LA-UR-08-1310

NNSA work at NSLS (and beyond)

Presented by

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Outline

- History of the U3c and X8a Beamlines
- The NNSA Customer(s)
- Diagnostics that use NSLS Calibrations
- Possible upgrades to U3c and X8a
- Emerging needs and growth areas
- Looking forward: NSLS-II Transition
- Conclusions

History of the U3c and X8a Beamlines

The nuclear weapons laboratories (NWLs) began using synchrotron radiation in the late 1970's / early 1980's.

National security programs required increased x-ray measurement precision.

- Inertial Confinement Fusion
- Strategic Defense Initiative
- Nuclear weapons diagnostics and effects
- Material science issues for nuclear and non-nuclear components

Very limited tools were available to characterize the necessary instrumentation.

- DC X-ray sources
- National Bureau of Standards SURF capabilities
- Early capabilities at Stanford
- University of Wisconsin

The NWLs partnered with the broader DOE in the early 1980's to develop necessary capabilities.

- **LANL and Sandia**

  LANL and Sandia staff developed the capabilities at NSLS on both the UV and X-ray rings (U-3 and X-8) for Optics/Calibration/Metrology and materials science

  The PRT (Participating Research Team) concept was a powerful mechanism to implement unique focused capabilities with U-3 and X-8 while maintaining capacity access.

- **LLNL**

  LLNL developed similar capabilities at SSRL with a focus on materials science.

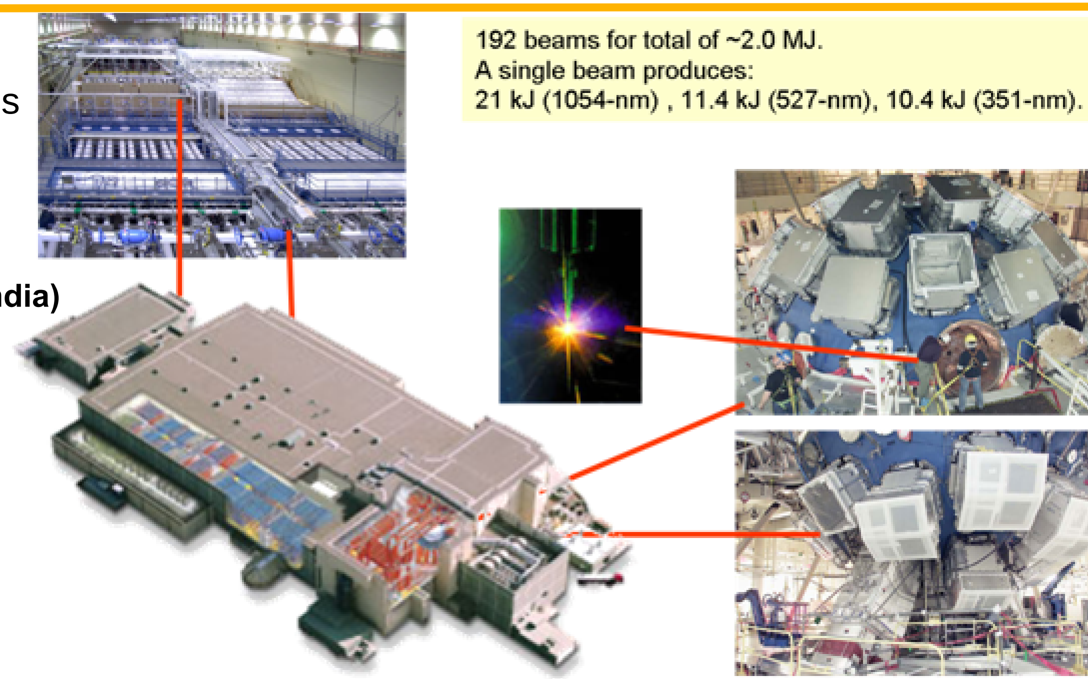
  LLNL also increased its effort at NSLS to support calibration of radiation temperature diagnostics at laser facilities like Nova, Omega, and NIF.

The NNSA Customer(s)

Calibration work at U3c and X8a supports many DOE National Nuclear Security Administration programs.

<u>Supported Programs</u>

- High Energy Density Physics Facilities
  - **Laser driven experiments**
    - **Omega (Univ. Rochester),**
    - **Trident (LANL)**
    - **Titan, Jupiter, and NIF (LLNL),**
    - **Z-Beamlet and Z-PetaWatt (Sandia)**
    - **Helen and Orion (AWE)**
    - **Vulcan PetaWatt (RAL)**
    - **LIL (CEA)**
  - **Pulse power experiments**
    - **Z accelerator (SNL)**
    - **Magpie (Imperial College)**
    - **Russia**
- Satellite systems
  - **NuDet (LANL)**
  - **X-ray observatories (NASA)**



<u>Specific requirements</u>

- Instrumentation, x-ray component, and detector characterization, development, and calibration
- Special studies (e. g., response of time resolved X-ray and XUV diagnostics)

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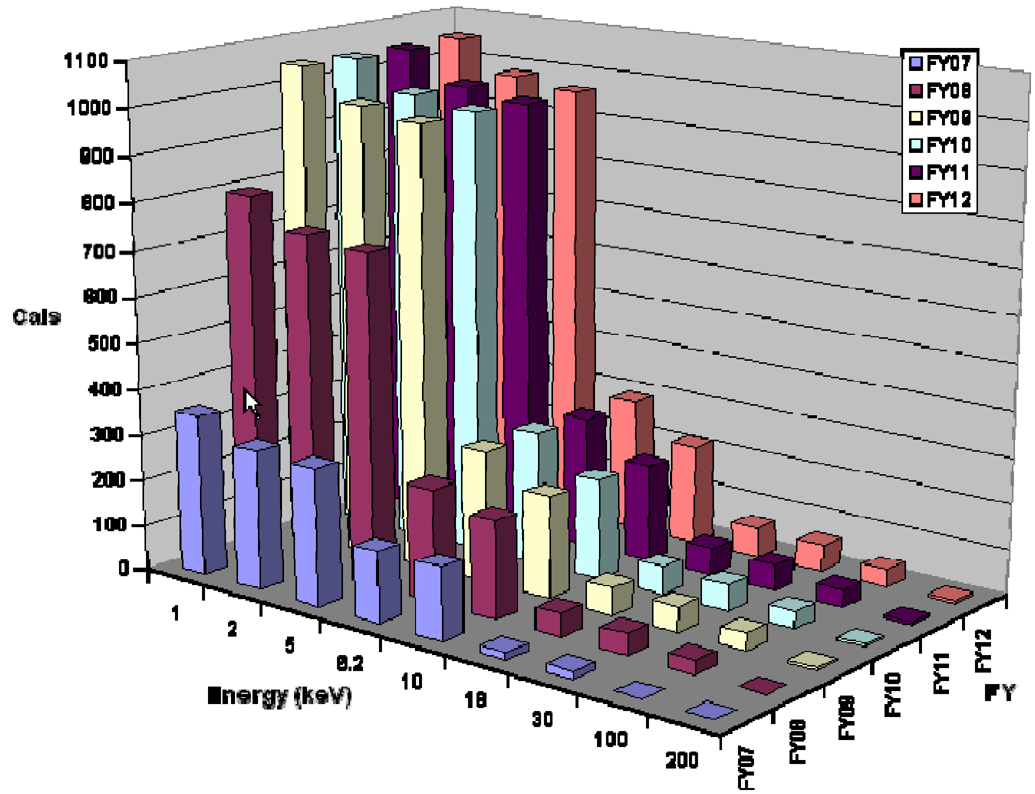
The core NNSA interest is calibrations for soft x-ray measurements of radiation temperature

