVma27F77T9AEZArfF6LWj9AGT3XkjyMYFpAIRNwYZOEC1pA



Radiographic Support Laboratory (Integrated Test Stand & DARHT assembly).

"Conventional Facilities" were also part of the project's scope

Project Evolution

Directed changes: 1. Technology Demonstration and project phasing (Phase 1 = 1st axis, Phase 2 = 2nd axis)

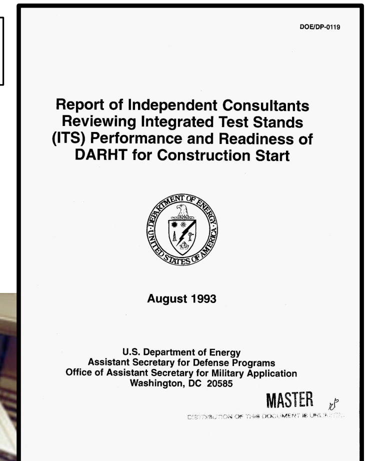
"In 1990, the project was suspended until additional testing could be performed to demonstrate conclusively that all technical uncertainties with the design were resolved"

- Asst. Sec. V.H. Reis

Project Changes:
- Extend schedule (no funding FY92 & 93)
- Cost changed to $81.4M (design changes & testing)
- Postpone tech decision for Axis 2

- "DARHT Feasibility Assessment Independent Consultants DFAIC Panel", Sandia National Laboratories, Sandia Report SAND92-2060/UC700, Sept. 1992
- "Hydrotest Program Assessment", Pacific-Sierra Research Corp., PSR Report 2320, Oct. 1992
- "Report of Independent Consultants Reviewing Integrated Test Stands (ITS) Performance and Readiness of DARHT for Construction Start", DOE/DP-0119, Aug. 1993: **"… the project is ready for construction to resume".**

https://digital.library.unt.edu/ark:/67531/metadc1277895/m2/1/high_res_d/10102470.pdf


DOE/DP-0119

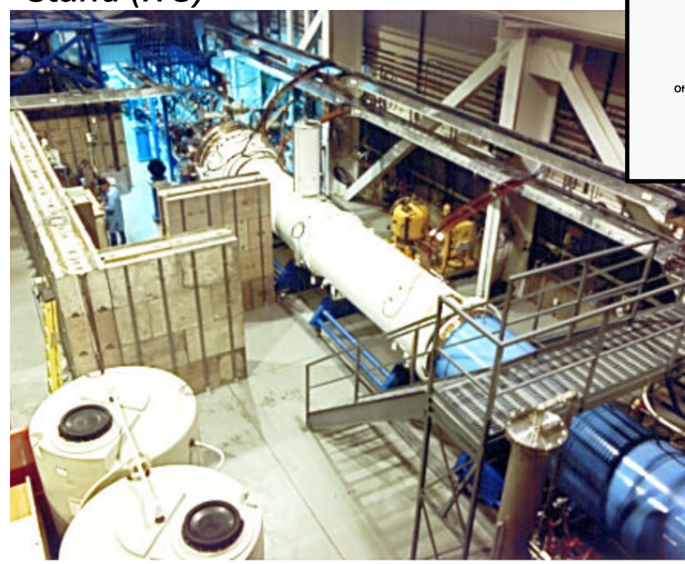
Report of Independent Consultants Reviewing Integrated Test Stands (ITS) Performance and Readiness of DARHT for Construction Start

August 1993

U.S. Department of Energy
Assistant Secretary for Defense Programs
Office of Assistant Secretary for Military Application
Washington, DC 20585

MASTER

DARHT Phase 1 Integrated Test Stand (ITS)



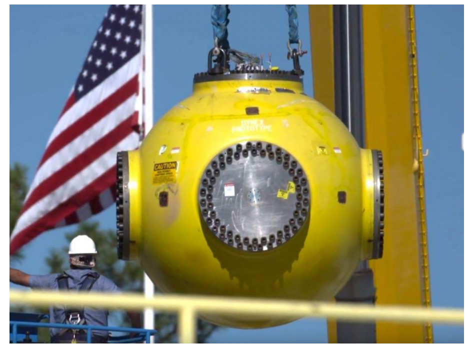
MJ Burns, et al, "Technology Demonstration for the DARHT Linear Induction Accelerators", *Proceedings of the 9th Intl. Conf. on High-Power Part. Beams*, Washington DC, May 1992

National Environmental Policy Act (NEPA) implementation at DARHT

Project Evolution

- DOE conducted a "series of environmental reviews" for the project between 1982 and 1989 and concluded that no significant environmental impact should result.
- Oct. 1994, three citizen groups asked DOE for an Environmental Impact Statement (EIS) and, in Nov. 1994, sued in US District Court to halt the project.
- Also Nov. 1994, DOE *Federal Register* notice that an (EIS) would be prepared.
- Jan. 1995, Injunction halted project and further planning
- Aug. 1995, Final EIS published. Oct. 1995, Record of Decision (ROD).
- April 1996, EIS "adequate", injunction lifted
- ROD directs implementation of "**Phased Containment**" – hydrotests done inside steel vessels.
- ROD also states that DOE might incorporate "**modified or improved technology" for second axis.**

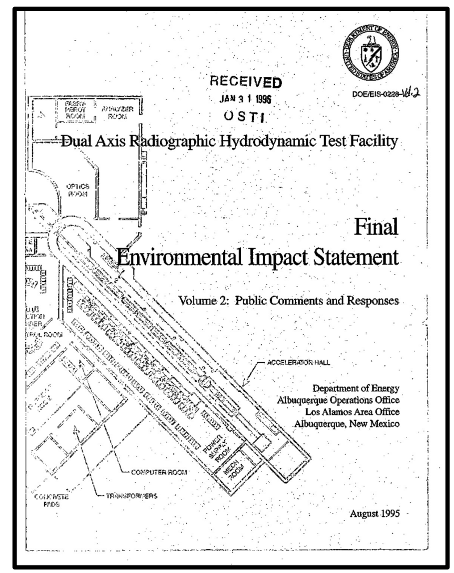
Containment Vessel



https://www.energy.gov/nepa/doeeis-0228-dual-axis-radiographic-hydrodynamic-test-facility-los-alamos-national-laboratory

