

APPLICATIONS OF HIGH-POWER ULTRAFAST LASERS DRIVEN X-RAY SOURCES

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PART II: FROM IMAGE TO MACHINE:

illustration through an attempt to build an industrial solution

- *Building a laser-based X-ray machine*
- *The industrial perspective with K-alpha X-ray sources*
- *The industrial perspective with LWFA-based X-ray sources*
- *To conclude*

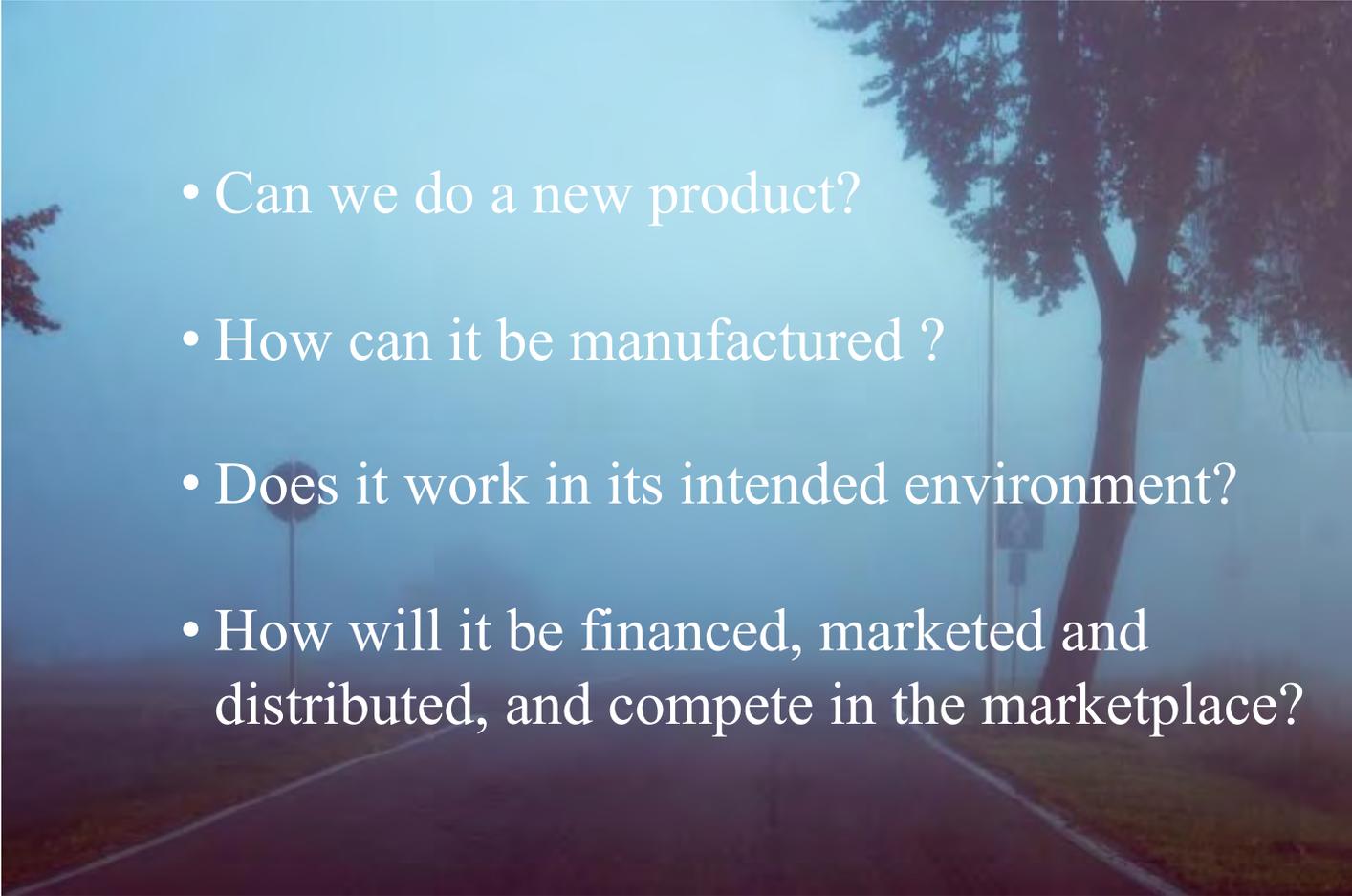
Building a machine



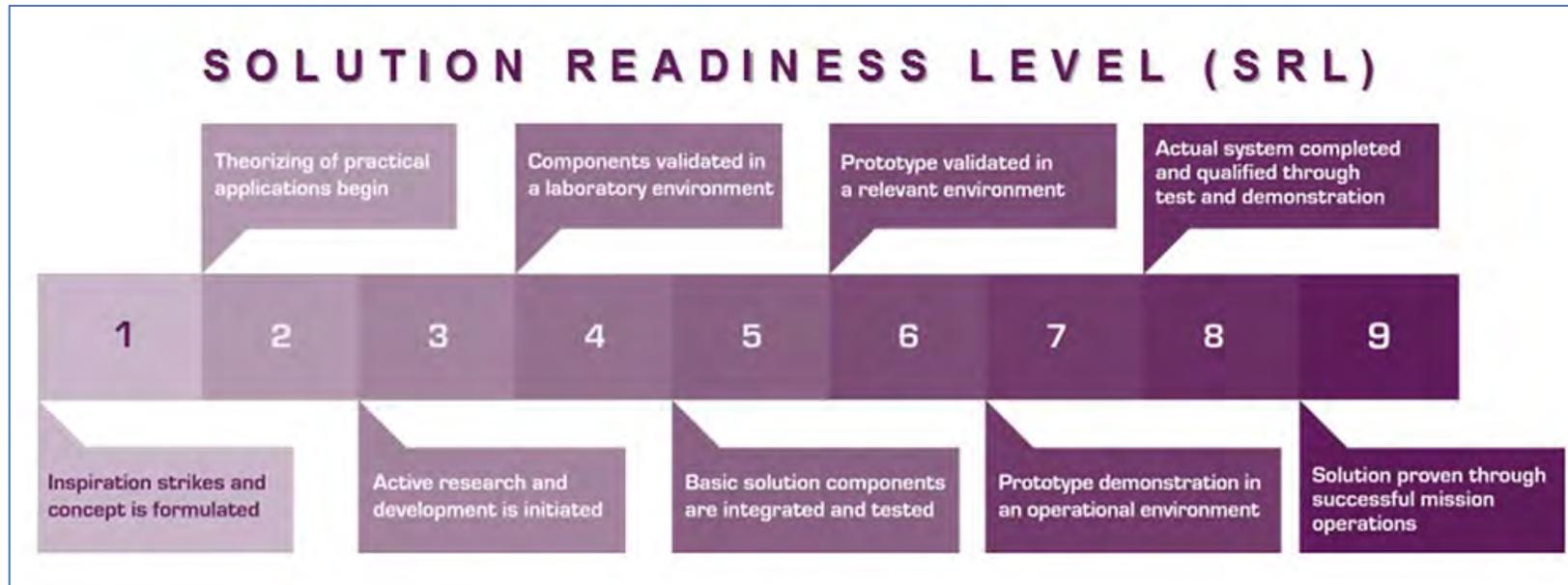
Building a Laser-based industrial solution



Building a Laser-based industrial solution

- 
- Can we do a new product?
 - How can it be manufactured ?
 - Does it work in its intended environment?
 - How will it be financed, marketed and distributed, and compete in the marketplace?