- Many high energy density physics facilities produce quasi-blackbody radiation temperatures in excess of 150 eV, and NIF is expected to peak near 350 eV.
- Nuclear event detection and treaty monitoring devices use a broad calibration spectrum.
- High Energy X-ray diagnostics with ultra-short intense lasers might require higher energy (up to ~100 keV).

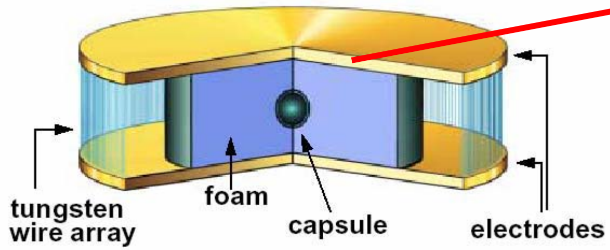


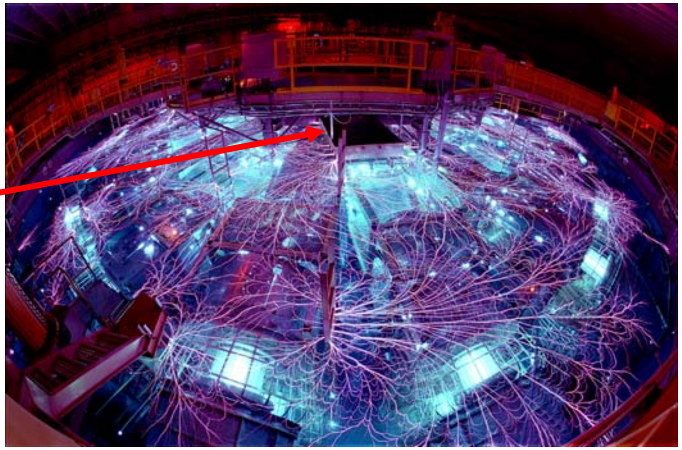
Instrument	< 1 (keV)	1 – 2 (keV)	2 – 6 (keV)	6 – 10 (keV)	10 – 20 (keV)	20 – 30 (keV)	30 – 100 (keV)	100 – 200 (keV)
Dante/XRDs	Y	Y	M	M	B	N	N	N

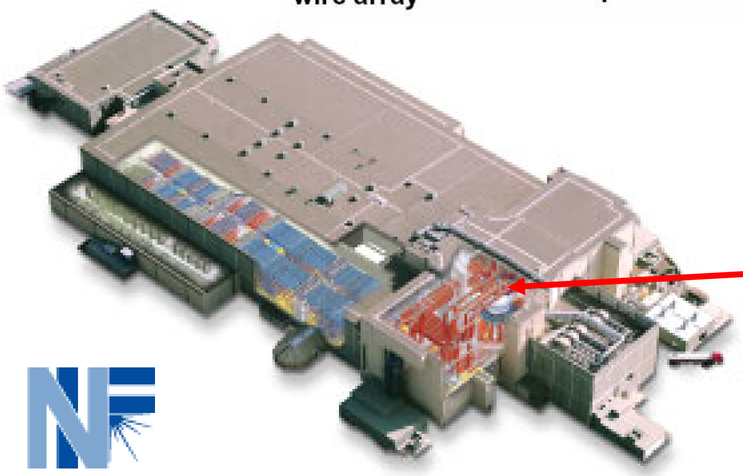
Y = Required
M = Might be required
B = Beneficial
N = Not required

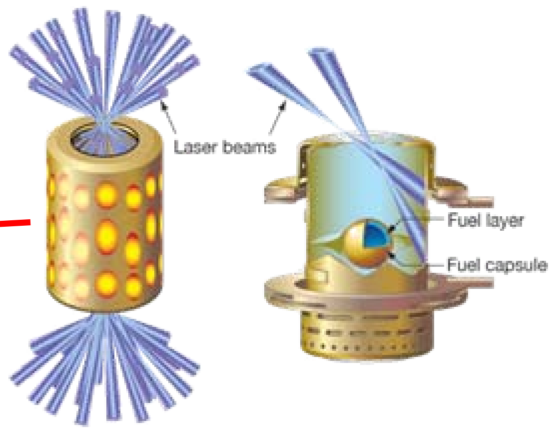
Today, DOE's National Nuclear Security Administration supports multiple high energy density physics facilities.

One method for inertial confinement fusion uses x rays to heat and compress a DT-filled capsule.









Principal focus of these facilities is inertially confined fusion energy research.

