SAND2021-9763PE

Z Machine Overview

Briefing for the Z Fundamental Science Program Workshop

Nathan Joseph on behalf of Chris Bourdon, Z Experimental Capability Management

8/9/2021

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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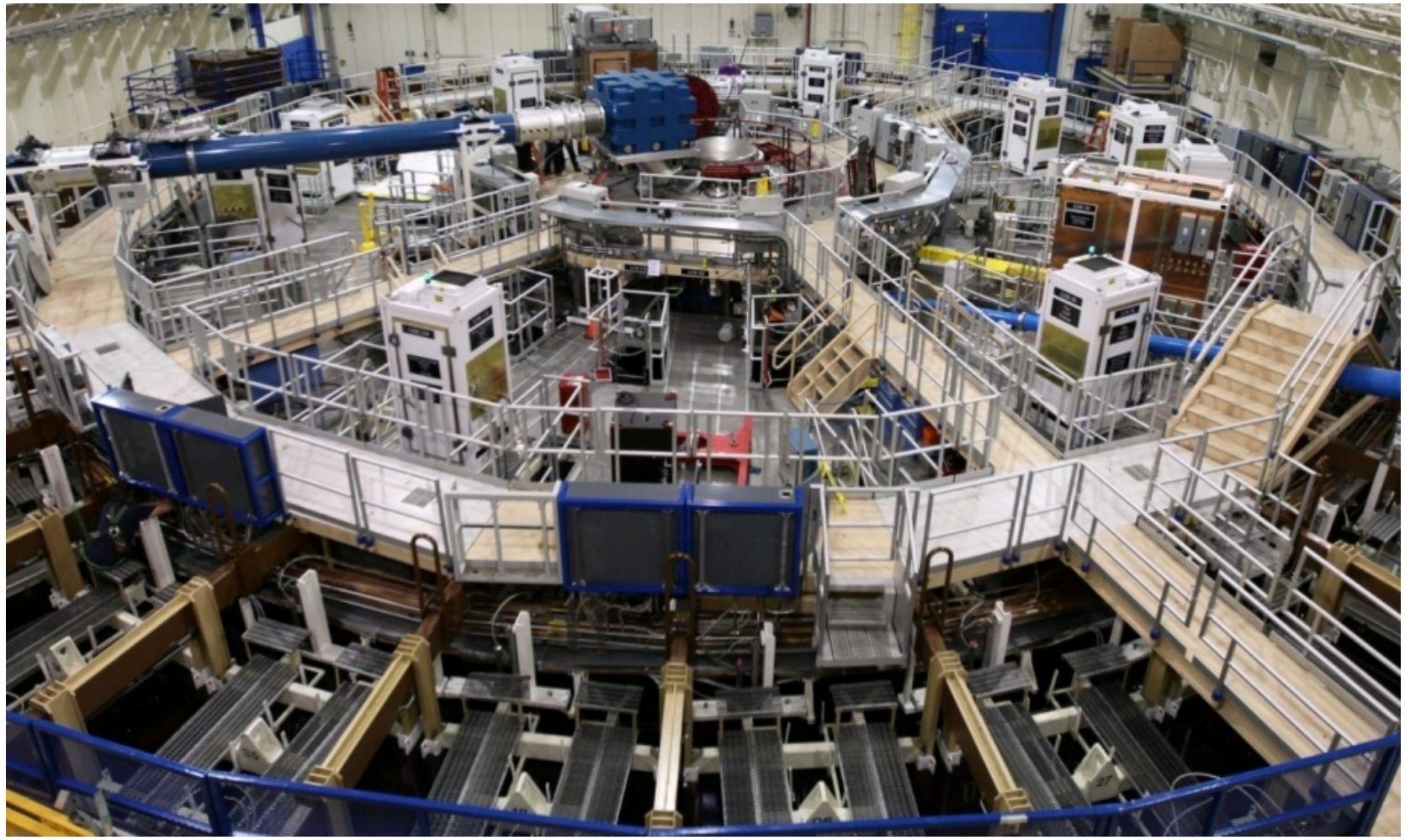
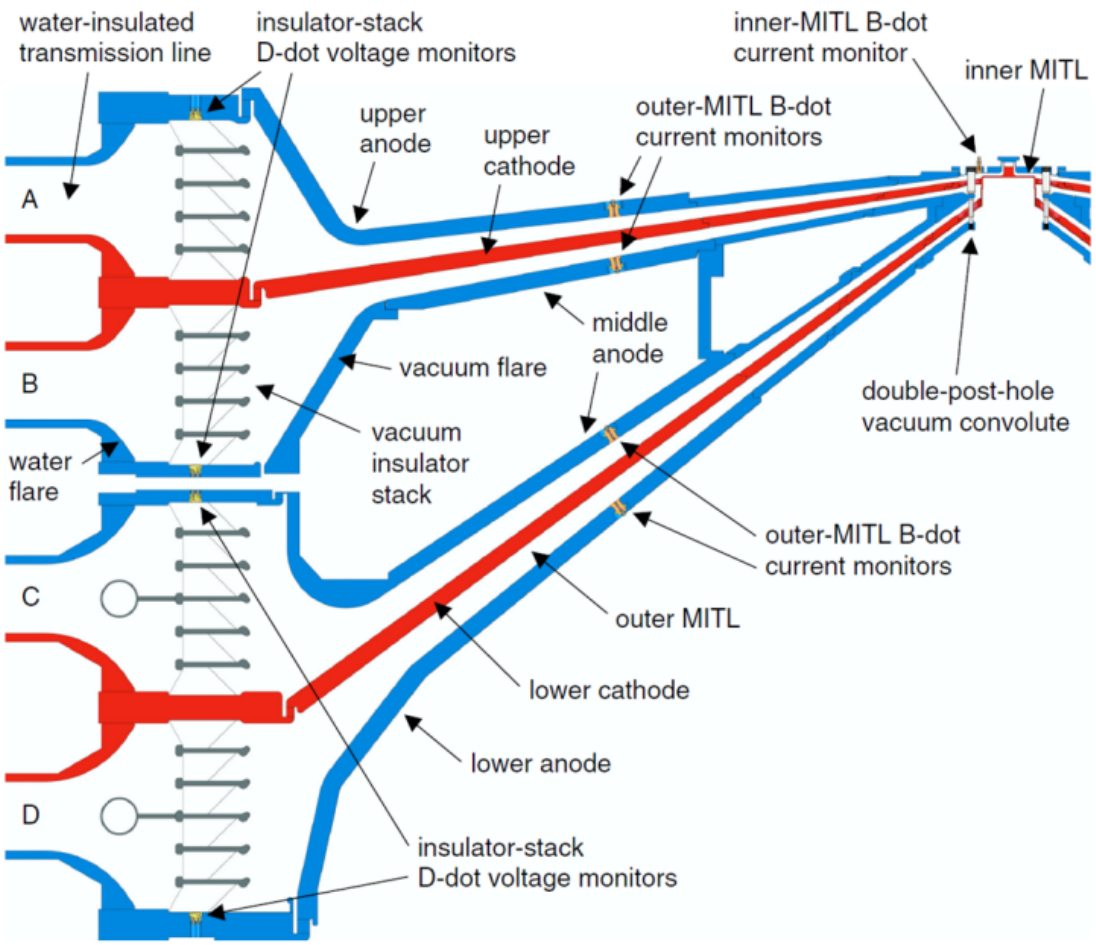
Z is a unique world class pulsed power facility at SNL