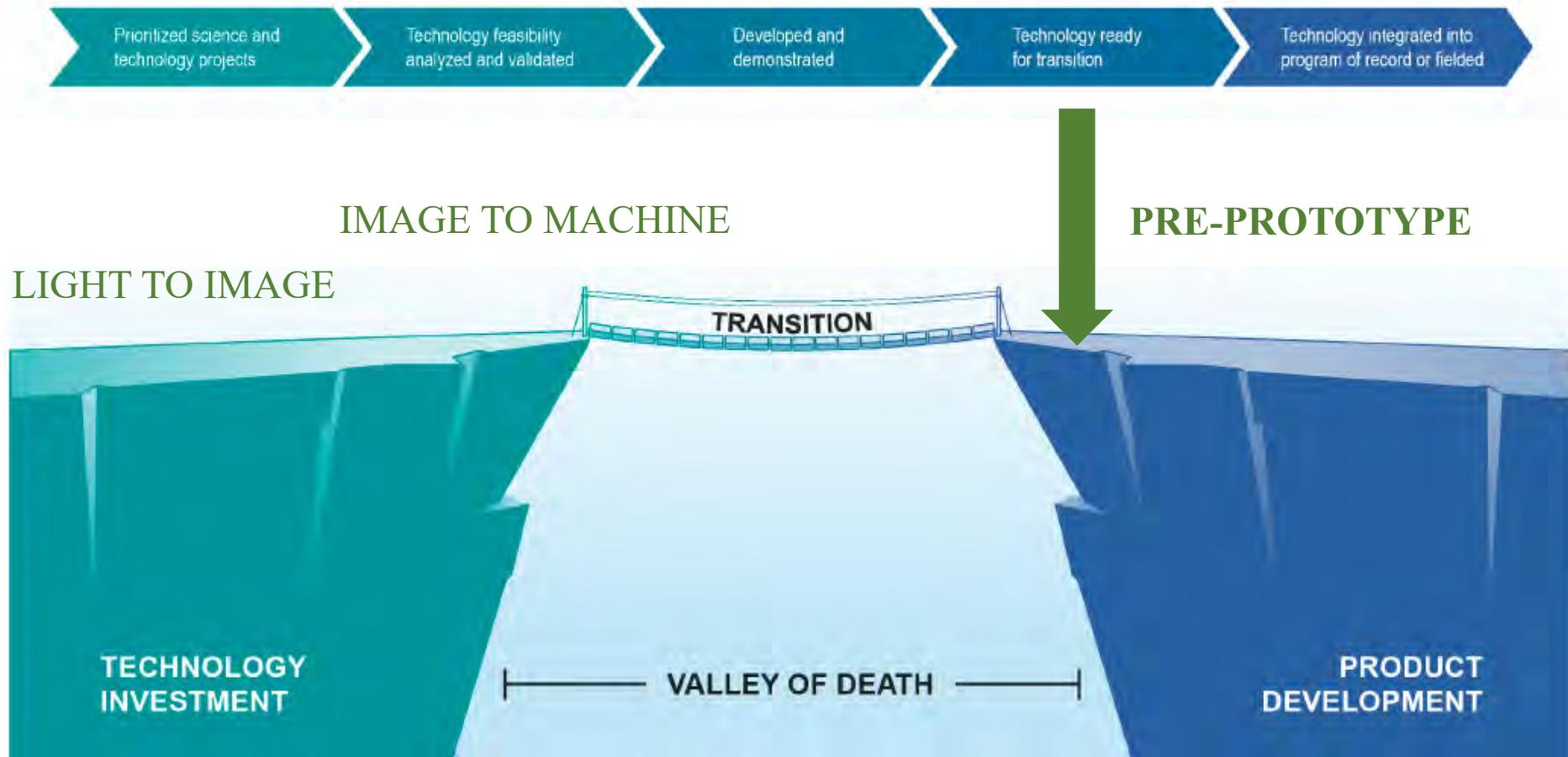
Building a Laser-based industrial solution



The SRL metric includes TRL, IRL, MRL, CRL

Technology, Integration, Manufacturing & commercialization readiness levels

Figure 3: Department of Defense (DOD) Technology Management Process and Depiction of Transition Vulnerability over the “Valley of Death”

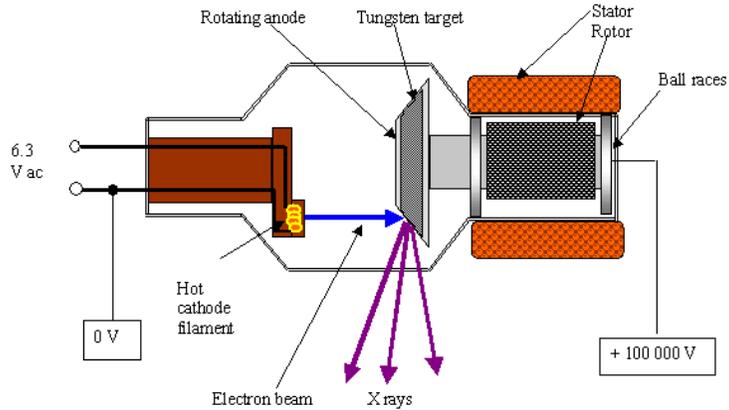


Source: GAO review of DOD information. | GAO-23-105868

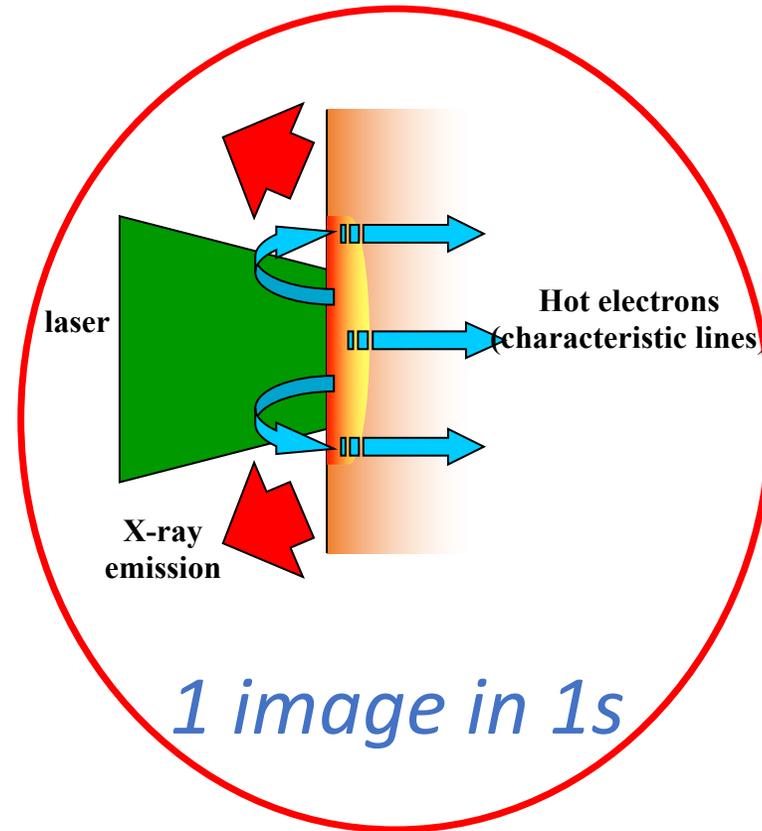
THE INDUSTRIAL PERSPECTIVES WITH K-ALPHA X-RAY SOURCES



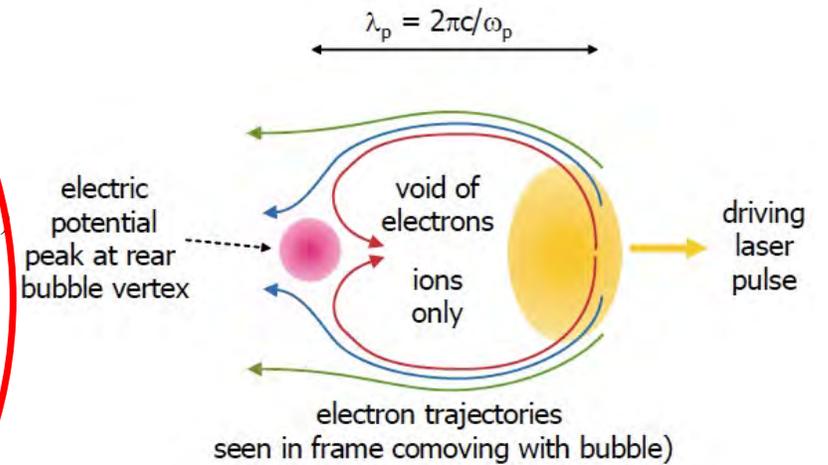
Is there a future for a laser-based X-rays?