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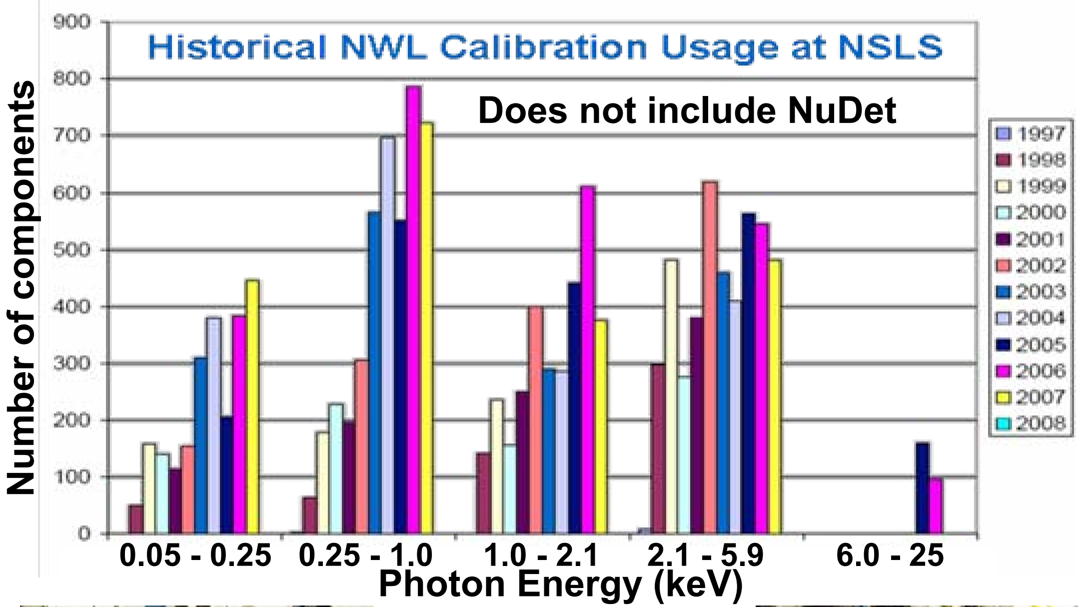
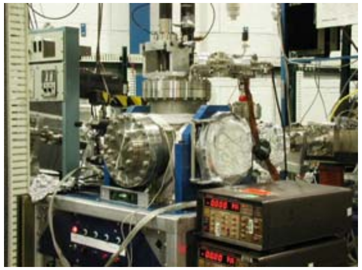
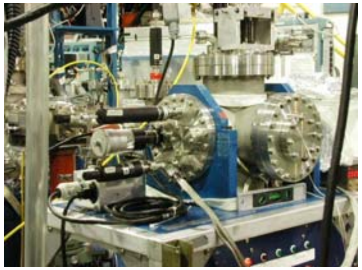
Both U3c and X8a are nearly fully occupied to the 75% maximum for NNSA instrument calibrations.





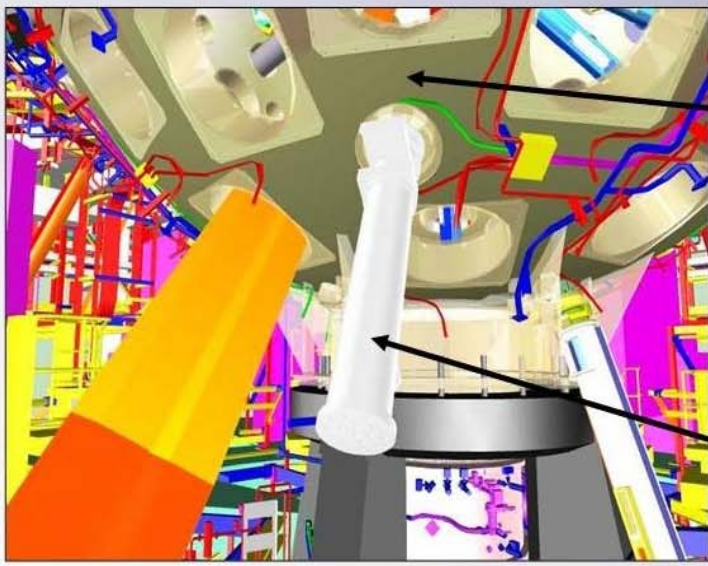


- High energy density physics facilities generate quasi-blackbody sources up to 350 eV.
- Treaty verification and nuclear detonation detection technology.

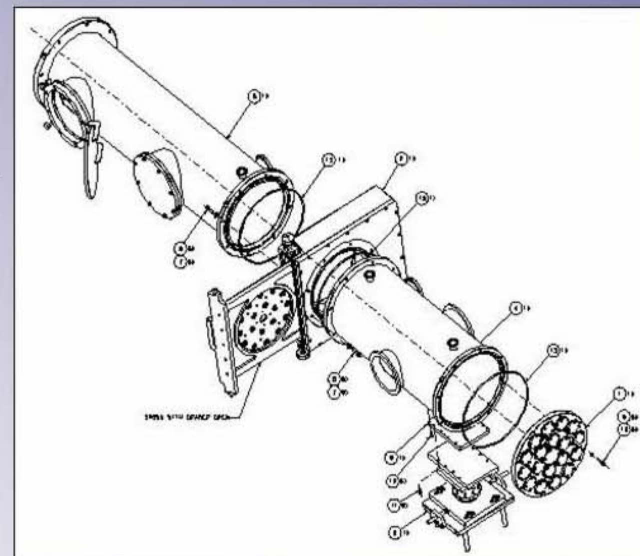
Diagnostics that use NSLS calibrations

Synchrotron calibrations of multi-channel x-ray diode arrays, like Dante, are used for flux diagnostics.

Soft X-Ray Power Diagnostic is Mounted to the NIF Target Chamber (Dante Time-Resolved X-Ray Spectrometer)



Dante Spectrometer Has Multiple Spectrally Segregated Channels as well as a Central Imaging System



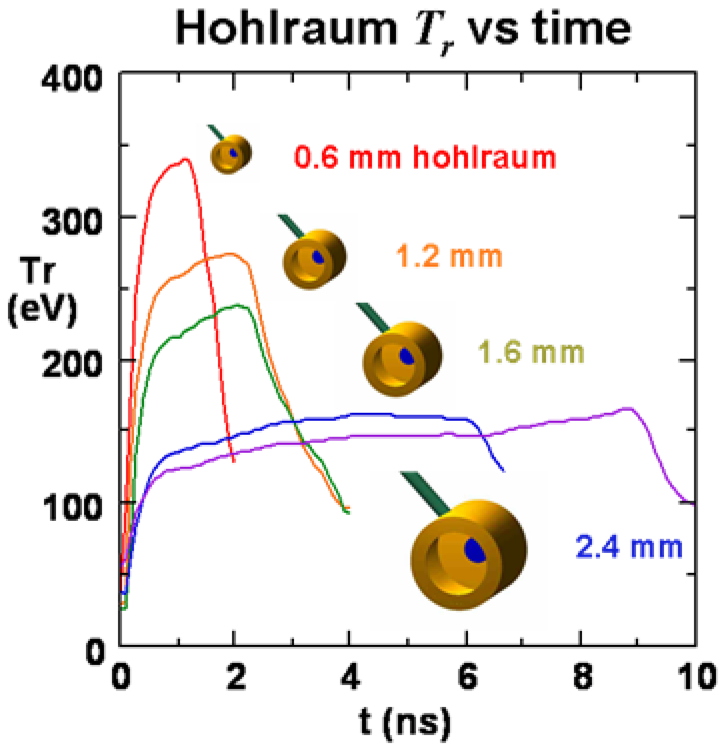
Spectral Channels
- Collimator
- Filter / Grid
- Mirror (E < 1 keV)
- XRD
- Power supply
- Power cables
- Signal cables
- SCD 5000