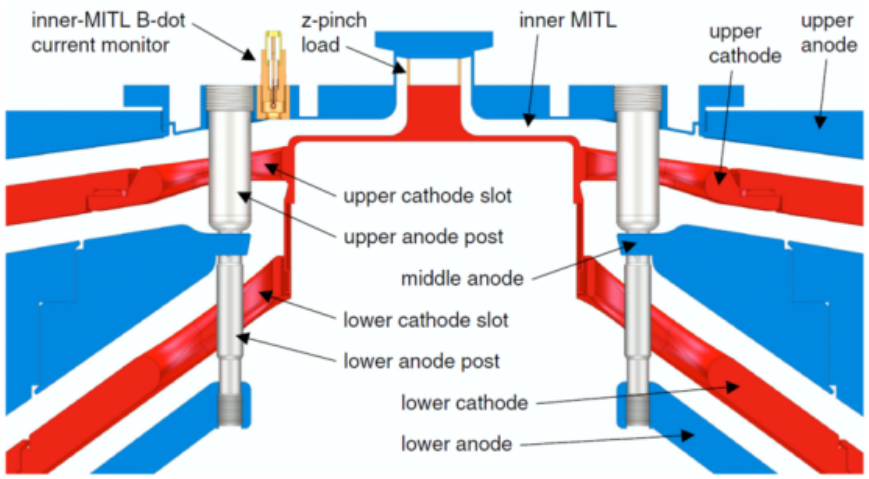
- 36 Marx generators
  - 2160 capacitors
- ~ 1M gallons of transformer oil
- ~ 0.5M gallons of deionized water
- 66,000 liter vacuum vessel

A complex series of conductors combine currents for the load

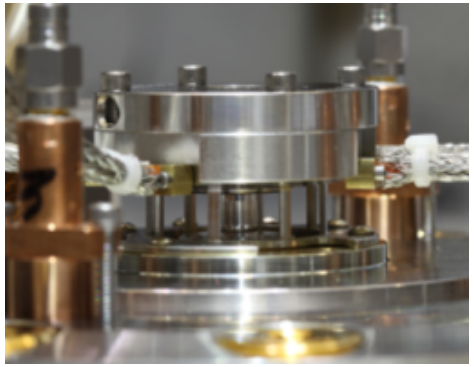
Z vacuum insulator stack and MITLs



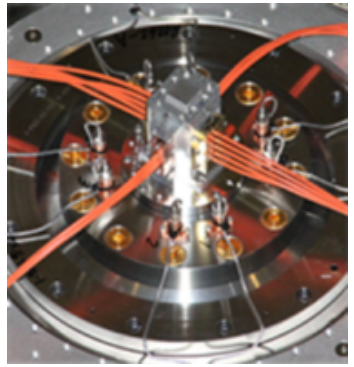
Post hole convolute system and load



ICF liner load



DMP load



Pulse Shape Flexibility and Reproducibility

Z was designed to drive dynamic hohlraum experiments.