500 μm



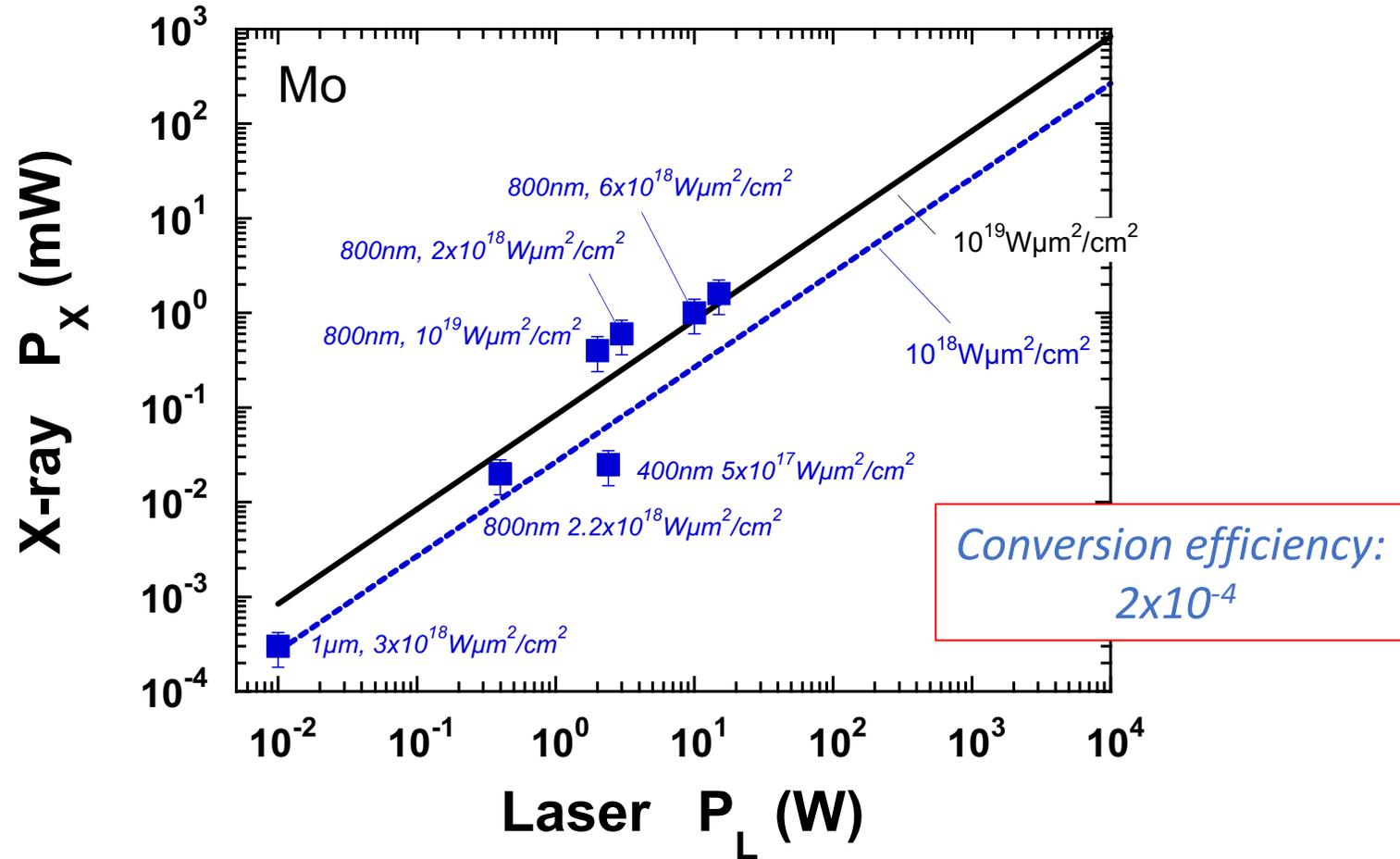
20 μm



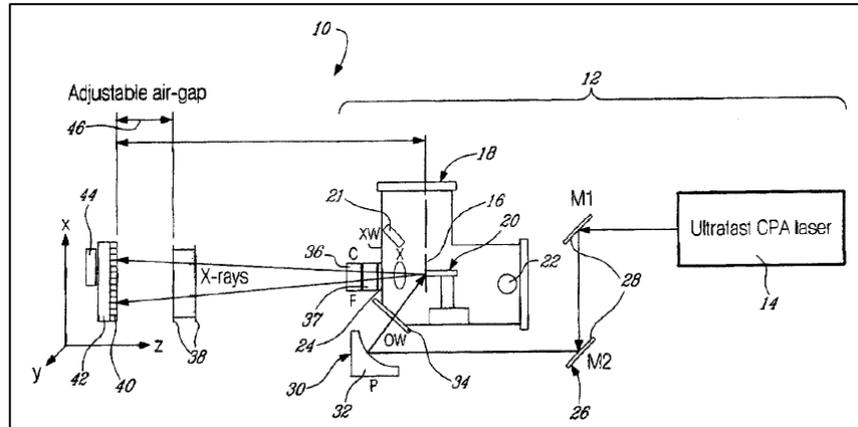
1 μm



UP TO 1mW (in 2π) of 17keV X-RAYS PRODUCED
(up to 60 μ J/shot)



2002: Conceptual Design of a K-alpha X-ray machine



(12) **United States Patent**
Kieffer et al.
(10) Patent No.: **US 6,980,625 B2**
(45) Date of Patent: **Dec. 27, 2005**

(54) SYSTEM AND METHOD FOR GENERATING MICROFOCUSED LASER-BASED X-RAYS FOR MAMMOGRAPHY	5,089,711 A	2/1992	Morsell et al.	250/492.3
	5,151,928 A	9/1992	Hirose	378/119
	5,175,757 A	12/1992	Augustoni et al.	378/120
	5,323,442 A	6/1994	Golovanivsky et al.	378/119
	5,335,258 A	8/1994	Whitlock	378/122
(75) Inventors: Jean-Claude Kieffer , 3801 av de Melrose, Montreal Quebec (CA), H4A 2S3; Andrzej Krol , Fayetteville, NY (US)	5,394,411 A	2/1995	Milchberg et al.	372/5
	5,418,833 A	5/1995	Logan	378/154
	5,606,588 A *	2/1997	Umstadter et al.	378/119
	5,712,890 A *	1/1998	Spivey et al.	378/37
	5,812,629 A	9/1998	Clauser	378/62
	5,832,007 A	11/1998	Hara et al.	372/5
	6,094,471 A	7/2000	Silver et al.	378/84
	6,249,566 B1	6/2001	Hayashi et al.	378/85
	6,324,255 B1 *	11/2001	Kondo et al.	378/119
	6,594,335 B2 *	7/2003	Davidson	378/43

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/227,704**
(22) Filed: **Aug. 26, 2002**

* cited by examiner
Primary Examiner—Craig E. Church
(74) Attorney, Agent, or Firm—Orum & Roth LLC
(57) **ABSTRACT**