Central Channel Imager
- Pinhole Array
- PCD
- MCP
- CCD Readout

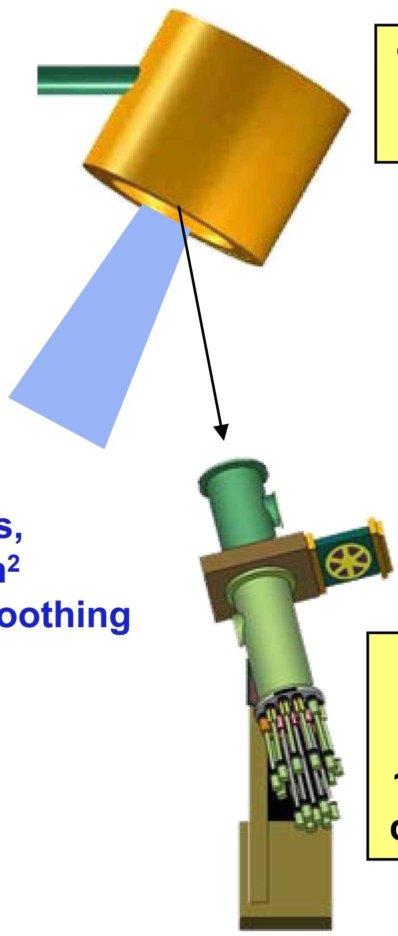
Drive flux helps us measure:
- Material albedos,
- Laser to x-ray conversion, and
- Blackbody temperatures

NSLS calibrated Dante-like instruments held central roles in >25 Phys. Rev. Lett. and >100 invited papers since 1998

Dante measures the flux emitted by hohlraums, which translates into radiation temperature T_r.



4-16 kJ, 1- 9 ns,
10^{15}-10^{16} W/cm^2
with beam smoothing



Thinwall Au Hohlraum

Hohlraum T_r (Dante)
18 channel soft x-ray detector (0.1- 10 keV)

NIF Dante's specification:

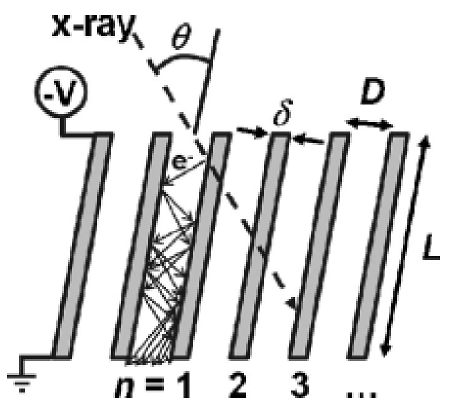
$dT_r/T_r \lesssim 1.5\%$

There are three Dante instruments among NNSA, three under development by UK, and two by France.

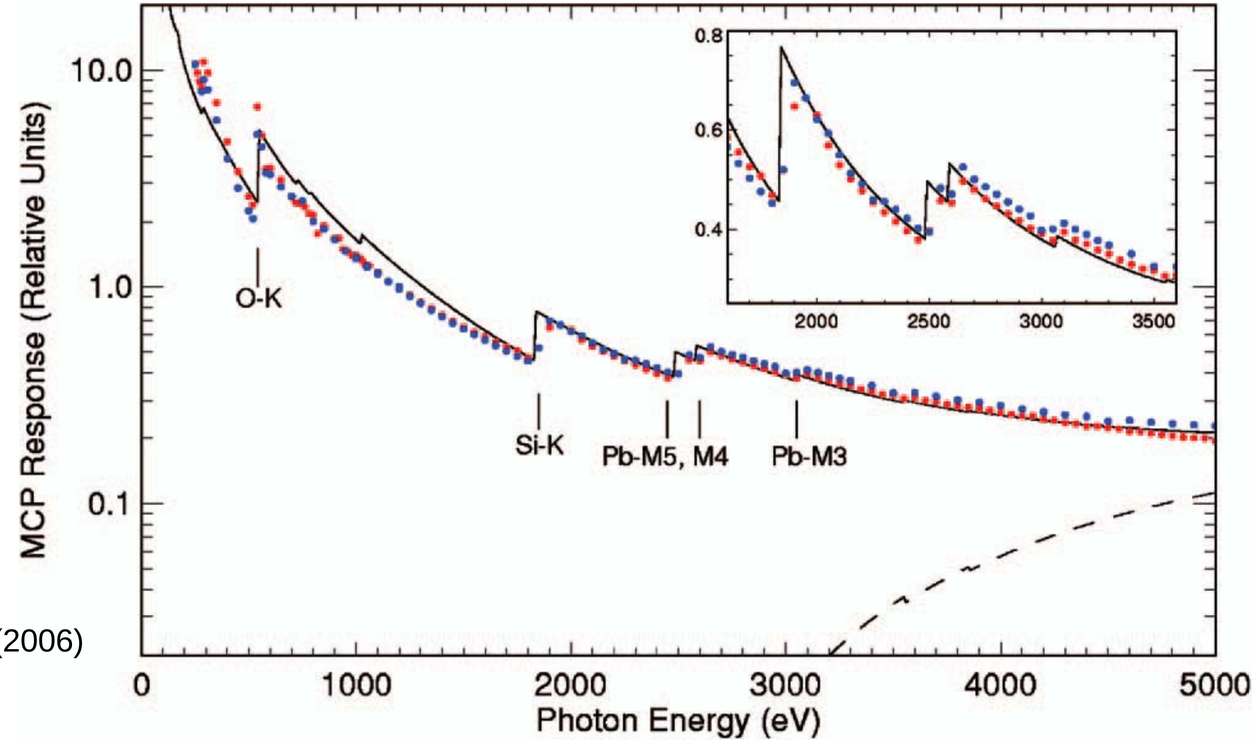
Component	Diagnostic	Calibration Type	Calibration Energy	Calibration Frequency	FY '08	FY '09	FY '10	FY '11
Mirrors	Omega Dante	Reflectance	0-1 keV	Semi-annually	6	6	6	6
	NIF Dante	Reflectance	0-1 keV	Semi-annually	14	14	14	14
				Totals	**40**	**40**	**40**	**40**
Filters	Omega Dante	Transmission	0-1 keV	Semi-annually	35	35	35	35
		Transmission	2-6.5 keV	Semi-annually	35	35	35	35
	NIF Dante	Transmission	0-1 keV	Semi-annually	50	50	50	50
		Transmission	2-6.5 keV	Semi-annually	50	50	50	50
				Totals	**340**	**340**	**340**	**340**
XRDs	Omega Dante	Responsivity	0-1 keV	Semi-annually	18	18	18	18
		Responsivity	2-6.5 keV	Semi-annually	18	18	18	18
	NIF Dante	Responsivity	0-1 keV	Semi-annually	42	42	42	42
		Responsivity	2-6.5 keV	Semi-annually	42	42	42	42
				Totals	**240**	**240**	**240**	**240**

The calibration workload will increase approximately when NSLS is transitioning to NSLS-II

NSLS continues to provide high quality micro-channel plate calibrations.