See also, Webb, MD, "DARHT – an Adequate EIS: A NEPA Case Study", **Proceedings of the 22nd annual conference of the National Association of Environmental Professionals**; Boulder, CO, May 1997

DOE Preferred Alternative in Final EIS differed from Draft EIS in response to public concern and comments



RECEIVED
JAN 3 1 1996
OSTI

DOE/EIS-0228-Vol.2

Dual Axis Radiographic Hydrodynamic Test Facility

Final
Environmental Impact Statement

Volume 2: Public Comments and Responses

Department of Energy
Albuquerque Operations Office
Los Alamos Area Office
Albuquerque, New Mexico

August 1995

Project Evolution

Directed Changes: 2. Phased Containment

"… the project was proceeding satisfactorily until a Federal Court injunction was issued in January 1995. This injunction was issued as a result of failure to prepare an environmental impact statement (EIS) for the DARHT project"

- Asst. Sec. V.H. Reis

Project Changes:
- Extend schedule ~20 months
- Containment vessels (1-ea for Axis 1 and 2 plus Clean-Out Facility)
- 20 MeV accelerators
- Cost increase to $105.7M for Phase 1 (Axis 1)
- FY98 CPDS TEC for 2nd axis ($186.7M) estimated based on copy of 1st axis – but new tech. being pursued

Examples of Open-Air explosives testing that can spread materials across the firing points of radiographic hydrotesting facilities

Project Evolution

Directed changes: 3. Multi-pulse 2nd axis

"In October 1996, the Department requested Los Alamos National Laboratory (LANL) to determine the best technology for the second x-ray machine. ...the Department approved a multi-pulse x-ray machine..."
- Asst. Sec. V.H. Reis

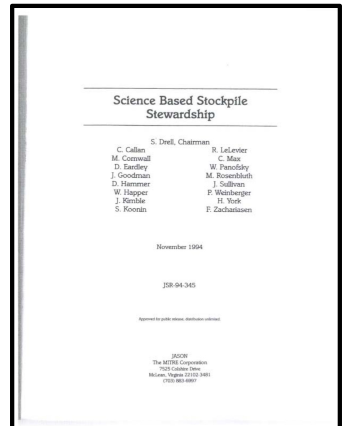
- "Technology Option Study" considered options. SNL, LBNL, LLNL invited to contribute.
- MIT/LL and LANL made a 4-image CCD chip
- LANL, LLNL, MIT/LL and LBNL to execute 2nd axis.

The FY 1994 National Defense Authorization Act directs DOE to establish a program to steward U.S. nuclear weapons in the absence of underground nuclear testing

"National Defense Authorization Act for Fiscal Year 1994", P.L. 103-160, Nov. 1993

Drell et al, "Science Based Stockpile Stewardship", **JSR-94-345**, The Mitre Corp., Nov. 1994

Reis, et al, "The Big Science of Stockpile Stewardship", AIP Conf. Proceedings, **1898**, 030003 (2017)



Science Based Stockpile Stewardship

S. Drell, Chairman

C. Callan	R. LeLevier
M. Cornwall	C. Max
D. Eardley	W. Panofsky
J. Goodman	M. Rosenbluth
D. Hammer	J. Sullivan
W. Happer	P. Weinberger
J. Kimble	H. York
S. Koonin	F. Zachariasen

November 1994

JSR-94-345

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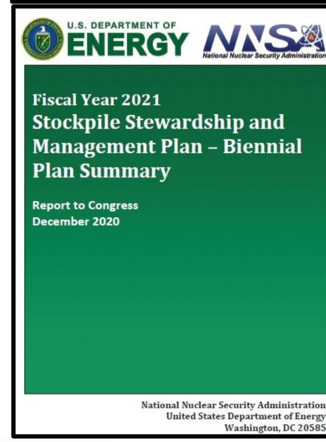


U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

Fiscal Year 2021 Stockpile Stewardship and Management Plan – Biennial Plan Summary

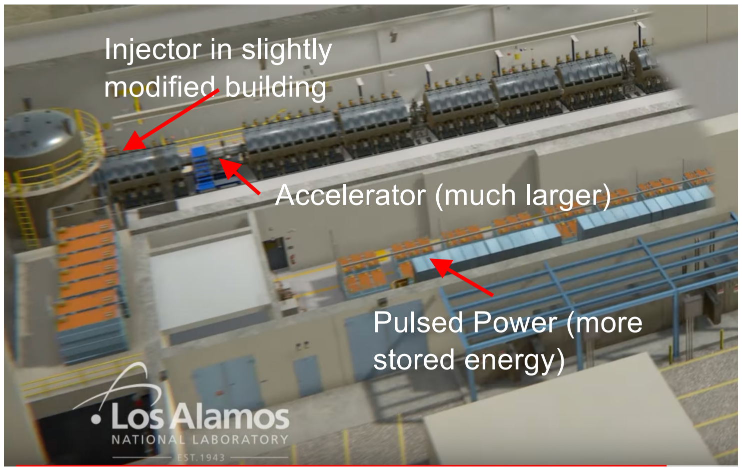
Report to Congress
December 2020

National Nuclear Security Administration
United States Department of Energy
Washington, DC 20585

Project Changes:
- Long-pulse LIA, Kicker, multi-pulse x-ray conversion target, 4-pulse gamma ray camera
- $259.7M TEC for both axes
- LBNL/LLNL/LANL/MIT-LL collaboration
- 2003 project completion during 1st axis operation. Full commissioning by ops program

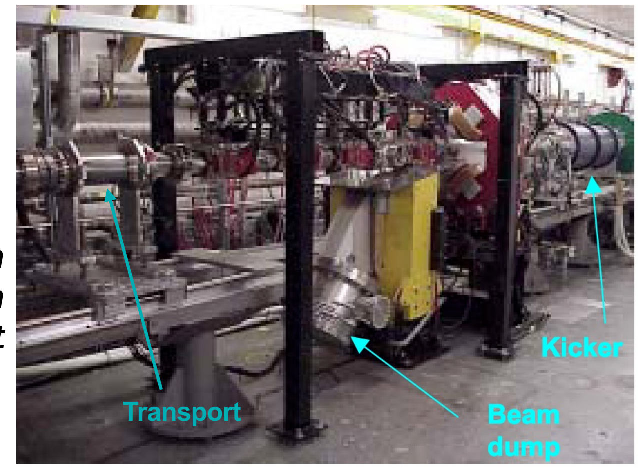
Phase 2 SFE WBS components required significant technical advances