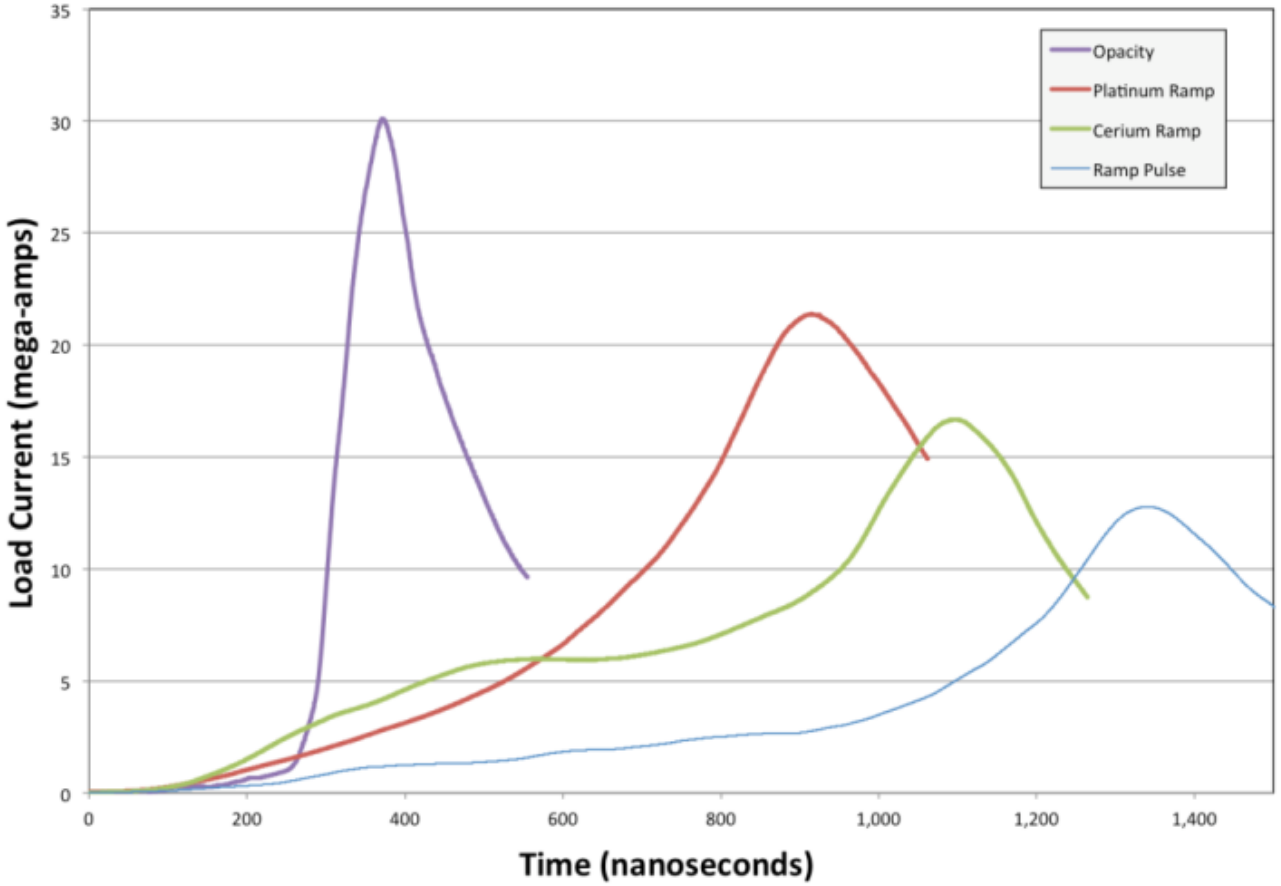
- ~150 ns current rise times

System improvements have enabled precisely tailored pulse shapes with multiple distinct drive characteristics.

- E.g., both shock and ramp drives can be produced by a single pulse shape
- Up to ~1 μs current rise times

Each of Z's 36 transmission lines have multiple triggers and switches that can be employed to produce a given pulse.

- The Sandia developed Laser-Triggered Gas Switches (LTGSs) are central to our pulse shaping capabilities.

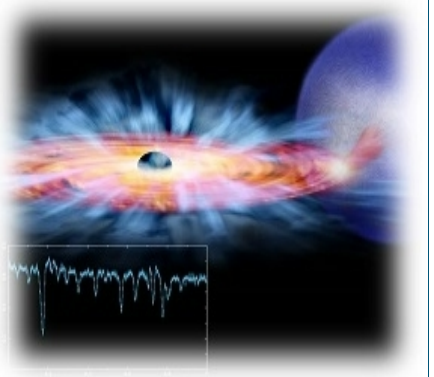


Z's purpose: provide the capability to answer questions that are not always possible to anticipate in advance

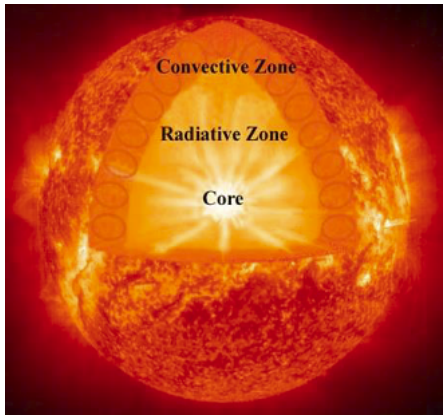
Z has evolved dramatically since 1996

- >90% of shots on Z in 2021 use experimental platforms that were not clearly envisioned in 1996.
- As new platforms are developed, we are able to address new missions and answer new questions, such as
  - **Capability to study dynamic materials + capability to use explosive containment vessels →Study of hazardous materials**
  - **Fusion research leads to opportunities in radiation effects, HED opacity**
  - **Laser backlighting capability + magnetic field capability → Study of new fusion physics regimes**

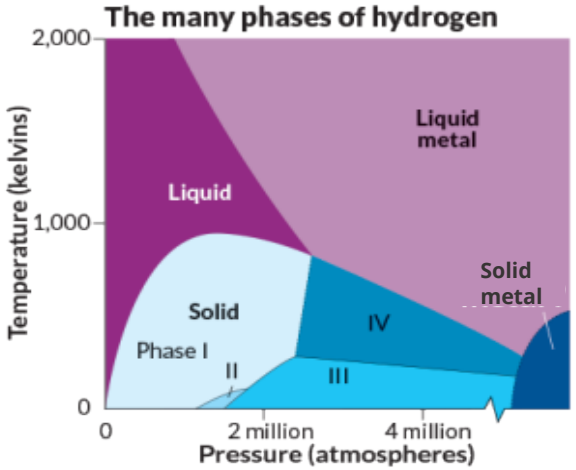
Z Fundamental Science Program benefits from this evolution



Accretion Disc
UC Berkley, University of Nevada- Reno, SNL Goddard



Opacity of Iron
SNL, University of Nevada- Reno, Ohio State University



Hydrogen metallization
University of Rostock, SNL

Iron Rain
Harvard University, UC Davis, SNL, LLNL,

Shot rate has been challenging to maintain in 2020-2021

Number of required unplanned maintenance days up significantly

- ~45 in CY2020 and ~61 in CY21 (current date) over historical averages (25-30)
- Activities are major, leading to significant down-time:
  - Two emergency stack rebuilds, LTS crossover tube SF6 gas misconfiguration, and Z-ESS oil quality issue