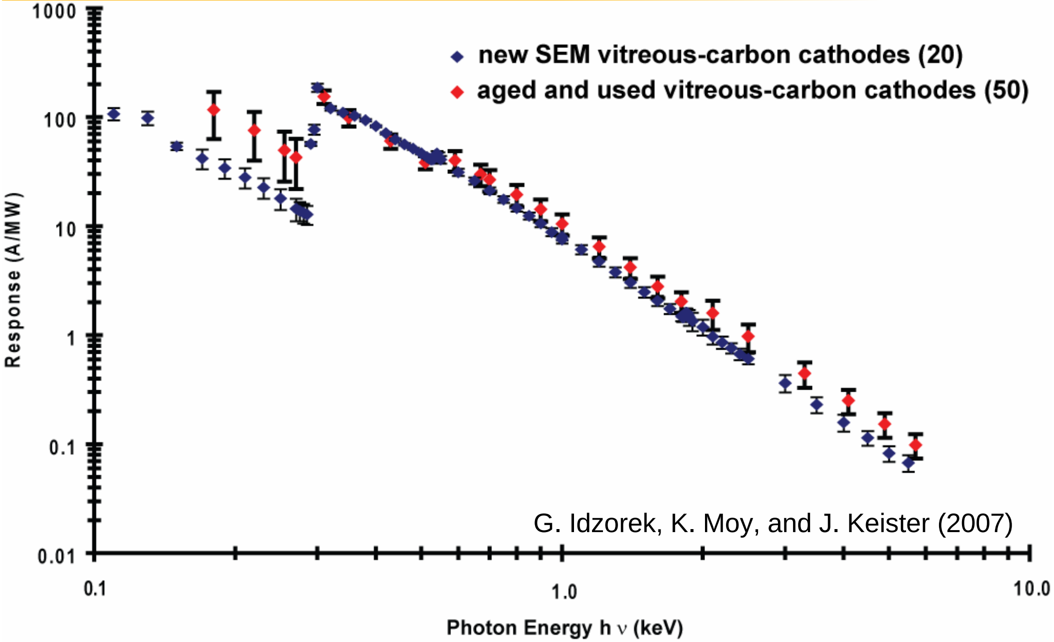


G.A. Rochau, *et al.*, RSI **77** 10E323 (2006)



Demonstrated the computational complexity required to accurately predict MCP performance.

X-ray Diode Calibrations for Sandia Z diagnostics



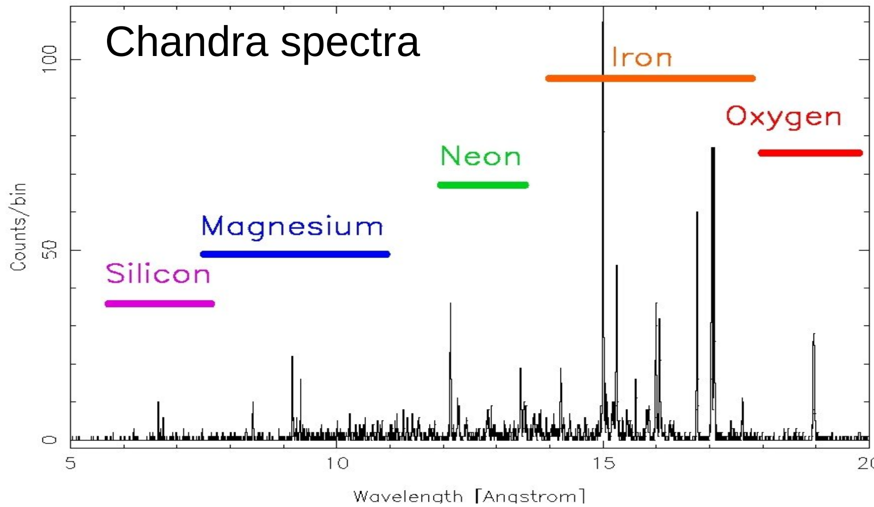
G. Idzorek *et al.*, Proc. of PPPS-2007,

Significantly reduced uncertainty using new, inexpensive vitreous-carbon SEM cathodes

50-250 eV, 20 eV steps
250-300, 5
300-500, 20
500-540, 5
550-1000, 50
1000-1700, 100
1700-1800, 10
1800-2400, 100
2500-6000 eV, 500 eV steps

- **Need to resolve higher-order light problem on U3c to reduce uncertainties near absorption edges [attempting to secure a TGS to make measurements].**
- **Transmission calibrations are done with two detectors, in front and behind filter. This method limits to transfer standard accuracy (about 5-10%). Using a single detector behind filter and moving the filter in and out of the beam will improve accuracy (probably 2-5%).**
- **More calibrations will be required to test aging (and use-deposition) response of these detectors. Might be possible to calibrate only a few in a batch and rely on reproducibility.**

The U-3/X-8 capability has been a vital contributor to both NNSA and non NNSA programs



- **Components of the Chandra X-ray Observatory were characterized and calibrated at NSLS in the range 0.05-12 keV.**
- **The calibration work resulted in iridium becoming one of the best understood x-ray optics materials.**

NNSA projects similar to this NASA Chandra success are on-going at U3c and X8a

Future desired calibrations expand beyond the current X8a capabilities.