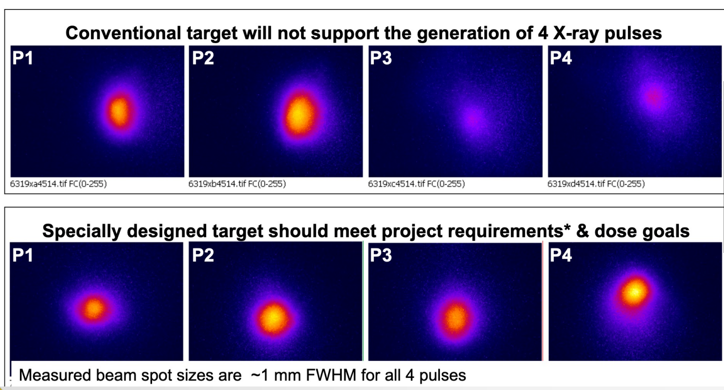
Project Evolution



Long-pulse LIA components

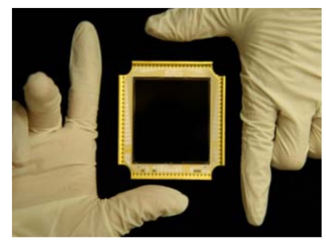
High-current Electron Beam Kicker, Beam Dump, and Transport

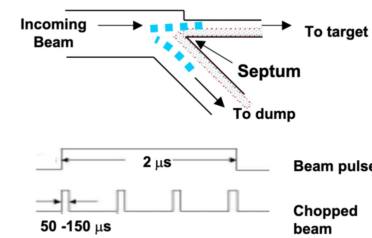




4-pulse x-ray target: images of x-ray spot

Scarpetti, “Status of the DARHT 2nd Axis Accelerator at Los Alamos National Laboratory”, *22nd Particle Accelerator Conference*, June 2007





4-pulse @ 2-MHz MIT-LL/LANL camera

Mendez et al, “A Multi-Frame, Megahertz CCD Imager”, *IEEE Transactions on Nuclear Science*, **56(3)**, June 2009

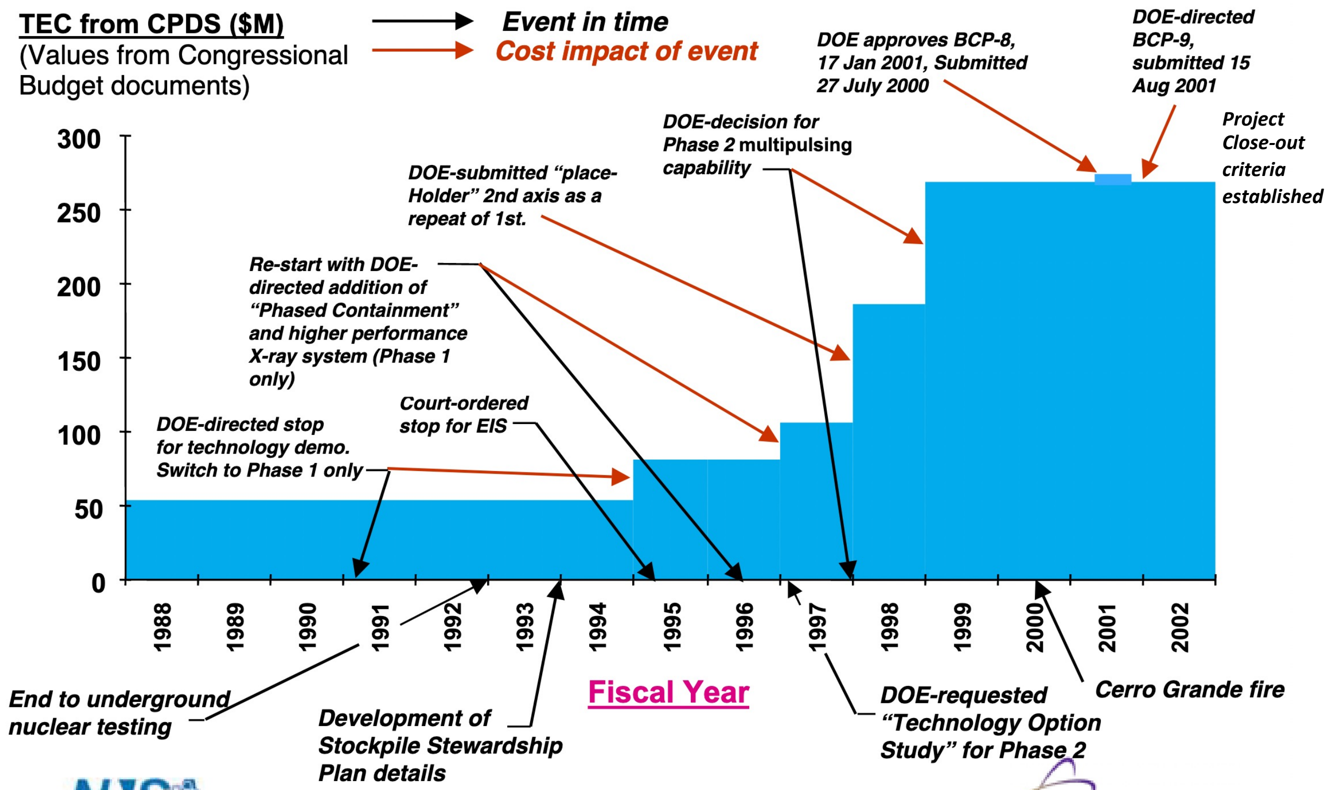
Harsh et al, Shot H3837: DARHT’s First Dual-Axis Explosive Experiment”, *AIP Conference Proceedings* **1426**, 261(2012)

Project TEC and schedule evolution as a result of directed changes

Project Evolution

"The DARHT project greatly increases the Department's confidence in our near-term ability to provide the scientific data necessary to support a SBSS program. "
- Asst. Sec. V.H. Reis

Figures from C. Wilkinson, "The DARHT Project", LIGO-G030500-00-M, Sept. 2003, https://dcc.ligo.org/public/0035/G030500/000/G030500-00.pdf