Appl. Phys. B 74 [Suppl.], S75–S81 (2002)
DOI: 10.1007/s00340-002-0870-3

Applied Physics B
Lasers and Optics

Future of laser-based X-ray sources for medical imaging

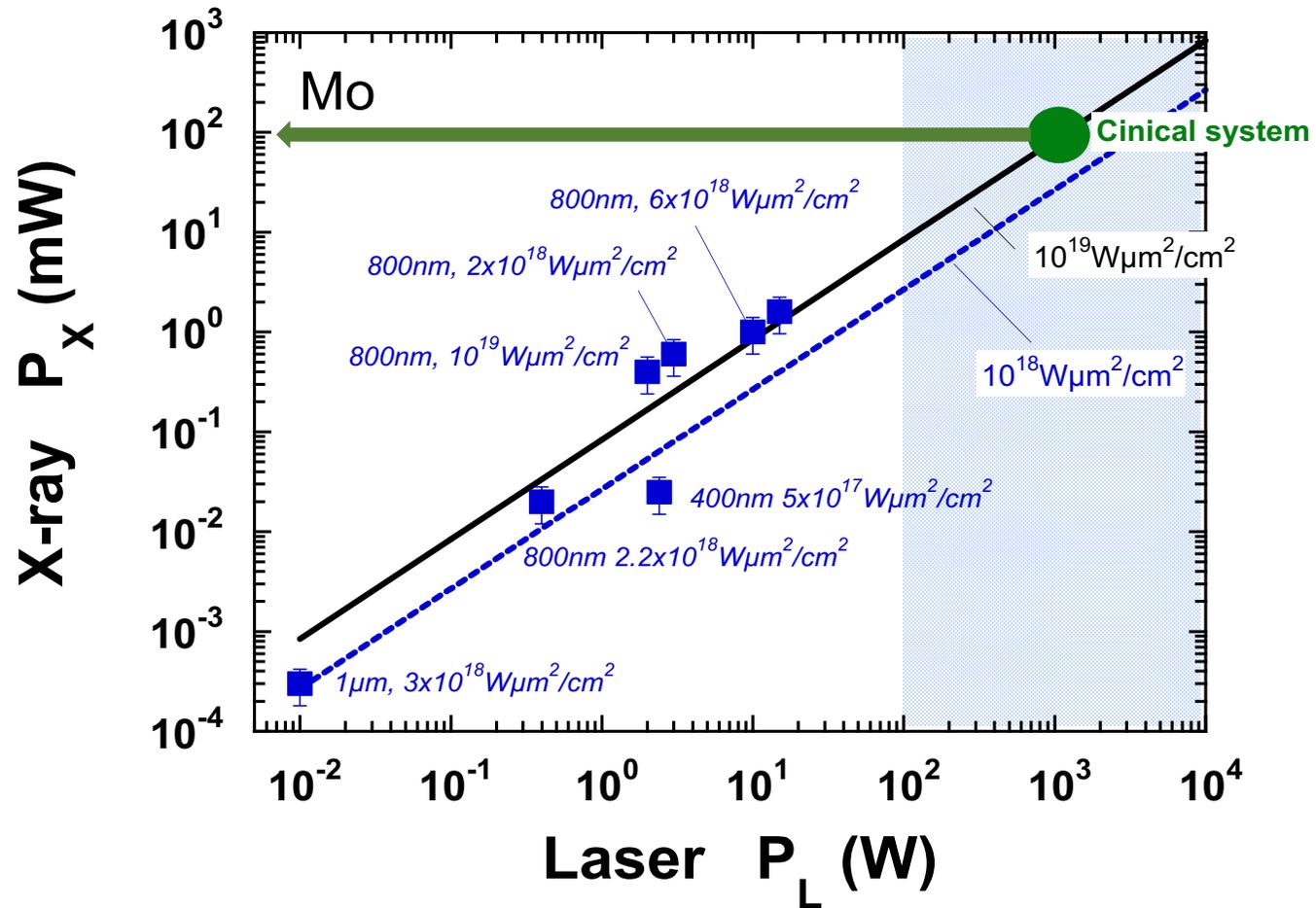
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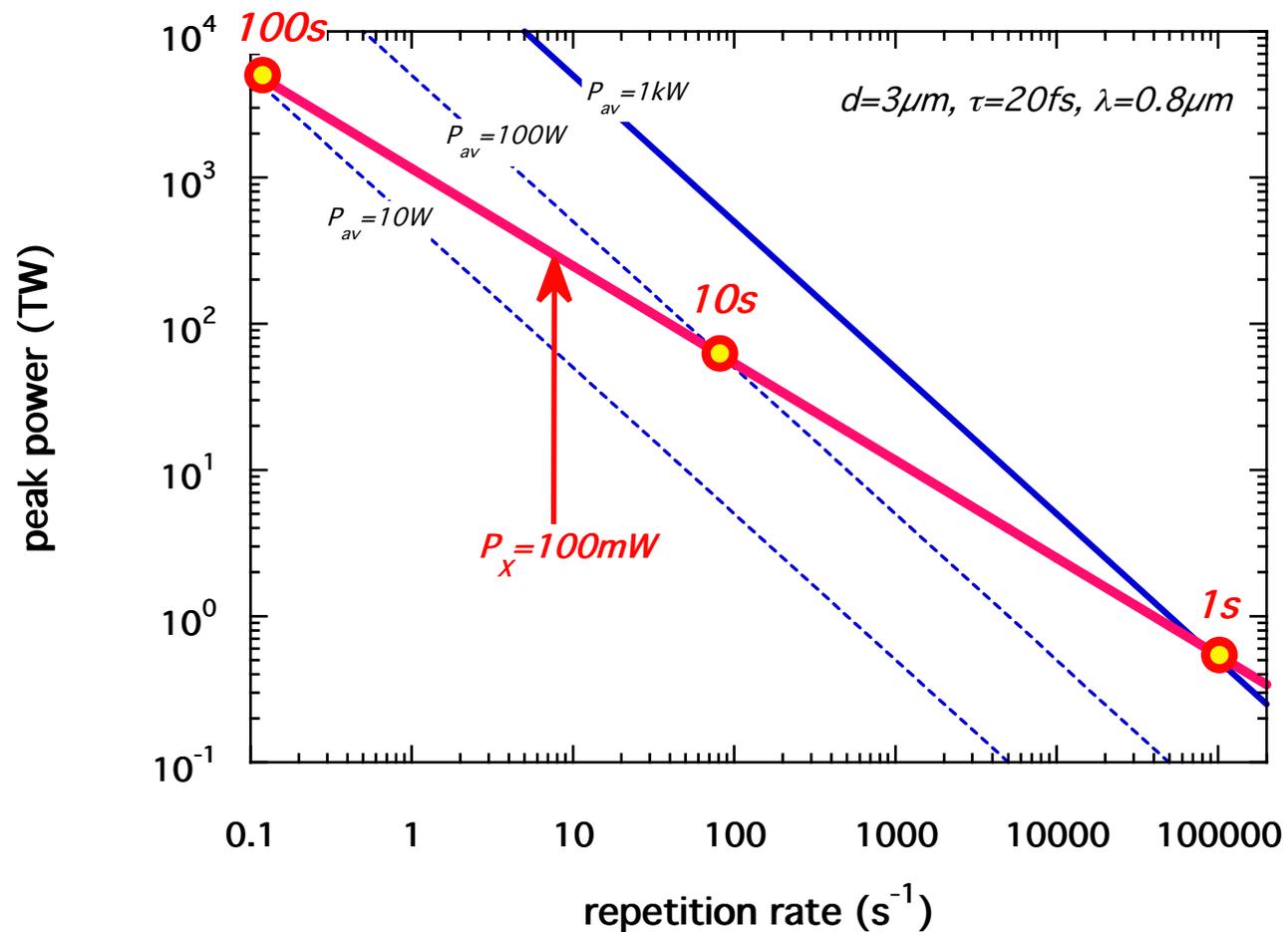
Received: 13 September 2001/
Revised version: 30 November 2001
Published online: 5 July 2002 • © Springer-Verlag 2002