- High Energy X-ray Imager response up to 50 keV
- High energy x-ray CCD Camera with 2” X 2” fiber-coupled fluor, wavelength responsivity up to 50 keV… most likely at Sm Kα at 40 keV.
- Snouts for streaked x-ray spectrometers, e.g. OMEGA’s SCC-A, as well as the camera, in the 1-10 keV range.
- 2-D imaging cameras with spectroscopic snouts in the 1-10 keV range

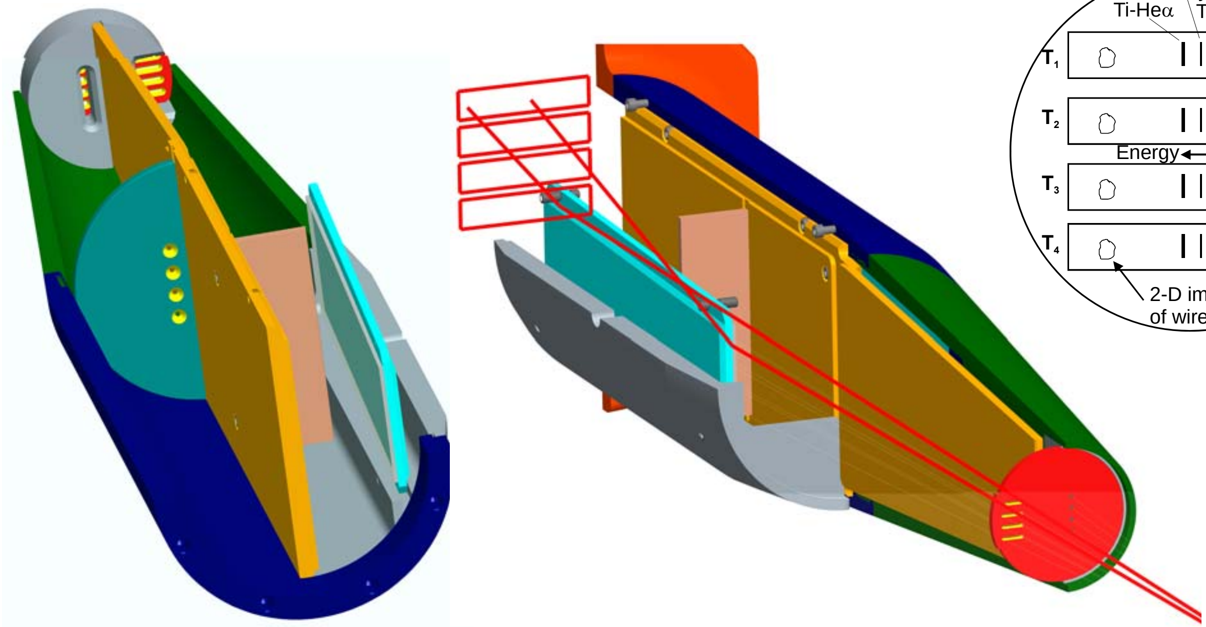
Possible NSLS upgrades to U3c and X8a

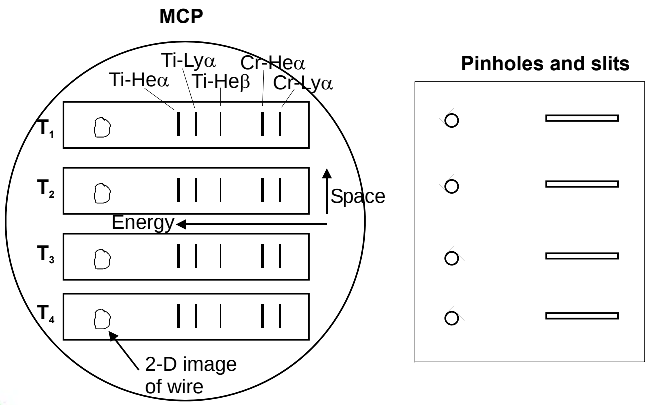
Desired upgrades for the current beamlines at NSLS

- Higher order trap – needs to be replaced. Alignment requirements are increasing due to reduced size of detectors.
- Spectral purity diagnostics.
- New end-stations – Increased automation and positioning accuracy. Currently just 8" conflats and a long-throw positioning system.
- Reflectometry system for mirror (e.g., Dante) calibrations; may be included in an end station refurb.
- Radiometer that is accurate to <0.1% in total power, which would improve our accuracy by nearly an order of magnitude ($190k).

Emerging needs and growth areas

Grazing Incidence Spectrometer (GIS)





Schematic Layout of Data on MCP

- **Relative reflectivity in the range 3-6 keV with 5 eV steps with 1 eV or better near 1-2, 1-3 transitions in titanium, scandium, and vanadium**
- **Absolute reflectivity at 4-6 points in the 4-6 keV range.**

DEF Film Replacement Calibrations*

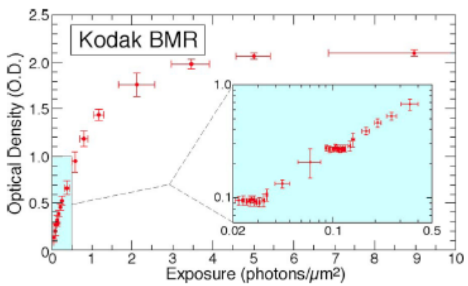


FIG. 4. The Kodak BMR response curve for 4.73±0.02 keV photons. The single side emulsion exhibits strong saturation at exposures near 2.0 photons/μm^2.

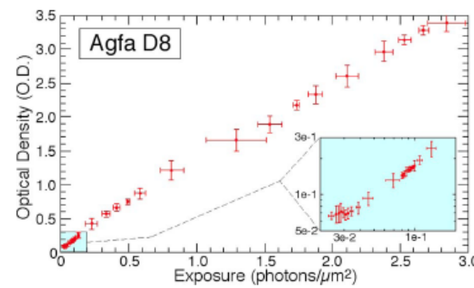


FIG. 5. The Agfa D8 response curve for 4.73±0.02 keV photons. A double-sided film, D8 sensitivity is equivalent to Kodak BMR without the early saturation.

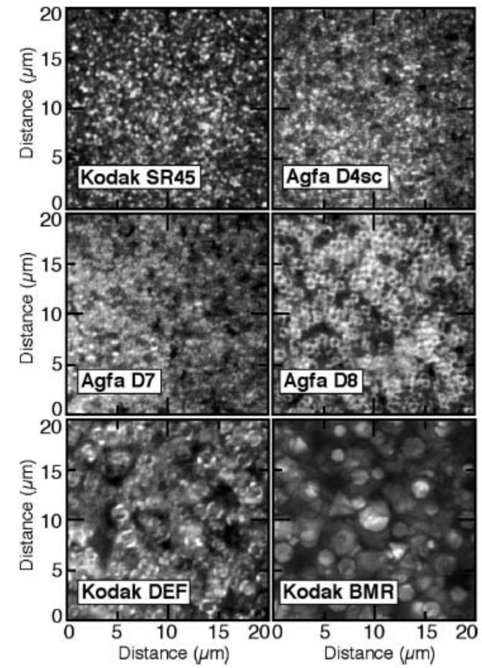


FIG. 9. High magnification face-on images of SR45, D4sc, D7, D8, DEF, and BMR emulsions. The silver halide grains appear as white spots. Their average grain sizes were measured to be 0.3, 0.4, 0.7, 0.9, and ~2.0 μm, respectively. Though they appear large, the BMR grains have a flakelike structure and are, in fact, very thin (Ref. 17).