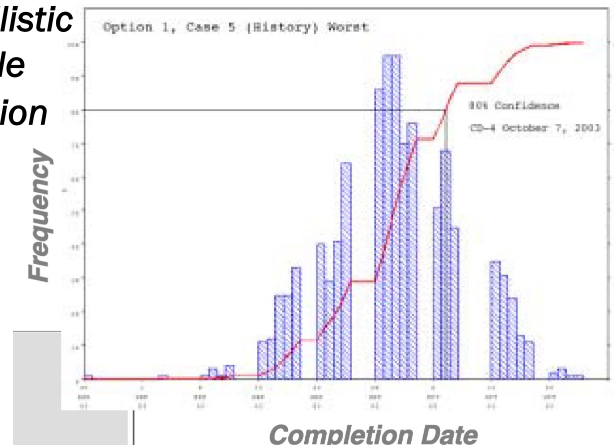
Project management processes evolved as DARHT progressed, but useful implementation was immature

Project Evolution

- ***Earned Value tracking and variance analysis*** – done monthly to establish performance to date and analyze deviations with respect to baseline plane. Earned value based on detailed, resource-loaded updates
- ***Trending Program*** – monthly process to identify, characterize, assess, and prioritize threats to the project and develop mitigation plans.
- ***Current Working Estimate*** – monthly bottoms-up update of project schedule developed from earned value calculations
- ***Contingency Analysis*** – monthly update of possible future budget adjustments, contingency on remaining work, EAC, and identification of possible budget cuts that may be needed to remain within TEC
- ***Project Reviews*** – Two-tiered review process to assess technical and overall project progress and status. Monthly DOE review. Weekly Laboratory Director's report

Project Organization dissolved March 2003 in order to transition to operations

Probabilistic Schedule Simulation



Introducing schedule confidence windows instead of "hard dates" challenged sponsor comms.

Project Close-out (w/o 2nd axis refurbishment)

WBS	Name	Baseline Estimate ($K)
1.	DARHT (TPC)	$275,880
1.1	Phase 1 OPC	$8,764
1.2	Phase 1 TEC	$105,775
1.3	Phase 2 OPC	$1,343
1.4	Phase 2 TEC	$159,998

Figure and table from C. Wilkinson, "The DARHT Project", LIGO-G030500-00-M, Sept. 2003, https://dcc.ligo.org/public/0035/G030500/000/G030500-00.pdf

Transition to Operations began in 1999 with single-axis Operational Capability (IOC)

1st Axis 1 explosive test Nov. 8, 1999

https://web.archive.org/web/20081121011433/http://www.lanl.gov/news/releases/archive/99-167.shtml

Aqueous Foam Shot

Explosive shot enclosed in a silo full of special aqueous foam to limit spread of material. A new type of "open air" shot to limit the spread of material while containment vessels and processes were developed.

DARHT Construction Project Continued During 1st axis operations

Coordination of construction & ops schedules

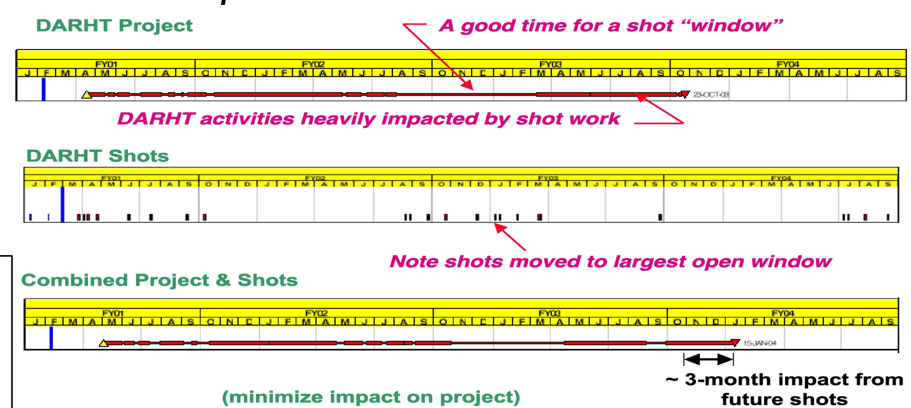


Figure from C. Wilkinson, "The DARHT Project", LIGO-G030500-00-M, Sept. 2003, https://dcc.ligo.org/public/0035/G030500/000/G030500-00.pdf

Transition to Operations

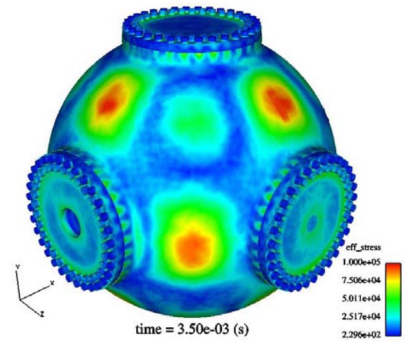
In accordance with EIS ROD, full containment was developed and phased-in over ~ 9-years

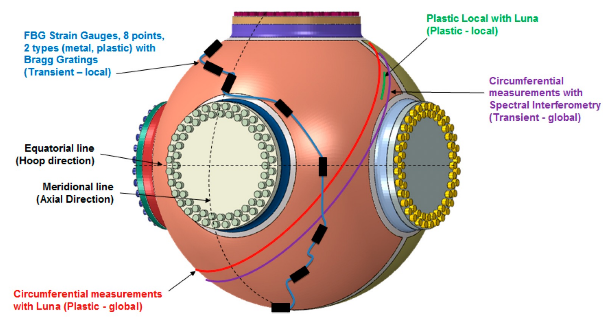
- Required development of dual-axis, 6-ft dia. re-useable explosive containment vessels
  - Two purchased during project
  - Others acquired with operating funds as use expanded
  - Vessel analysis tools and techniques
- Vessel clean-out facility built
- Vessel use processes developed
  - Experiment mounting
  - Vessel clean-out
  - Vessel inspection
    - End of life criteria established
    - Vessel diagnostics and processes
  - Vessel refurbishment processes developed
    - 10 shot life per vessel
- Publication of annual Mitigation Action Plan Report begun

Vessel stress calculation

Rodriquez et al, "Design Considerations for Blast Loads in Pressure Vessels", *19th Intl. Conf. on Structural Mechanics in Reactor Technology,* 2007