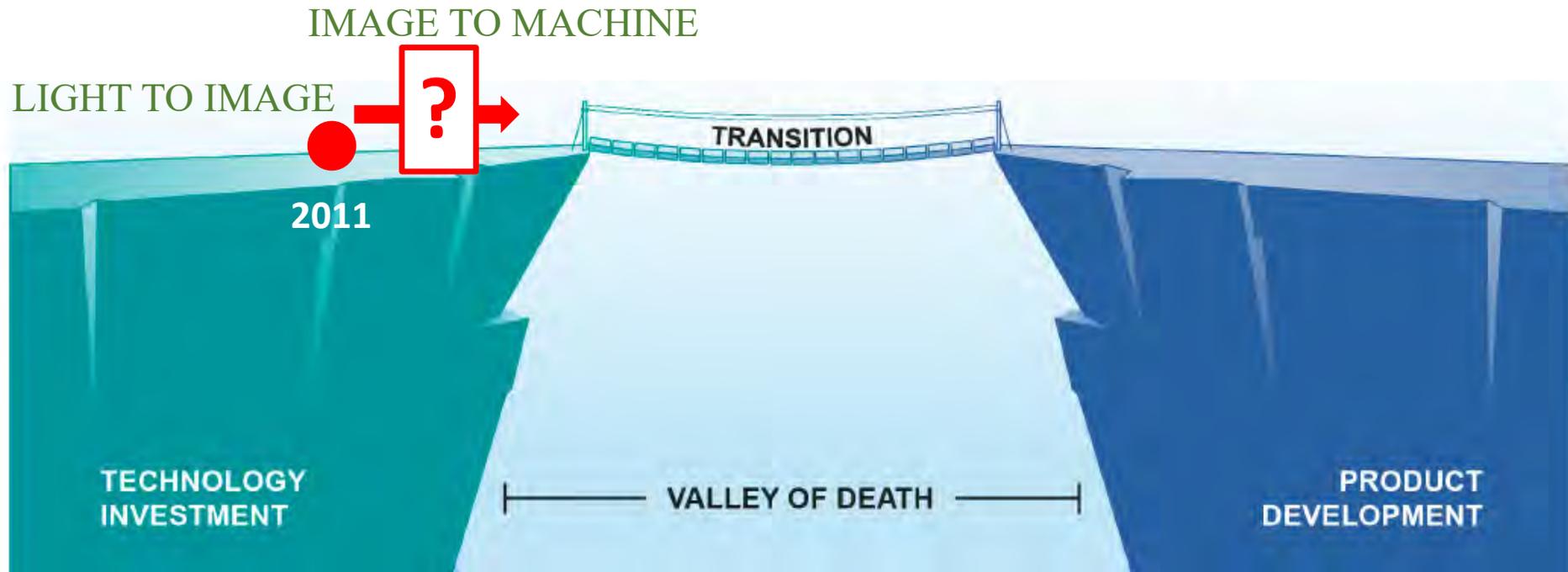
filter change and in some mammography systems by target track change). The low output necessitates a long exposure time and results in motion blur.

NEED 100mW OF X-RAYS FOR A CLINICAL SYSTEM
WITHOUT PHASE IMAGING



In 2011, the required laser technology is not existing

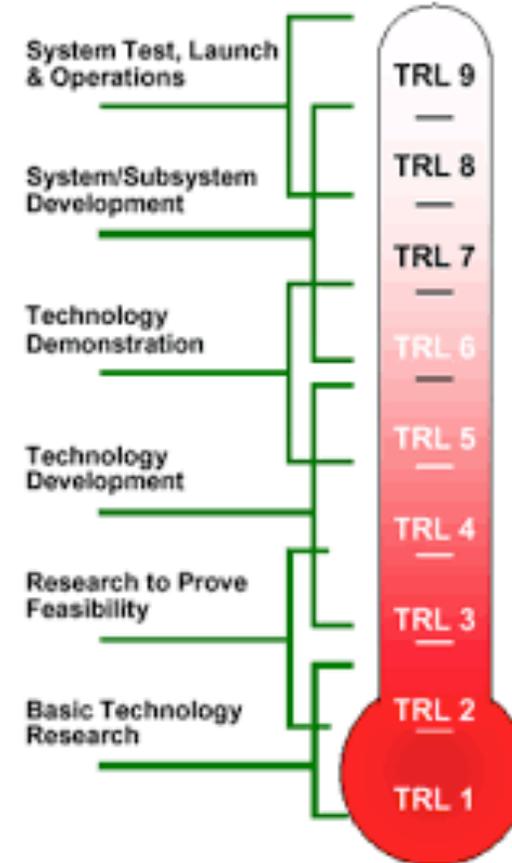




Source: GAO review of DOD information. | GAO-23-105868

Facing a valley of death in 2011

- 1989 – 2011:
 - *High Benefit demonstrated*
 - *But laser technology had to be developed **TRL=3***
- 2011: **NO GO: 1st valley of death**
 - *No appropriate local industrial ecosystem*
 - *Development costs too high*
 - *Development time scale too long*



THE INDUSTRIAL PERSPECTIVES WITH LWFA-BASED X-RAY SOURCES

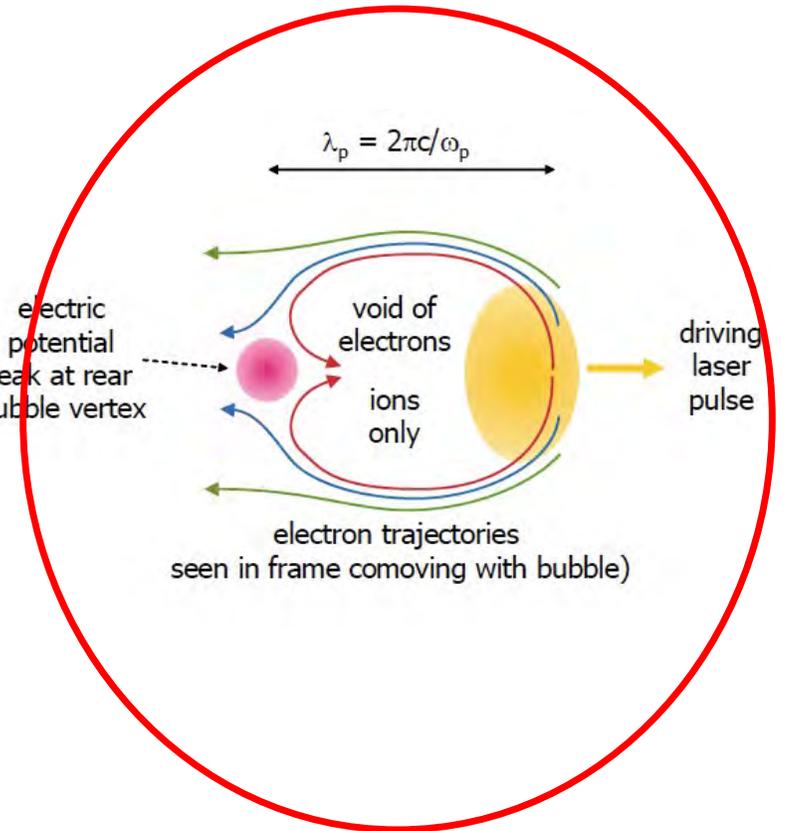
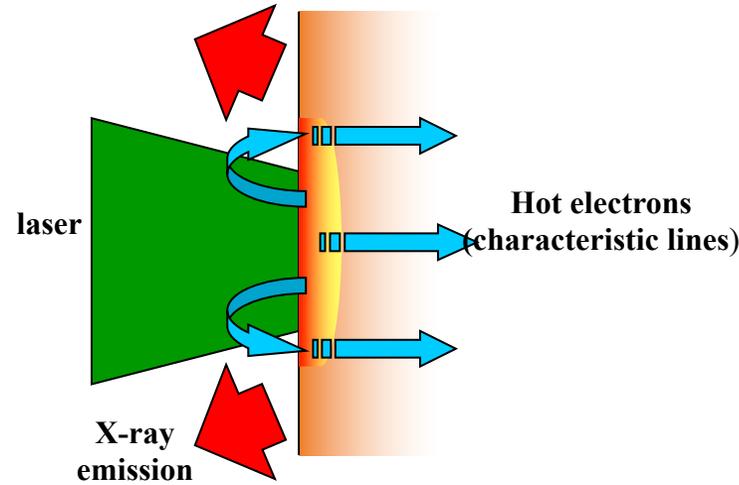
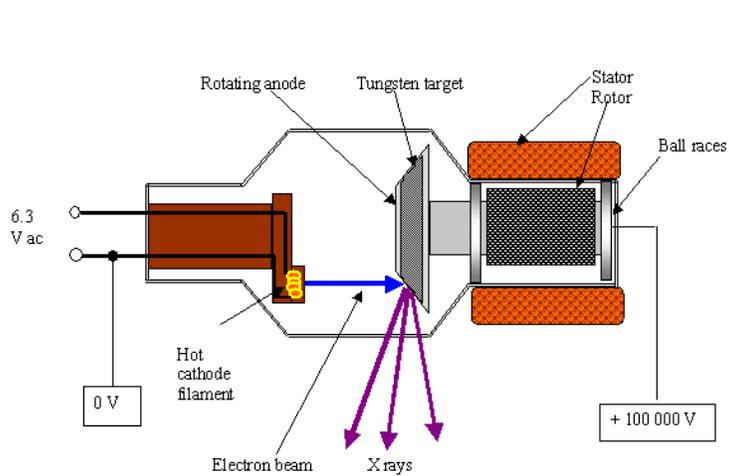


2015: Our main goal

- ✓ Help to deliver innovative solutions for the production of globally sustainable Food
- ✓ From concept to commercialisation
- ✓ Going inside the farm



Is there a future for a laser-based X-rays?