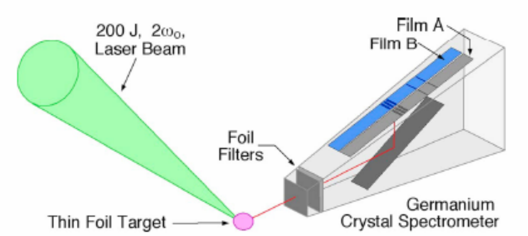


FIG. 1. A laser strikes a metal foil of Sc, Ti, or V creating a highly ionized plasma. The resulting x-ray emission is resolved with a germanium crystal spectrometer that distributes the spectral lines equally across both film planes.

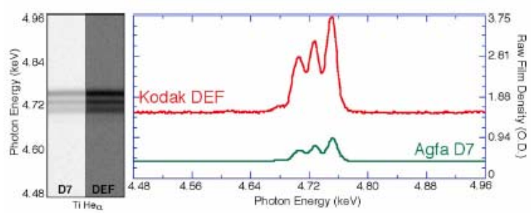
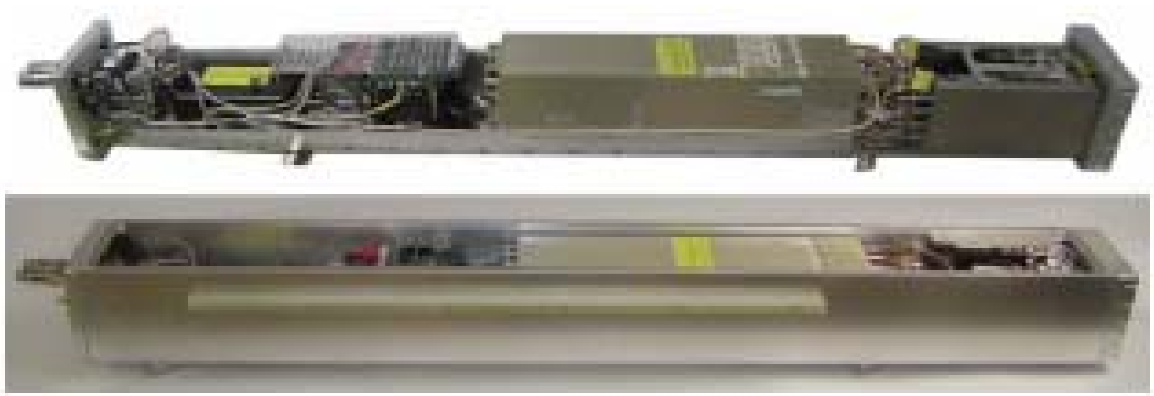


FIG. 2. Spectrometer data from shot 17 971 showing the He-like titanium emission (left). The average spectra (right) clearly show that DEF is much more sensitive, but with significantly more fog, than D7.

- **Absolute (few locations) and relative response characteristics of AGFA D4, D7, and D8 and Kodak SR45 films from 2 to 20 keV**
- **Similar wavelength-dependent calibrations would be desirable for Fuji Image Plates**

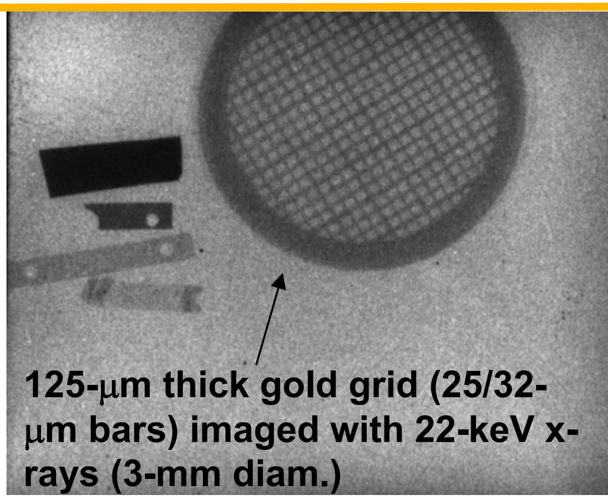
*From N. Lanier, Cowan, and Workman, Rev. Sci. Instrum. **77**, 043504 (2006)

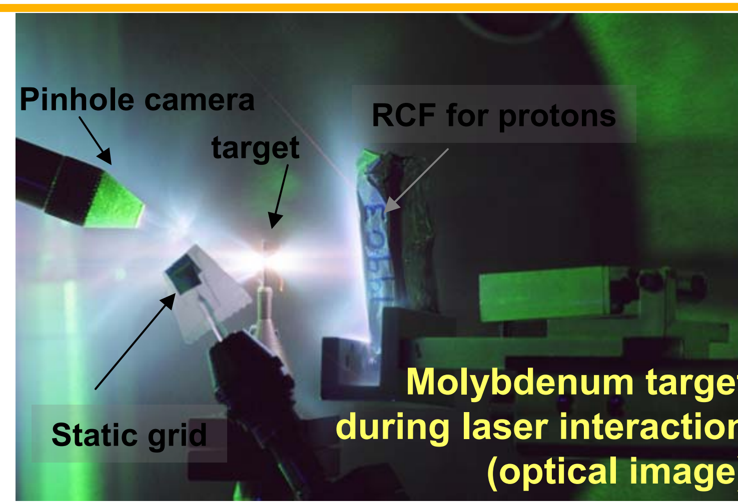
NIF diagnostic -- Gated X-ray Detector (GXD)

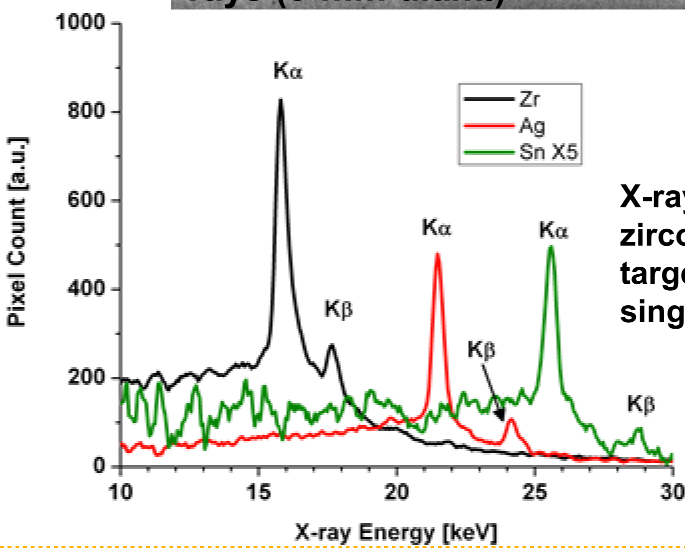


- Need NSLS calibration of response, sensitivity, and noise (electrons from the ccd/ eV) for pulsed MCP operation with large x-ray flux in range 5-20 keV.
- Will combine with flat fielding data and system MTF across GXD face for x-ray energies 5,10,15, 20 keV at few irradiance levels
  [1 , 2, 4,10 photons/micron or per MCP channel].