Vessel operations





Vessel Diagnostics

Gilbertson et al, "High Speed, Localized Multi-Point Strain Measurements on a Containment Vessel at 1.7MHz Using Swept-Wavelength Laser-Interrogated Fiber Bragg Gratings", *Sensors* **2020**, 20, 5935, Oct. 2020

2nd axis refurbishment was required after the project due to high-voltage breakdown – a major confidence impact

Transition to Operations

- Construction project Baseline Change Proposal (BCP)-9 closed-out project in March 2003 after completion of accelerator, with commissioning to occur under the operating program
- During subsequent 2nd axis operations **high-voltage breakdown observed in several LIA cells** by July 2003
  - **Quality Control error**: DARHT-II cells originally fitted with voltage monitors that were later found to be non-linear, resulting in the cells being tested at ~18% below nominal performance levels
- **DARHT Recovery and Commissioning Project** prelim project execution plan, March 2004. CD-0 approved Dec. 2004. Induction cells modified and re-installed while 1st axis continued operations.
  - See Scarpetti et al, "Status of DARHT 2nd Axis at Los Alamos National Laboratory", *2005 IEEE Pulsed Power Conf.,* June 2005
  - **Estimated $90M refurbishment** (Scarpetti et al, "Status of the DARHT 2nd Axis Accelerator at Los Alamos National Laboratory", *22nd Particle Accelerator Conference*, June 2007, slide 7) required until Dec. 2008 to remove and refurbish LIA cells and finish commissioning
  - Modified LIA cells exceeded performance requirements. (See Nielsen et al, "Upgrades to the DARHT Second Axis Induction Cells", *2005 IEEE Pulsed Power Conf.,* June 2005)
- July 2004 LANL safety and security work suspension and restart affected progress for 9 months or more

Cell removal at DARHT

Cells staged in TA 35-125

Cell disassembly and cleaning

FY2006 Energy & Water Approps. conference directed JASON review conducted June 2006

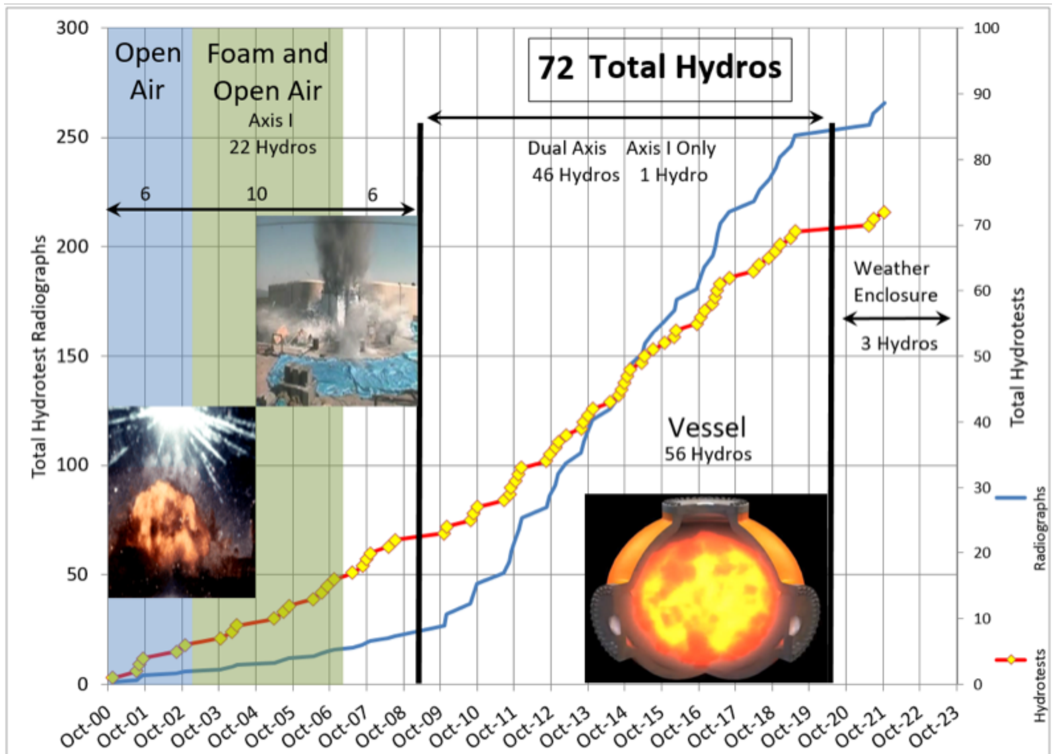
"The rebuilding and testing program give high confidence that the problems associated with the induction cells are solved."

https://irp.fas.org/agency/dod/jason/dahrt.pdf

Transition to Operations

Dual-axis, multi-pulse IOC achieved Nov. 2009

The rate of data generation greatly increased with dual-axis IOC to address NNSA program needs



DARHT TPC:	$275,880M
2nd axis Refurbishment	$ 90,000M
Weather Enclosure:	$ 13,200M
TOTAL:	**$379,080M**

DARHT Recovery and Commissioning Project Critical Decision-4 in December 2008 supported by the Advanced Radiography Program

The DARHT firing point has been enclosed to permit more efficient year-round operations

Transition to Operations

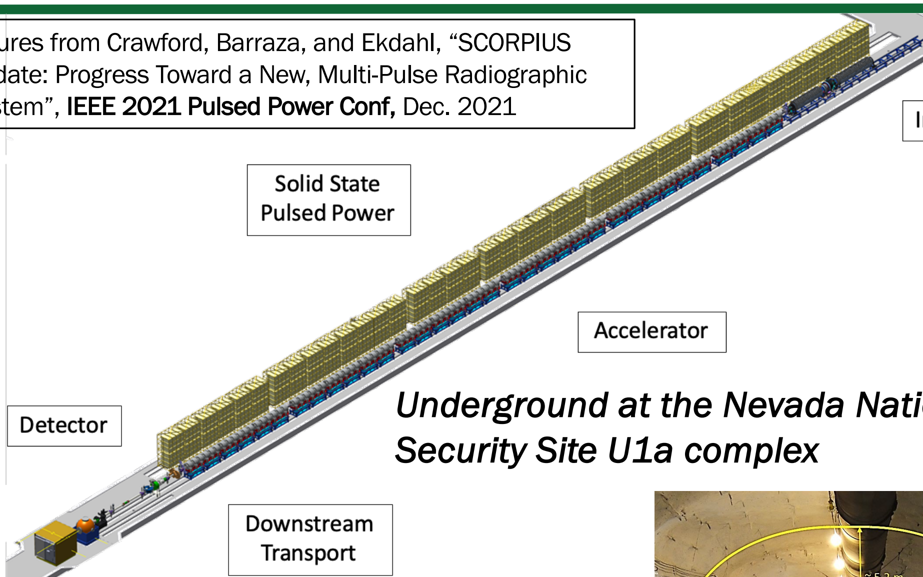
- $13.2M DARHT Weather Enclosure Project, substantially complete June 2020, is expected to increase DARHT productivity 40%
  - See https://www.energy.gov/nnsa/articles/nnsa-completes-darht-weather-enclosure