1 image in 1s

500 μ m

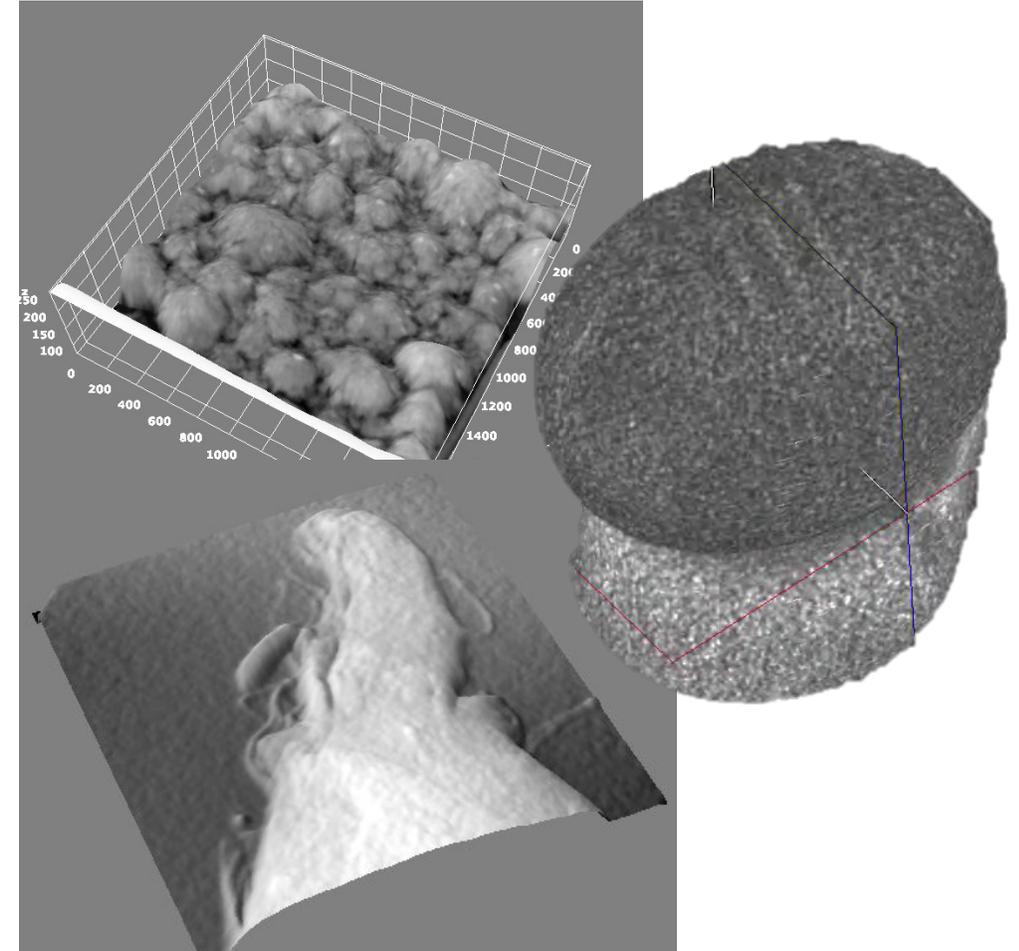
20 μ m

1 μ m

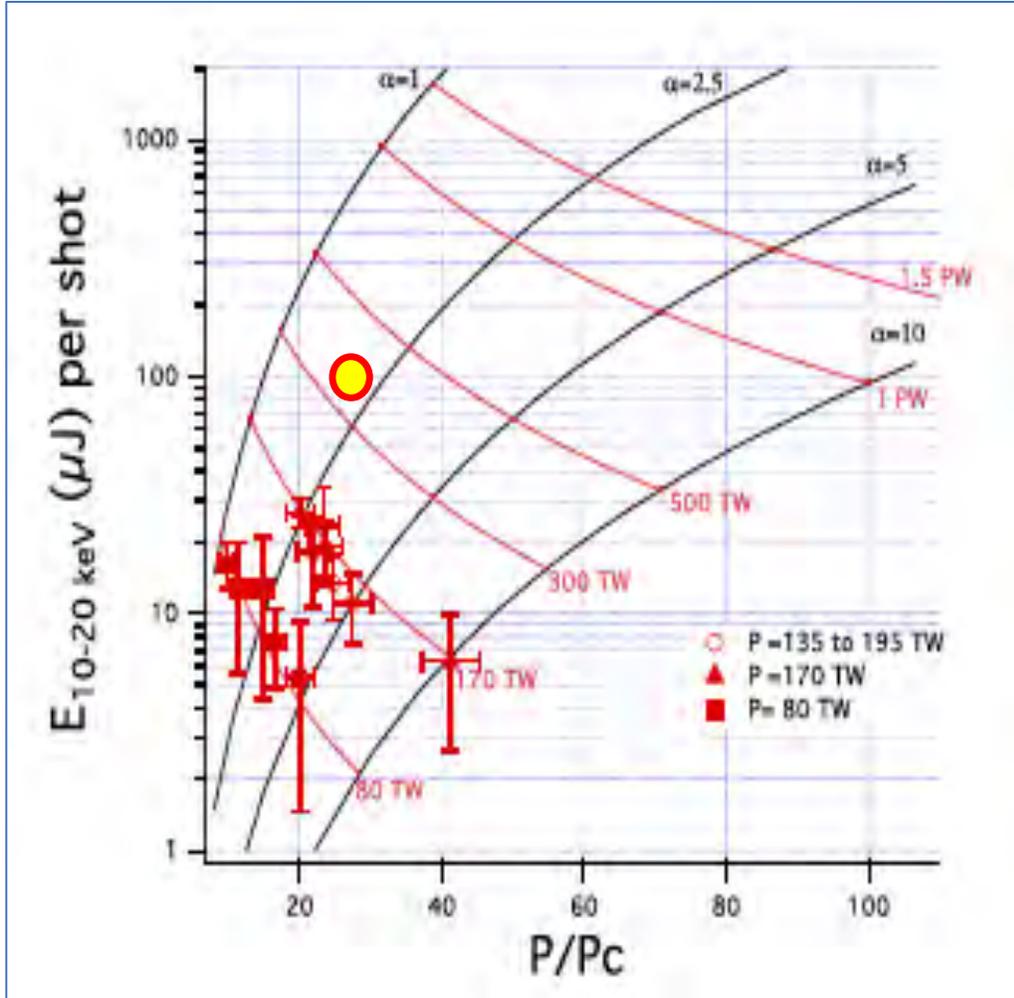


Building an industrial solution

- 2009 – 2011:
 - *Assess a new laser technology*
 - *Assess a new physics concept (LWFA)*
 - *Assess imaging potential*
- 2011 – 2018:
 - *FEASIBILITY demonstration*
 - *DESIGN of a functional system*
 - *Discussion with end users*
 - *Define integration levels*



Defining scaling, feasibility



Research Article Vol. 28, No. 3/3 February 2020 / Optics Express 3147

Optics EXPRESS

Laser-based synchrotron X-ray radiation experimental scaling

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¹Institut National de la Recherche Scientifique - Énergie, Matériaux et Télécommunications, Université du Québec (INRS-EMT), 1650 Lionel Boulet, Varennes J3X 1S2, Québec, Canada
²Global Institute for Food Security, 110 Gymnasium Place, University of Saskatchewan, Saskatoon S7N 4J8, Saskatchewan, Canada
³ELI Beamlines, Institute of Physics CAS, Prague 182 21, Czech Republic

$$E_c \sim (I\lambda^2)^{5/4} n^{-3/2}$$

$$N_x \sim (I\lambda^2)^{1/2} n^{-2}$$

preliminary manufacturing readiness

The ultrafast high-peak power lasers in future biomedical and medical X-ray imaging

Jean-Claude Kieffer, S Fourmaux, A Krol

2016

To cite this version:

Jean-Claude Kieffer, S Fourmaux, A Krol. The ultrafast high-peak power lasers in future biomedical and medical X-ray imaging. 19th International Conference and School on Quantum Electronics, Alexandros Serafetinides; Sanka Gateva; Latchevar Avromov, Sep 2016, Sozopol, Bulgaria. pp.1022612-1, 10.1117/12.2261795. hal-01441646

Applied Physics B (2019) 125:34
<https://doi.org/10.1007/s00340-019-7144-9>

Applied Physics B
Lasers and Optics



2019

Optimization of laser-based synchrotron X-ray for plant imaging

S. Fourmaux¹ · E. Hallin² · P. G. Arison^{2,3} · J. C. Kieffer¹

Received: 21 February 2018 / Accepted: 27 January 2019 / Published online: 5 February 2019
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THALES



LASER-BASED X-RAY MACHINE PROJECT

20/09/2021



(12) **United States Patent** (10) **Patent No.:** US 11,438,997 B2
 Fourmaux et al. (45) **Date of Patent:** Sep. 6, 2022

(54) **METHOD AND SYSTEM OF LASER-DRIVEN INTENSE X-RAY PHOTONS IMAGING** (51) **Int. Cl.**
 H05G 2/00 (2006.01)
 G01N 33/00 (2006.01)
 G01N 23/041 (2018.01)

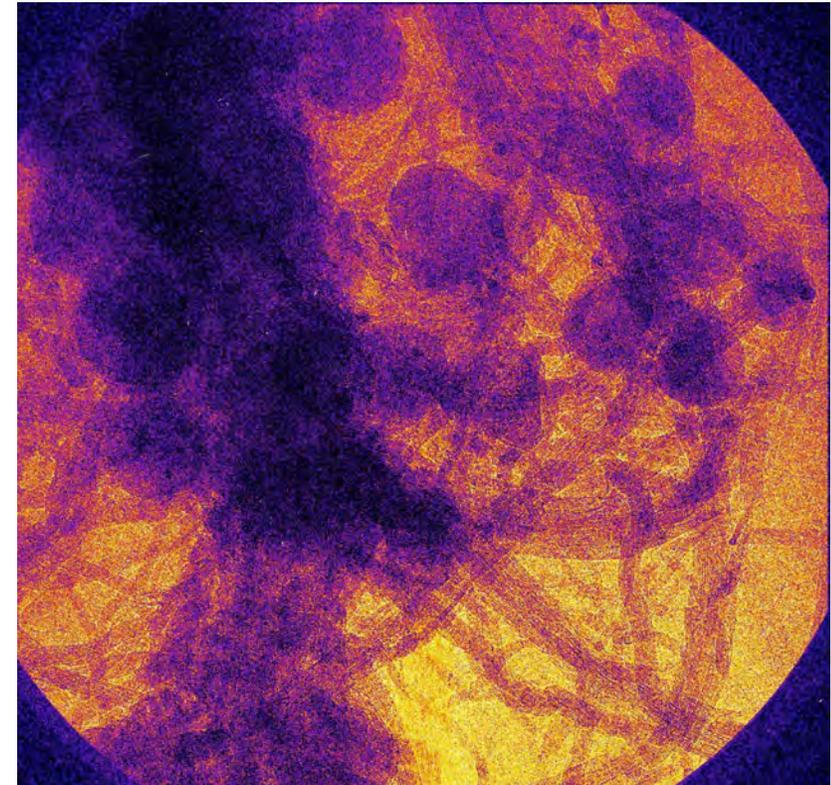
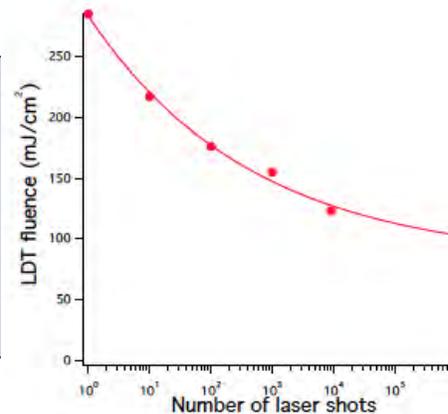
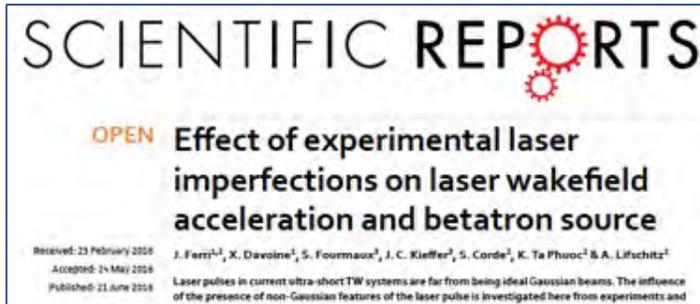
(71) **Applicants:** INSTITUT NATIONAL DE LA RECHERCHE SCIENTIFIQUE, Québec (CA); UNIVERSITY OF SASKATCHEWAN, Saskatoon (CA) (52) **U.S. Cl.**
 CPC H05G 2/008 (2013.01); G01N 23/041 (2018.02); G01N 33/0098 (2013.01)

(72) **Inventors:** Sylvain Fourmaux, Drummondville (CA); Jean-Claude Kieffer, Montréal (CA); Emil Hallin, Riversides Estates (CA) (58) **Field of Classification Search**
 CPC H05G 2/008; H05G 2/003; G01N 23/041; G01N 33/0098
 See application file for complete search history.

(73) **Assignees:** INSTITUT NATIONAL DE LA RECHERCHE SCIENTIFIQUE; UNIVERSITY OF SASKATCHEWAN (56) **References Cited**
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 7,321,604 B2 1/2008 Umstadter et al.
 8,705,692 B2 4/2014 Umstadter et al.
 (Continued)

2022

2020 – 2022: Testing reliability & sustainable operating for
3D phase contrast tomography of complex objects
➤ **54 000 consecutive shots/day @ 2.5Hz**



Quantum Electronics 51 (9) 751–758 (2021)

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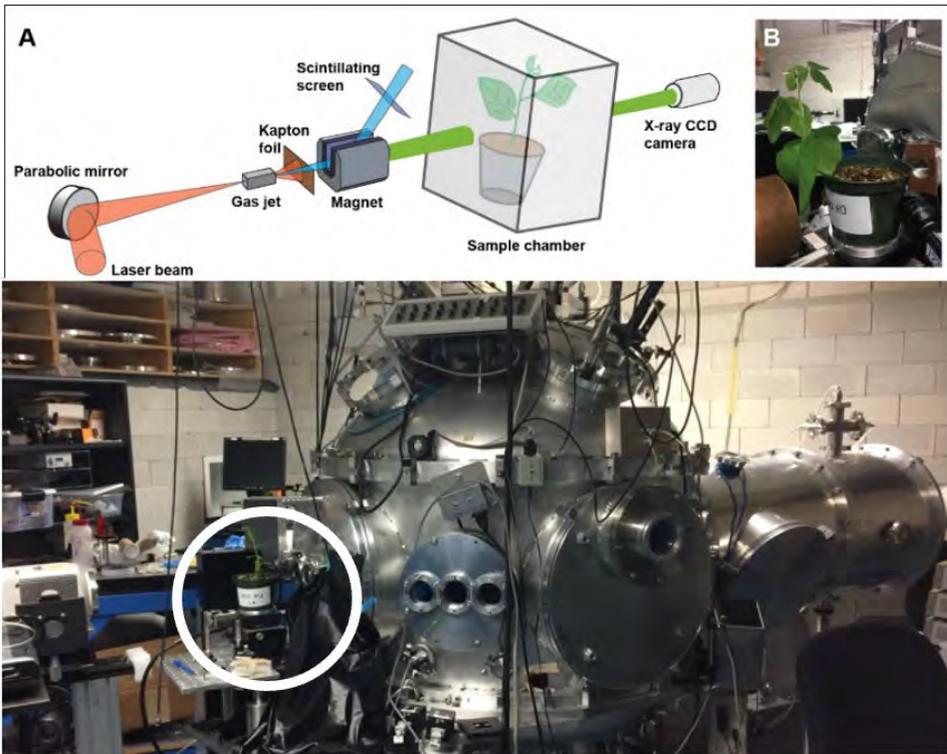
INTERACTION OF EXTREME LIGHT FIELDS WITH MATTER