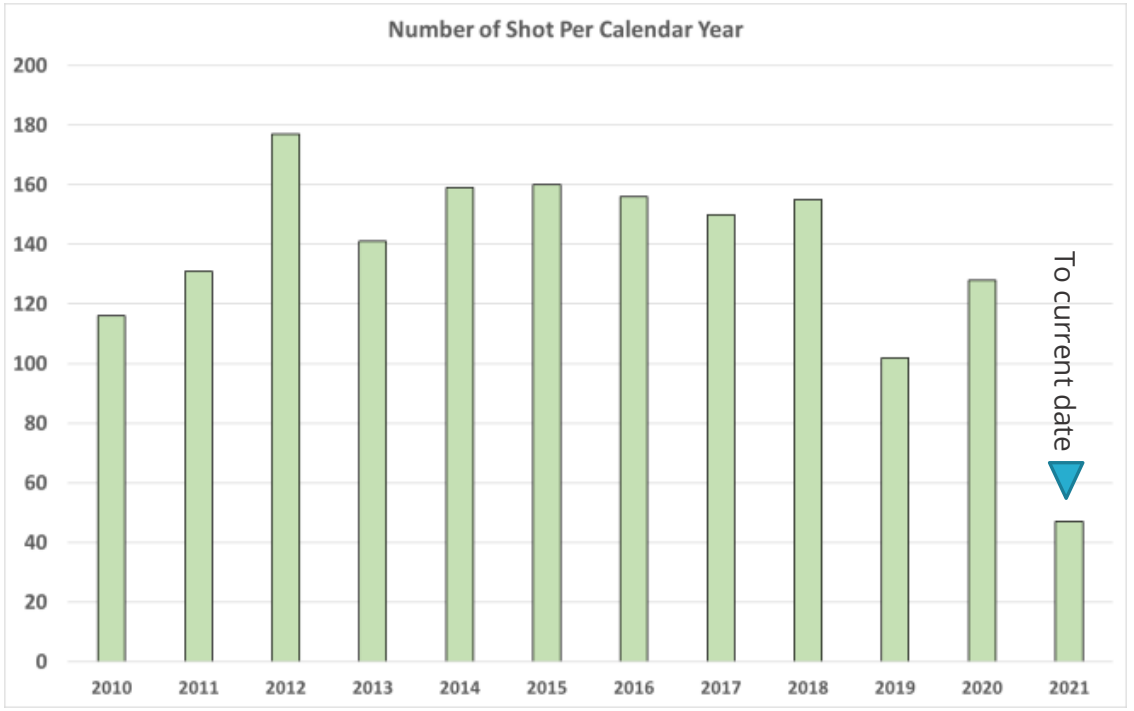
COVID-19 impacting operations tempo, leading to machine down-time

- 5 day downtime due to COVID-19 spread

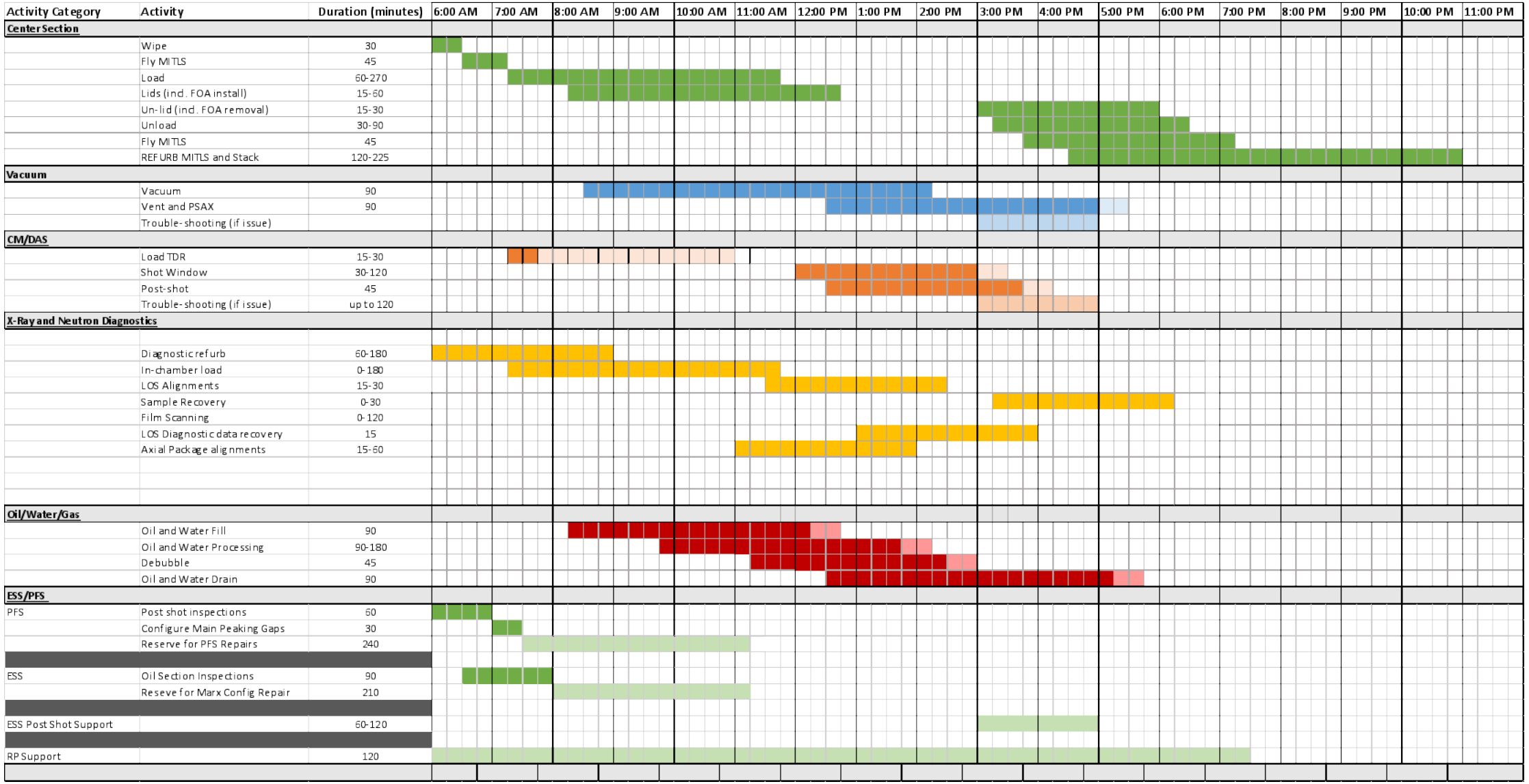
Introduction of Z Extended Workflow July 8th

- Split shift operations for critical path center section activities 6AM-10:30PM
- Allows 1.5 day experiment timelines to be condensed into 1 day
- Adds contingency for unanticipated delays, stabilizes shot window, and de-stresses work force with a repeatable schedule