Future investments to add more pulses and lines of sight, and to refurbish facility systems are under study.

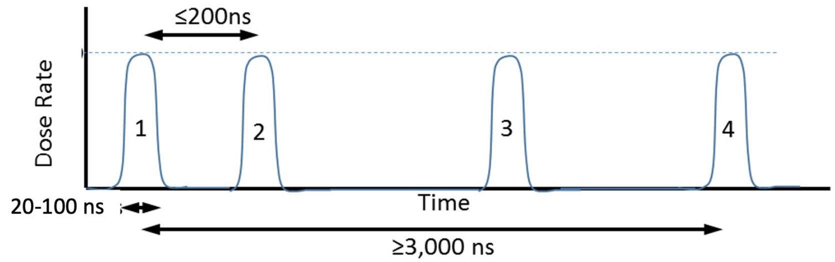
DARHT motivated the nation's next hydrotest machine: Advanced Sources and Detectors Program "SCORPIUS"

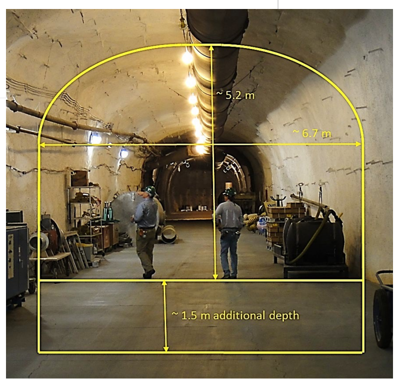
Transition to Operations

Figures from Crawford, Barraza, and Ekdahl, "SCORPIUS Update: Progress Toward a New, Multi-Pulse Radiographic System", **IEEE 2021 Pulsed Power Conf,** Dec. 2021



Underground at the Nevada National Security Site U1a complex





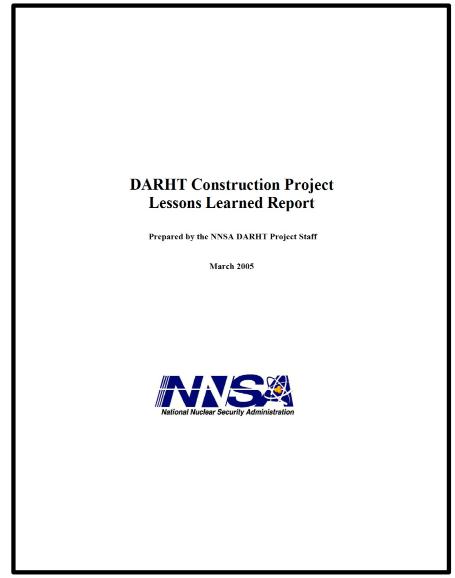
- 4 (or more) "DARHT-quality" single-axis radiographs in 3-msec
- Project originally described in 2017. Significant changes in scope since featuring full solid-state pulsed power with fully tunable waveforms. Final Design anticipated in early 2022
- CD-0 in 2014, CD-1 in 2019, anticipate CD-2/3 in 2022
- $500 - $1100M estimated at CD-1

NNSA issued a DARHT Construction Project Lessons Learned report, approved March 2005

Lessons

NNSA chaired an independent review of DARHT in December 2004 that reported the following most significant factors contributing to “management failures” :

1. Failure of DOE Defense Programs to adequately manage the Critical Decision Process, including establishing completion criteria.
2. Failure of laboratory management to treat the project as a laboratory priority
3. Inadequate project contingency
4. Poor design practices, QA/QC practices, high-voltage and cleanliness practices
5. NNSA and laboratory review processes not designed to identify and address problems
6. Failure to adhere to established NEPA requirements
7. Failure to establish and follow component design review and testing plans


DARHT Construction Project
Lessons Learned Report

Prepared by the NNSA DARHT Project Staff

March 2005

NNSA
National Nuclear Security Administration

NNSA DARHT Project Staff, “DARHT Construction Project Lessons Learned Report”, NNSA, March 2005

Projects should match the Federally Funded Research & Development Center (FFRDC) context of a national laboratory

Lessons

National Lab context can be characterized by FFRDC definition (FAR 35.017)

- meets some special **long-term R&D need** which cannot be met as effectively by existing sponsor or contractor resources
- enables private-sector resources to accomplish tasks **integral to the mission** of the sponsor
- FFRDC has beyond normal access to USG data, equip, property
- FFRDC has **special relationship** with USG, operates **independently** and **objectively** in the **public interest**, **free from COI** (Conflict of Interest), with **full disclosure**
- **Does not compete** with private sector
- **Long-term FFRDC/sponsor strategic relationship** for FFRDC continuity, recruiting, expertise, mission knowledge, quick response

National Lab governance evolved during & after DARHT

- see "Federally Funded Research and Development Centers (FFRDCs): Background and Issues for Congress", Congressional Research Service R44629, April 2020
- 10.5% of FY2019 federal R&D obligations by FFRDC ($14.9B). 57% of FFRDC spending by DOE FFRDCs
- Questions include effectiveness of federal oversight, FFRDC/private sector competition, FFRDC "mission creep", "noncompetitive" FFRDC contracts, adequacy of FFRDC infrastructure
- GAO designated DOE contract management "high-risk"
- DOE O413.3B policy, order, and manuals state objective is project performance at original baseline, independent AOA, Tech Readiness Level ≥ 7 @ CD-2