Projects with high intensity short pulse lasers need calibrated x-ray diagnostics, film, and image plates.





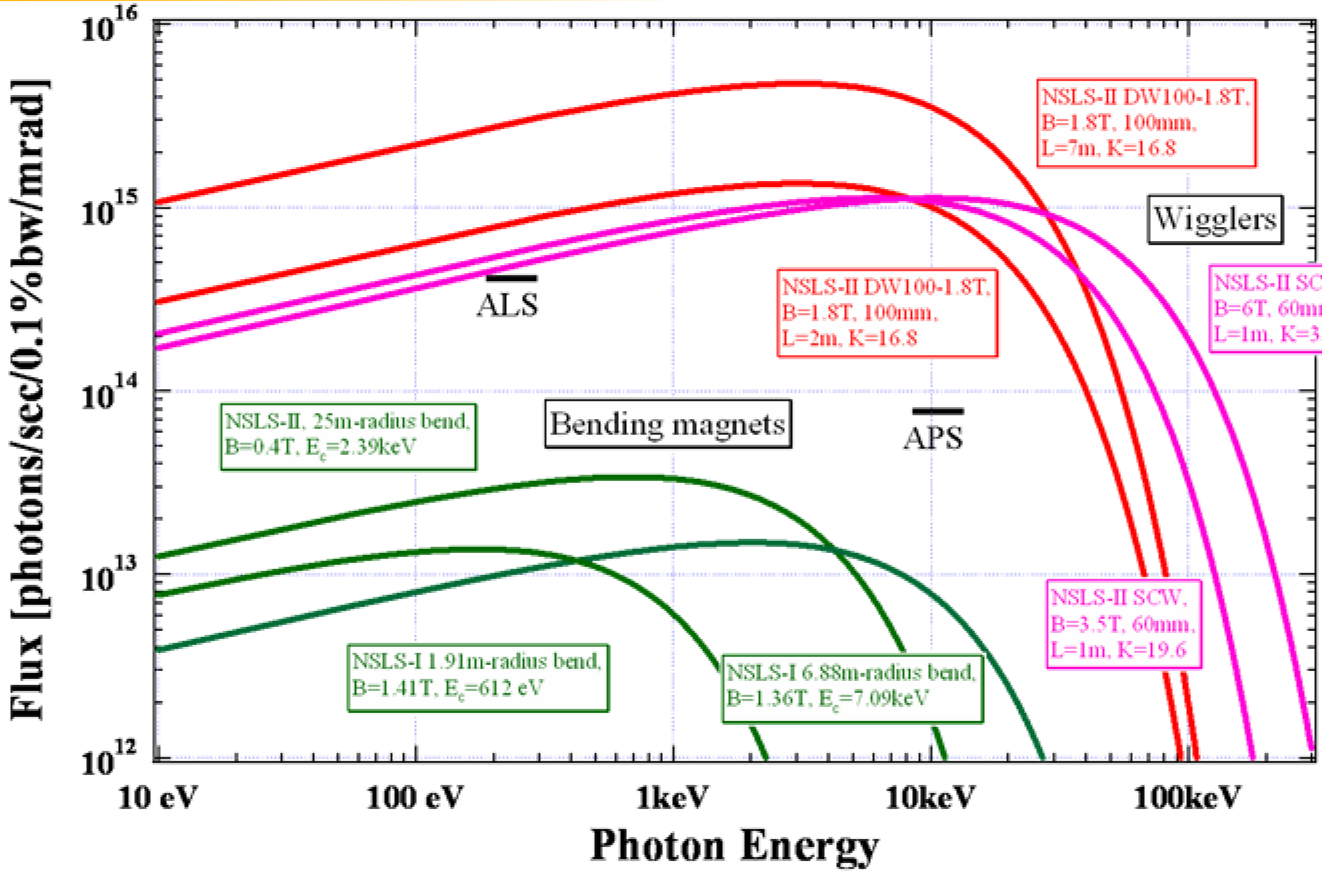


X-ray spectra from zirconium, silver and tin targets obtained from a single photon counter

High energy x-ray sources is a growing area of interest in high energy density physics as ultra-short pulse, high fluence petaWatt lasers come online.

Looking forward: NSLS-II Transition

NSLS-II will offer us an opportunity to dramatically expand capabilities over NSLS.



- Critical need in range of 0.01 to 2 keV, some requirements out to 20 keV.
- Growing needs out to 100 and 200 keV.

We are examining (ballpark) construction and commissioning costs for equivalent NSLS-II beamline(s)

30 eV to 3 keV (UV) Beamline	$ M
First optics enclosure	0.2
Front End mirror	0.4
White Beam slits	0.2
VLS-PGM mono, with M2 and gratings	1.1
Exit slits	0.1
Refocusing	0.4
Endstation, beamline controls, control station	1.5
Utilities, layout, transport, and interlocks	1.0
Design, construction, and commissioning staff	2.0
CY07 $$ TOTAL	6.9

2 keV to >30 keV (X-ray) Beamline	$ M
First optics enclosure and experimental hutch	0.5
White Beam slits and other beam conditioning	0.5
White Beam components: silicon mono, mirror	1.0
Endstation, beamline controls, control station	2.0
Utilities, layout, transport, and interlocks,	1.0
Design, construction, and commissioning staff	2.0
CY07 $$ TOTAL	7.0

- **The proposed NSLS-II beamlines maintain and enhance current capabilities with modest improvements in accuracy, range, and white light capability.**
- **X-ray beamline extend energy range over current X8a to 30 keV.**
- **The duration is 2 or 3 years starting in FY11.**

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Conclusions

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- The NSLS beamlines have been an internationally recognized as a preferred calibration source for high energy density diagnostics.
- NNSA programs greatly benefit from the availability of the beamlines and make excellent use of available capacity.
- NNSA Laboratories are assessing needs and capacity requirements for beamlines at NSLS-II

The NSLS beamlines ENABLE World-leading science at high energy density facilities.