Annual Z shot rate by Calendar



Taking a tactical approach towards timeline stabilization

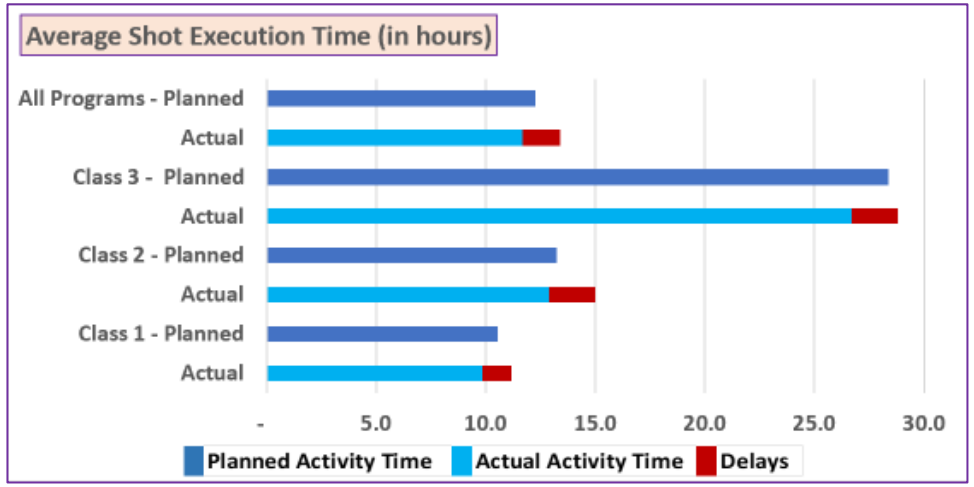


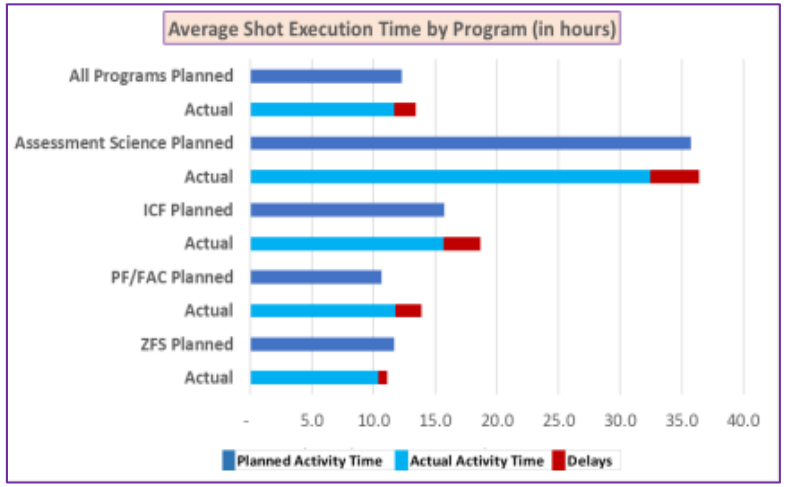
Activity Category	Activity	Duration (minutes)
Center Section		
	Wipe	30
	Fly MITLS	45
	Load	60-270
	Lids (incl. FOA install)	15-60
	Un-lid (incl. FOA removal)	15-30
	Unload	30-90
	Fly MITLS	45
	REFURB MITLS and Stack	120-225
Vacuum		
	Vacuum	90
	Vent and PSAX	90
	Trouble-shooting (if issue)	
CM/DAS		
	Load TDR	15-30
	Shot Window	30-120
	Post-shot	45
	Trouble-shooting (if issue)	up to 120
X-Ray and Neutron Diagnostics		
	Diagnostic refurb	60-180
	In-chamber load	0-180
	LOS Alignments	15-30
	Sample Recovery	0-30
	Film Scanning	0-120
	LOS Diagnostic data recovery	15
	Axial Package alignments	15-60
Oil/Water/Gas		
	Oil and Water Fill	90
	Oil and Water Processing	90-180
	Debubble	45
	Oil and Water Drain	90
ESS/PFS		
PFS	Post shot inspections	60
	Configure Main Peaking Gaps	30
	Reserve for PFS Repairs	240
ESS	Oil Section Inspections	90
	Reseve for Marx Config Repair	210
ESS Post Shot Support		60-120
RP Support		120

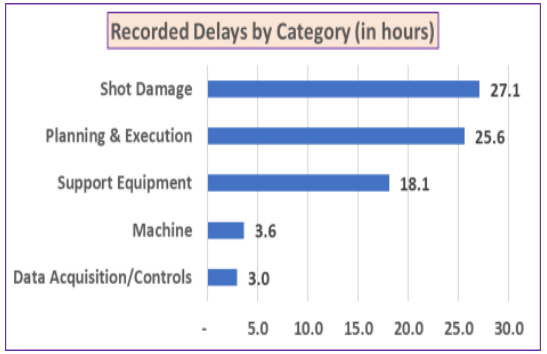
Z-Extended Workflow Timeline Diagram

Data analysis informs decisions, improves efficiency and effectiveness – Quarterly Reports to NNSA

Each shot is categorized into one of four shot classes (complexity levels), has an individual execution timeline and observation data that captures shot tempo (execution timing) and delays by the minute - this informs design, process, and training improvements



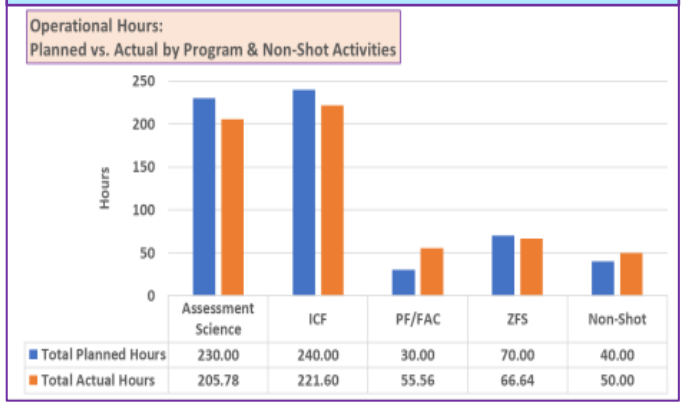




Legend: Machine, Diagnostic, Subsystem Performance: Worked as Intended; Had Issues/Failures

Objective Results: Met; Partially Met; Not Met

Time devoted to shots and non-shot time are tracked to enable understanding of facility issues and availability for shot execution



Performance of the machine, diagnostics, and subsystems along with objective results are evaluated to determine relative effectiveness of shots – this is a subset of ICF shots conducted in CY20Q4

Experiment Name	Class	Z Shot #	Output	Timing	Power	Delivery to Load	systems		Objective(s) Results	NNSA Summary Notes
Sierra Spectroscopy	2	Z3551								Target design and fielding issues believed to cause insufficient spectrometry signal, causing the object to not be met
Sierra Hydro Scaling	2	Z3563								Gated backlighting diagnostic failed due to electromagnetic interference; did not impact the objective
MagLIF Current Scaling	2	Z3564								
Harding IEC 19a	2	Z3565								
Sierra Stagnation (Tritium)	3	Z3566							#1 #2	