The DARHT project in a National Lab context

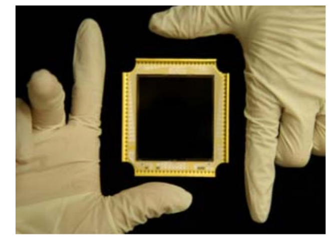
- Long-term R&D need (evolve radiographic hydrotesting after UGT), integral to DOE/NNSA mission (stockpile stewardship), did not compete with private sector (technology not commercialized), required mission knowledge, was "quick response" (DARHT was built while Science Based Stockpile Stewardship was being defined)
- Not executed according to current orders. Many changes driven by external factors and project performance. Many high technical risks with one realized. Cost "reasonable" compared to next machine. Program benefit & continued investment

Lessons

Scope instability driven by fast, fundamental change requires exquisite leadership, comms, collaboration, and acumen

- DOE/NNSA policy maker directed changes during the project because of:
    1. Increased scientific demands following end of UGT;
    2. Emergence of new radiographic technology;
    3. Increased sensitivity to environmental impacts
- Government risk tolerance was high
    - Stockpile Stewardship was being defined during this time. NNSA understanding of need influenced by design labs.
    - Level of 2^{nd} axis risk not widely understood beyond the project
    - Of all the technical risks, it was a straightforward electro-static design error that was not caught due to QA/QC weakness that led to the need for 2^{nd} axis refurbishment
- Would technical advances by the project have occurred without the project?
    - When should a leader support risk-taking vs. counseling caution ?
    - Projects vs. technical development programs are a government policy decision
- Several project management processes, especially contingency calculations, were superficial. "Process for Process sake" rather than fostering insight and action
    - Insightful project management processes can mitigate project risk

Final Underground Nuclear Test, "Divider", Sept. 1992



Lessons

Management of threats & opportunities should include consideration of benefit as well as risk and mitigation

Technical Risks

FY2006 Energy & Water Approps conference-directed JASON review concluded the following risks remained as of 2006:

1. High-voltage breakdown (realized/addressed)
2. Restricted space in the building
3. 2nd axis injector (cathode/insulator stalk)
4. E-beam stability & transport limit on spot size
5. Ions from Kicker dump affecting beam
6. Multi-pulse target (ions & target survival)
7. ”Inadequacies” in the infrastructure required for hydrotesting
8. Developing the hydrotest program

Other Risks include:

1. Cost and schedule increase (realized)
2. Project (2nd axis) during operations (1st axis)
3. Replacement/maintenance of one-of-a-kind equipment

Strategic Benefits

1. 9-year multi-pulse head start

Table 3. Nominal parameters of linear induction accelerators built for flash radiography, listed in order of their commissioning dates. Final, upgraded parameters are listed where applicable; blanks indicate that the data were unpublished at press time.

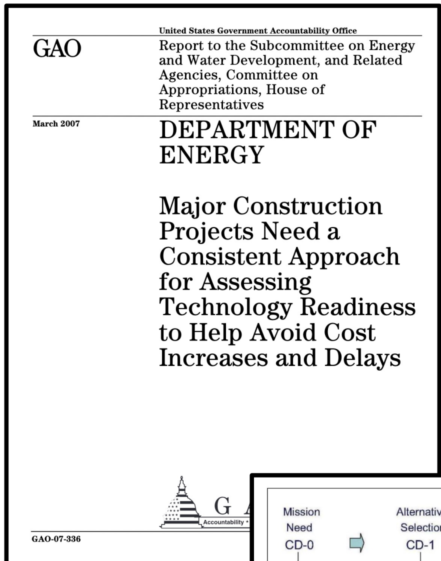
Accelerator	Laboratory	Year	Energy (MeV)	Current (kA)	Number of pulses	Pulse width (ns)	Spot size FWHM* (mm)	Dose (rad@1m)
FXR	LLNL (USA)	1983	18	3	1	65	2.2	450
LIAXFU	IFP (PRC)	1992	12	2.7	1	60	4	
DARHT Axis-I	LANL (USA)	1999	19	1.8	1	60	0.7	570
AIRIX	PEM (FR)	1999	19	2	1	60	1.6	350
DARHT Axis-II	LANL (USA)	2003	17	1.7	4	20–90	< 1	80–360
Dragon-I	IFP (PRC)	2003	19	2.5	1	70	~1	
Dragon-II	IFP (PRC)	2012	20	2.5	3	60		

Peach and Ekdahl, “Particle Beam Radiography”, *Reviews of Accelerator Science and Technology*, **6 (2013)**, pp 117-142

2. 72 radiographic hydrotests for SBSS and all DOE/NNSA labs (49 multipulse with 5X data return)
3. Reduced environmental emissions from hydrotesting and protection for endangered species
4. Modular design addressed emerging needs and provided for future investment
5. Provided validation of multi-pulse program benefit motivating next-generation SCORPIUS machine

The appropriate level of technical risk has long been a DOE issue

Lessons


GAO

United States Government Accountability Office

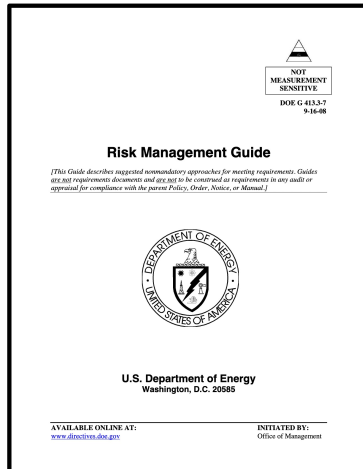
Report to the Subcommittee on Energy and Water Development, and Related Agencies, Committee on Appropriations, House of Representatives

March 2007

DEPARTMENT OF ENERGY

Major Construction Projects Need a Consistent Approach for Assessing Technology Readiness to Help Avoid Cost Increases and Delays

GAO-07-336


NOT MEASUREMENT SENSITIVE

DOE G 413.3-7
9-16-08

Risk Management Guide

[This Guide describes suggested nonmandatory approaches for meeting requirements. Guides are not requirements documents and are not to be construed as requirements in any audit or appraisal for compliance with the parent Policy, Order, Notice, or Manual.]