Shot Execution Notes

A #	Gantt	Actual Time	Actual date	Comments	Z #	E/L	Actual Hours	Gantt Projection hours	Delta	Delay(s)	Delay comments
A0871A	10:42	11:27	4/9/2020	rescheduled	z3475	L	10:07	10:18	(0:11)	0:45	C&D issues
A0934B	11:09	12:04	4/10/2020	rescheduled	z3476	L	9:15	11:39	(2:24)	0:00	
A0867B	13:13	15:13	4/13/2020	rescheduled	z3477	L	11:09	11:31	(0:22)	0:35	Target Panel back to lab 101/ Wrong LTS sheet
A0835B	15:19	15:04	4/14/2020	rescheduled	z3478	E	10:35	12:29	(1:54)	0:00	
A0932A	16:46	16:56	4/30/2020	rescheduled	z3485	L	9:45	10:24	(0:39)	0:00	
A0935A	11:45	11:35	5/11/2020	rescheduled	z3489	E	14:43	10:24	4:19	0:45	Broken ceramic isolater/Communication delay PI-SD after Comms check
A0934C	14:45	9:09	5/15/2020	rescheduled	z3490	L	20:12	10:36	9:36	6:26	Smoking Lights, C&D from Maint/prev shot, MITL extraction/Flipper issue.
A0950A	13:04	13:24	5/21/2020	rescheduled	z3492	L	10:18	11:32	(1:14)	0:00	
A0949A	12:37	10:48	6/19/2020	rescheduled	Z3499	E	11:05	11:13	(0:08)	1:15	SD reported PDV trigger issues
							Averages of 9 DMP shots above				
							11:54	11:21	0:49	1:05	
							Averages less Z3490 Above				
							10:52	11:17	-0:16	0:25	

Baseline Q3 = 13 shots in 13 schedule allocated days
Executed Q3 = 9 shots in 12 schedule allocated days
All 13 downline dates were rescheduled or shelved during the Q
Average DMP Gantt estimate 11:21 hh:mm to execute (wipe to refurb complete)
Executed actual time to execute 10:52 (with one exception removed)
4 of 9 shots had zero recorded delays
Average delay over 8 shots 25 min.
Z operations performance over 8 shots beat Gantt estimate by 16 min on average
A few early Q shots CS overcame short staffing issues
Of 50 "Shot Days" in Q3 DMP = 24%

Averages of 13 ICF Shots Q3 for comparison			
18:57	15:40	3:17	3:09

- Delay and exception data will be binned for analysis and trending
- Validated timeline data will be used for future experiment planning and trending

Science Objectives

A Number	Experiment Name	Program	Z Shot	Shot Date	Primary Objective 1	Primary Objective 1 Met?	Comment
A0397D	Short Circuit	Fac (PF)	Z3474	4/7/2020	Primary Objective: Verify proper pulsed power operation following extensive Marx bank maintenance due to Z3473 pre-fire event	Yes	Note this is a legacy hardware set, which we keep several on the shelf to assist with evaluating major machine repairs (for example the recent Marx cascade); as a result this load design does not complete a rigorous design review process, instead the objectives are determined ad hoc with the PI/PM
A0871A	Sn Strength	DMP	Z3475	4/9/2020	Primary: Obtain tin strength data in the bcc phase	No	Suspected debris in final feed significantly affected current deliverly to the load.
A0934B	AM Materials II	DMP	Z3476	4/10/2020	Primary: Obtain flow strength measurements near 2 Mbar on three additively manufactured (AM) 304L stainless steel (SS) samples having undergone a different heat treatment	Yes	
A0867A	Al Phase Transitions II	DMP	Z3477	4/13/2020	Primary: Obtain shock-ramp EoS data on aluminum (pure and alloy) to ~4 Mbar	Yes	
A0835B	Flyer Phase Transition	DMP	Z3478	4/14/2020	Primary: Obtain a Hugoniot data point on platinum above 700 GPa	Yes	
A0907B	MagLIF Mix 19a	ICF	Z3479	4/16/2020	Obtain data with a new three -crystal imager in order to develop a technique to measure T_e and/or n_e	Yes	
A0905D	Montrose Convergence Ratio Scan	HEDP	Z3486	5/4/2020	Primary objective: Investigate the performance of a Montrose target as the stagnation convergence ratio is modified.	Yes	Notes: There was an obstruction in one of the radiographs (a key diagnostic), which obscured enough of the image to compromise the data. The other radiograph was fine.
A0935A	Pre-Heat Containment 1	DMP	Z3489	5/11/2020	Primary: Test a new preheat configuration within a mock containment system. This is the first step towards establishing a preheat capability for SNM materials. Heat panels to ~325C with minimial powerflow impact to stripline load as diagnosed by velocimetry.	Partially Met	Pre-heat system was sucessfully tested in mock containment on a Z shot. Panels were heated to ~325C. One of the two panels had an 80 degree temperature gradient (up to ~400C); cause is under investigation. Powerflow was not as anticipated, the cause of this is also under investigation. Velocimetry data loss occured on the North panel with the LiF samples, so no LiF data was returned. Improvments are being discussed for the next shot.