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Washington, D.C. 20585

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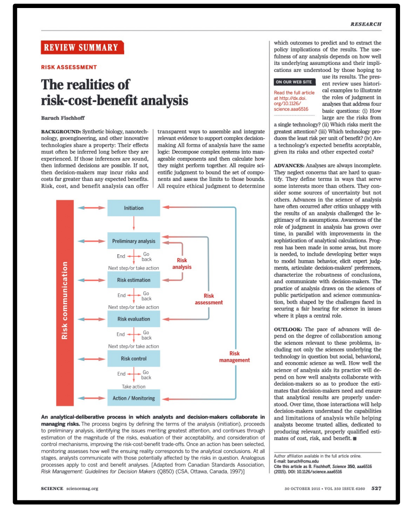
INITIATED BY: Office of Management


REVIEW SUMMARY

RISK ASSESSMENT

The realities of risk-cost-benefit analysis

Baruch Fischhoff

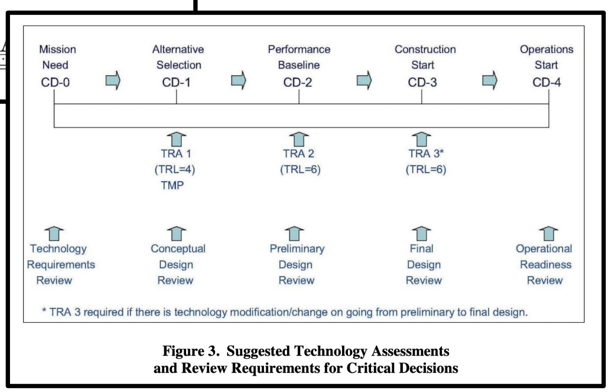
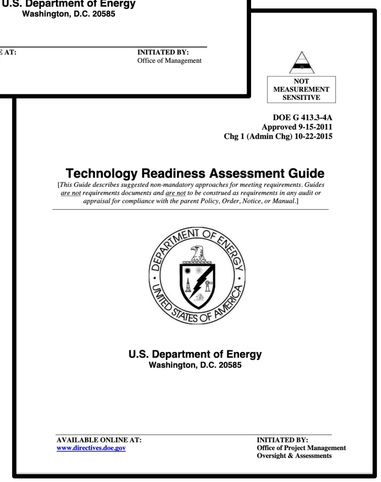


Figure 3. Suggested Technology Assessments and Review Requirements for Critical Decisions


NOT MEASUREMENT SENSITIVE

DOE G 413.3-4A
Approved 9-15-2011
Chg 1 (Admin Chg) 10-22-2015

Technology Readiness Assessment Guide

[This Guide describes suggested non-mandatory approaches for meeting requirements. Guides are not requirements documents and are not to be construed as requirements in any audit or appraisal for compliance with the parent Policy, Order, Notice, or Manual.]

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INITIATED BY: Office of Project Management Oversight & Assessments

- Adequate contingencies
- Well-defined system performance allowing sub-system trades
- External reviews
- React to issues

Open communication is important to manage risk and momentum

Lessons

- Essential for FFRDC activities ("operate in the public interest… full disclosure of its affairs to the sponsoring agency…")
- Objectively provide technical options for policy- and decision-makers (what role w.r.t "advocacy"?)
- While respecting information security and intellectual property, establish and maintain communication with stakeholders. Build "community-wide" support.
- Be a trusted, respected, objective source of information for stakeholders
- Proactively identify stakeholders and their needs. Develop comms plan.

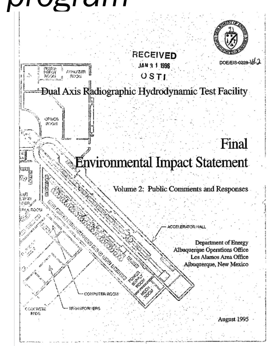

BERKELEY LAB | SCIENCE ARTICLES ARCHIVE

Berkeley Lab to Build Linear Induction Accelerator for DARHT

November 14, 1997

Example: *LBNL explained to its stakeholder community why it was involved in a nuclear weapons program*

Example: *The DARHT EIS contained a classified appendix. DOE arranged for federal judge to have the necessary clearance*



Lessons

Collaboration is essential for complex projects

- Enables access to technology, personnel, facilities
- There should be a formal designation of roles, responsibilities, authorities, and accountabilities
- Diverse experiences, cultures, and opinions can build stronger teams and build better solutions if opportunities are made
- More voices builds momentum for the project
- Essential to be a "collaborator" instead of "controller". Provide significant roles and project influence for collaborators.
- Understand collaborator strategies, intentions, and plans. Structure collaboration to support these
- Security issues or Intellectual Property issues need not impede collaboration
- Collaboration includes sponsors and stakeholders as well.

Los Alamos NATIONAL LABORATORY

Lawrence Livermore National Laboratory

MIT LINCOLN LABORATORY

Lawrence Berkeley National Laboratory

Considerations motivated by the DARHT experience

- What are the appropriate project roles for national labs? End user? "General contractor"? Performer? Advocate?
- Should national labs pursue only high-risk/high payoff projects? How does DOE appropriately steward public funds in that context?
- How should the possibility of future benefit or future developments drive risk-tolerance in projects? Is this situation dependent?
- In a project context, what constitutes "rapid response", "maintaining mission expertise", "knowledge of sponsor mission", "objectively and independent"?
- How would the DARHT project be conducted today?
- What is the "role" of the project leader? Simply "Do as you're told" and implement processes? Cat Herder? Technical expert? Influence policy & alternative decisions?

Summary

- DARHT is an important tool to steward the US nuclear deterrent.
- The project was characterized by a significant number of directed changes and significant efforts were required during transition to operations to realize an effective facility. These led to criticism of the project, but DARHT has generated significant programmatic benefit, capability enhancements have been made, and more are being considered.
- The project began before DOE O 413.3 was implemented, but some of its formalism were put in place. It was found that project management processes alone, of whatever sort, are insufficient without substantive attention to important details in a high-risk/high pay-off environment
- Important lessons from DARHT merit consideration during the 2022 PLI capstone study, including:
  1. The national laboratory context for conduct of technical construction projects
  2. Scope instability requires exquisite leadership, communication, collaboration, and acumen
  3. Mgmt. of threats & opportunities should include consideration of benefit as well as risk and mitigation
  4. Communication (policy makers, project stakeholders, public, team, etc.)
  5. Collaboration