Feedback on science objectives example

Machine Performance

Shot	Z3607: SAT Opacity		
General Notes	87.4 kV, 35 module (Line 24 bussed out), Synchronous experiment. Overall looked good; no major issues with machine performance.		
Pulsed Power Quality	Monitor Quality	Section	Notes
		LTS100	LTS100A Poor Splitting. Normal LTS100B operation. LTS100A: t_0 =435.7 ns (Bottom); Current Split = 56%; Runtime = 45 ns. LTS100B: t_0 =437.7 ns (Bottom); Current Split = 42.7%; Runtime = 47 ns.
		HVU	Charged with HVU2. Peak imbalance 26.1 mA (10.5 mA after initial transient). Charged to 87 kV; charge at shot 86.6 kV (87.4 kV requested).
		MTG	Normal MTG operation. Timing Spread = 9.4 ns; Current Spread = 0.86 kA.
		Marx	Marx 11: High amplitude > 3σ; Low pulse width > 3σ. Timing Spread = 70.7 (70.7 with outliers) ns; Current Spread = 16.7 (26.5 with outliers) kA.
		ISVD	Spread = 155 ns ISVD31 clipping on digitizer
		LTGS Tempest	Spread = 3.0 ns (from LTS report)
		PFL	PFL spread = 15.7 ns (from LTS report) Line 3 signal bad (damaged cable?) Unusual large noise spike on line 30
		Stack Voltage	B-level flashed about 3120 ns (after reversal); C-level flashed about 3100 ns (during reversal). Not expected to reduce load current measurably. VSB044, VSB164 noisy VSC274 reading high VSD164 drift; VSD346 flatline
		Stack Current	BSA196 half amplitude BSB344 noisy BSC356 noisy and drift; BSC276 high amplitude BSD086 high amplitude
		MITL Current	Large amplitude spread on BMAs due to known monitor damage BMD035 flatline; BMD235 half amplitude; BMD315 low amplitude
		Load Current	Signals look good
		Post-Shot MTG	N/A
		Post-Shot Chg&Dump	N/A

Shot based performance reports

- Individual system performance analysis mapped to pass/fail metrics reported after each shot
- Allows for data trending on system health and indicates areas of needed repair or pre-cursor event of failure
- When in normal operations tempo, report is discussed at daily status meeting.
- Teams are informed of issues very rapidly after shot has occurred
- Machine diagnostic data analysis routine established and accurate

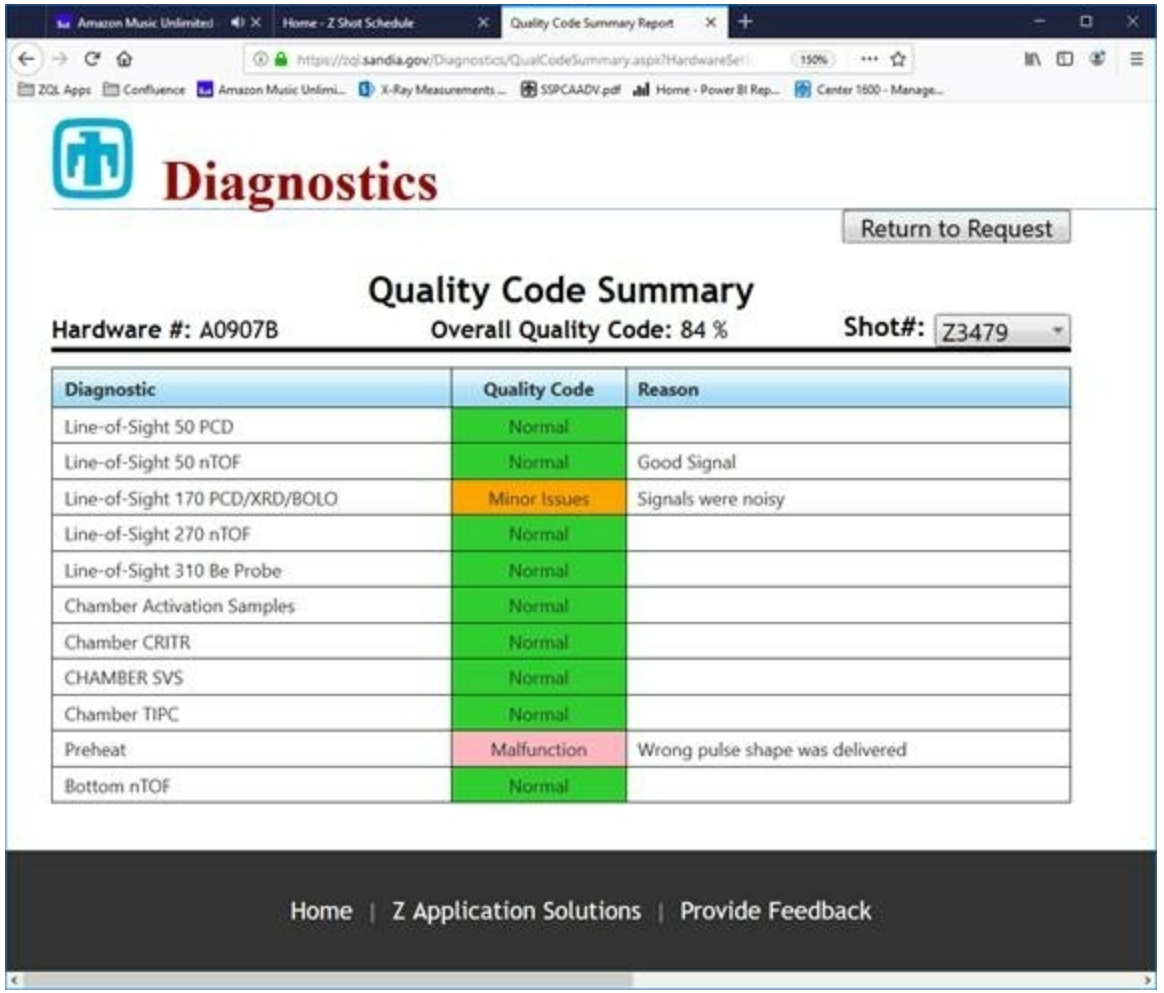
Diagnostic Performance

Goal is to collect and report on the configuration and performance of all diagnostic capabilities that support the shot science objectives

Currently, quality codes are implemented and used along with notes

- Using existing diagnostic code infrastructure within ZQL shot management tools

First report will be primarily exception (fault) reporting, along with some quality code information



Diagnostic	Quality Code	Reason
Line-of-Sight 50 PCD	Normal	
Line-of-Sight 50 nTOF	Normal	Good Signal
Line-of-Sight 170 PCD/XRD/BOLO	Minor Issues	Signals were noisy
Line-of-Sight 270 nTOF	Normal	
Line-of-Sight 310 Be Probe	Normal	
Chamber Activation Samples	Normal	
Chamber CRITR	Normal	
CHAMBER SVS	Normal	
Chamber TIPC	Normal	
Preheat	Malfunction	Wrong pulse shape was delivered
Bottom nTOF	Normal	

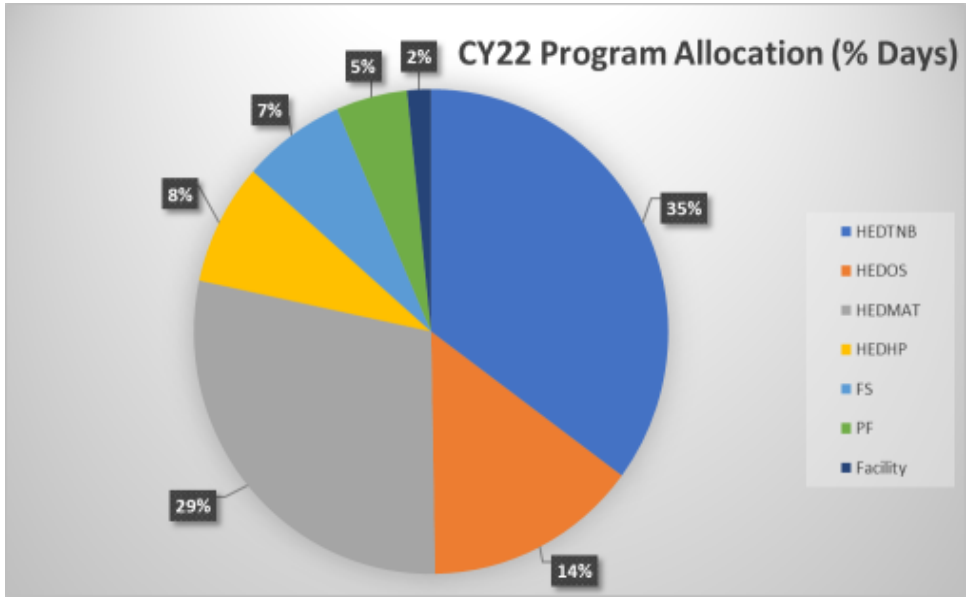
CY22 Shot Schedule development underway

Joint call for Z shot proposals out on June 1st
- 272 shots proposed for ~122 slots

HED and ICF councils approved allocations on July 15th and July 17th
- Facility/Power Flow allocations also set
- FS program allocations set based on previous year's allocations

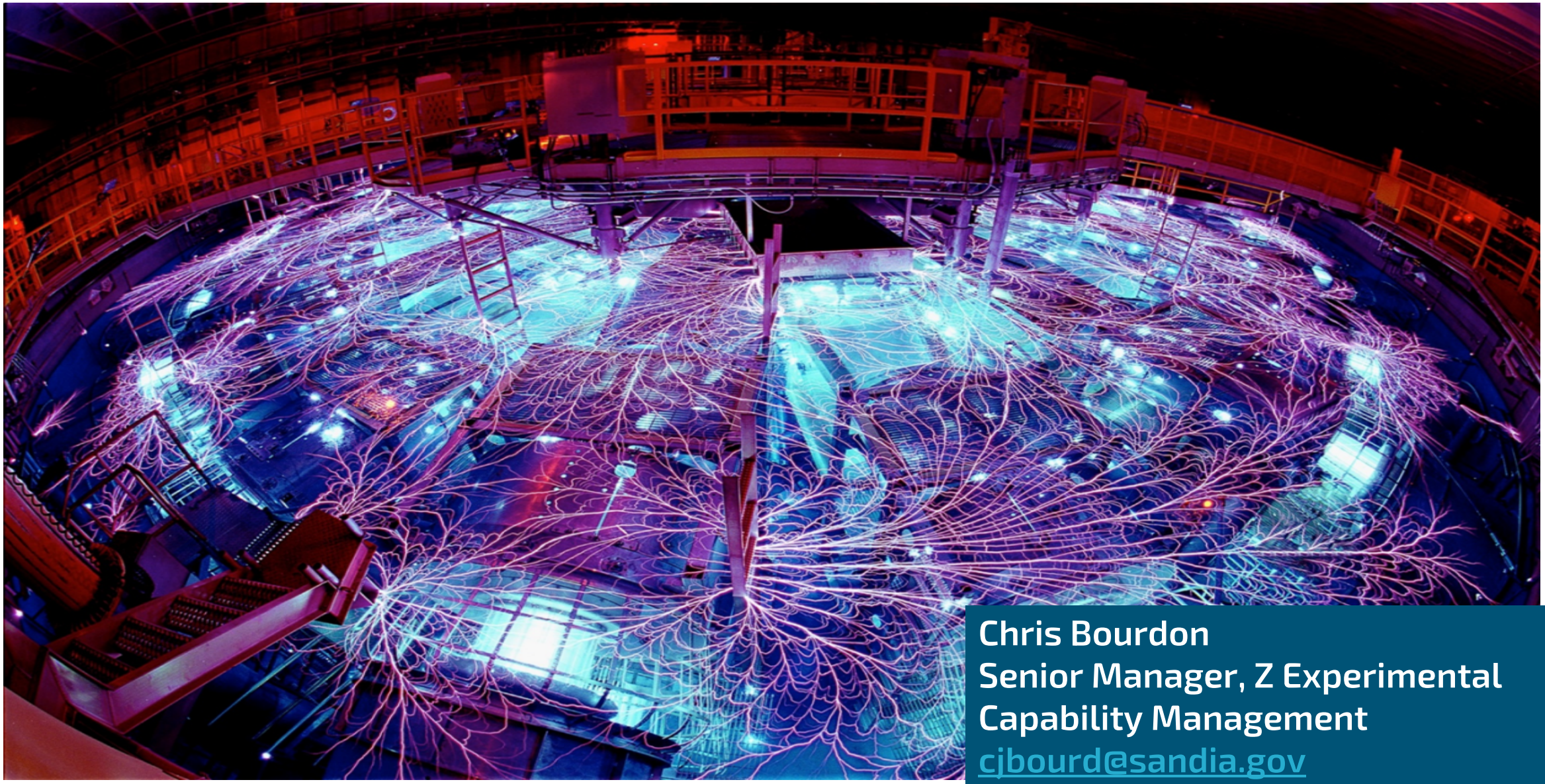
Program scheduled blocks currently under development; on track for finalization next week
- Z-SPRINT: Change in philosophy this year defines extended program block allocations to hold constant on schedule
  - Goal is to better manage schedule volatility, resource scheduling, and supply chain
  - Will require additional controls to be in place for full implementation
    - Resource loaded planning schedule, contingency planning, etc.

Current goal is to have CY22 schedule approved and ready for release in mid-August- 20 weeks before the start of the CY



	Q1	Q2	Q3	Q4
FS Program Days	8	0	0	5

Questions?



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