<https://doi.org/10.1070/QEL17618>

**Laser induced damage threshold and incubation effects
of high-power laser system optics**

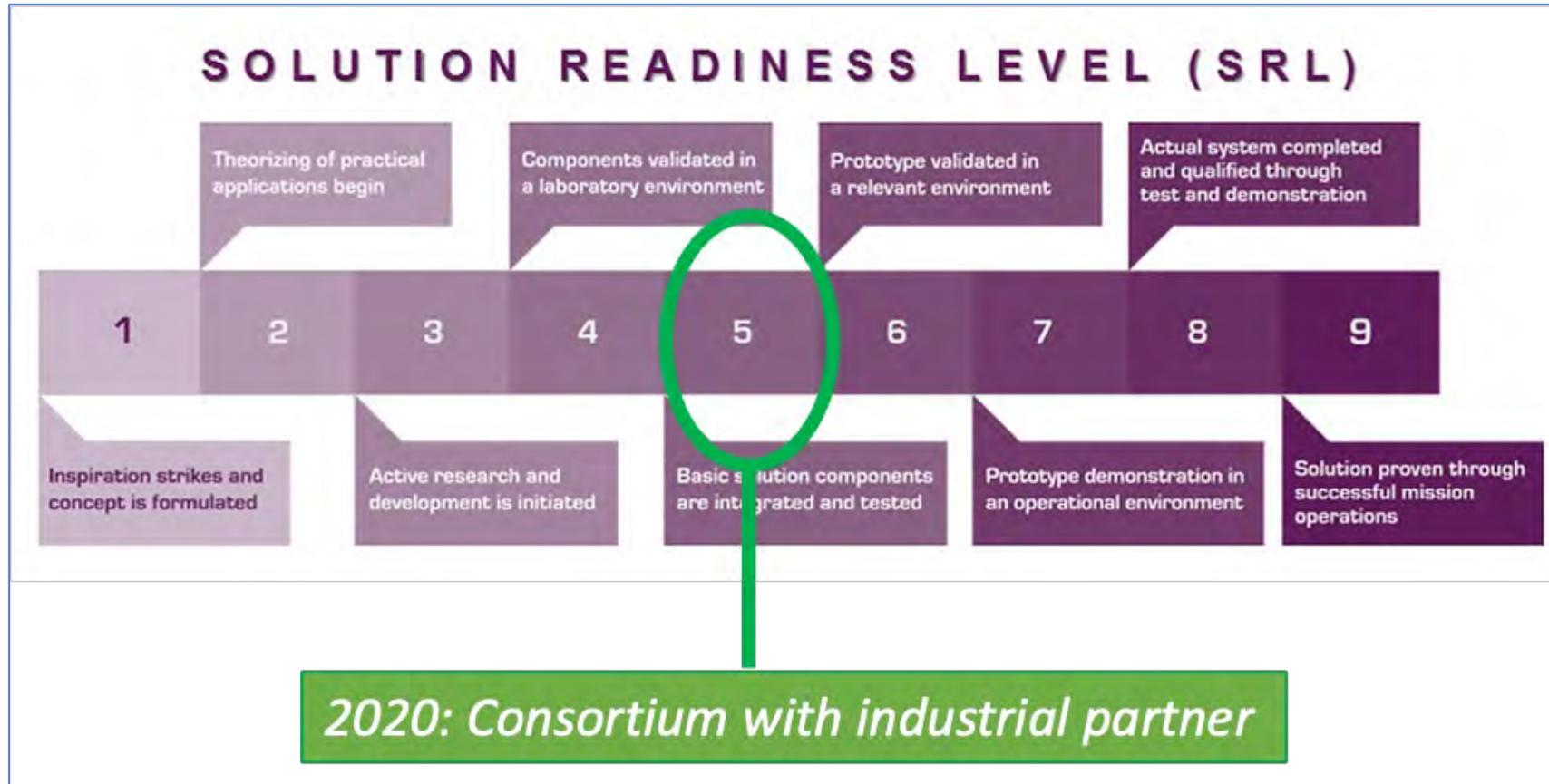
S. Fourmaux, J.C. Kieffer

Prepare integration engineering



- *Integrate AI to control the machine (alignments, stability, safety ...)*
- *Integrate AI for imaging optimization*

Where are we today



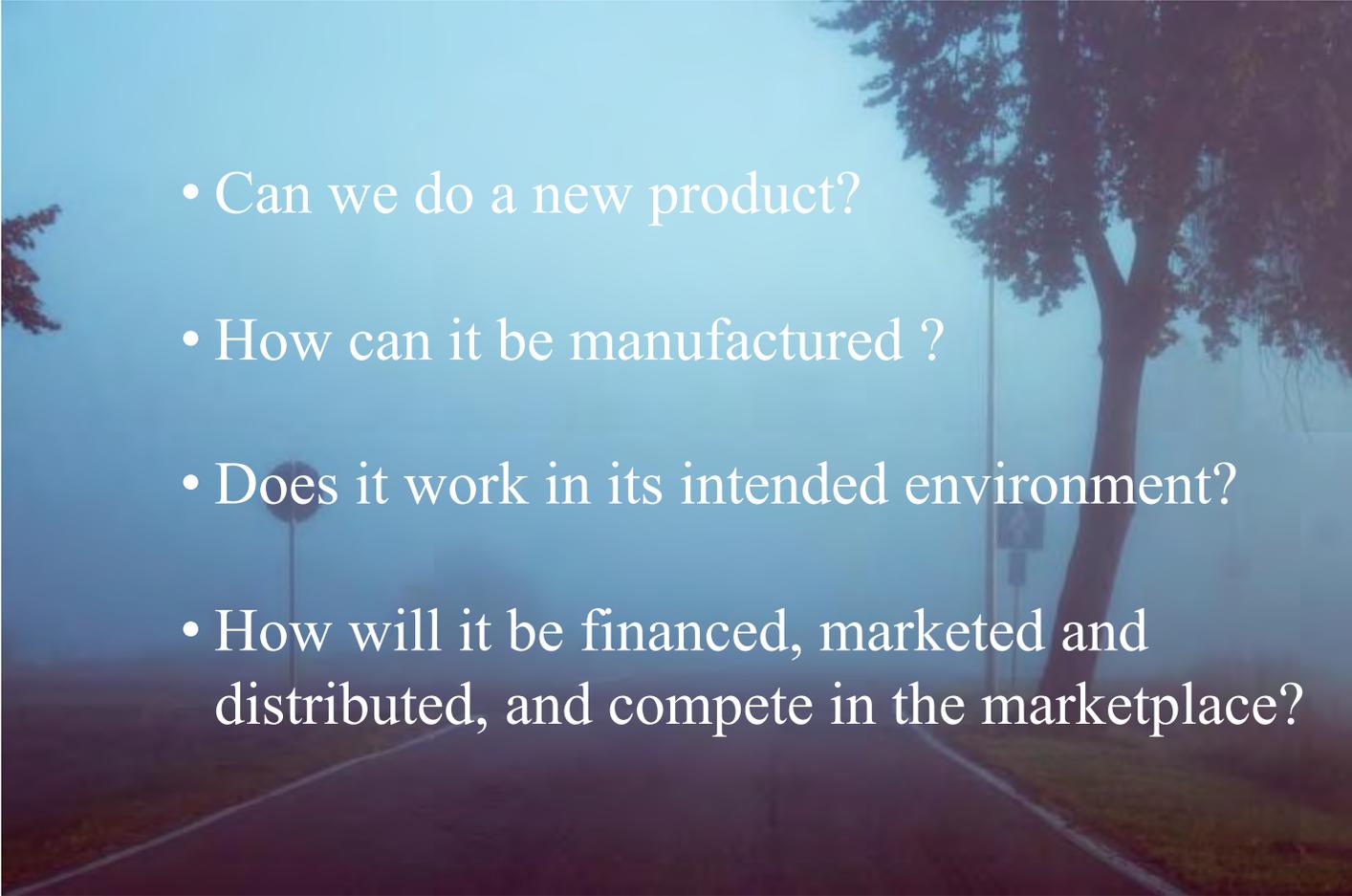
To conclude

X-ray phase contrast imaging start to be widely used

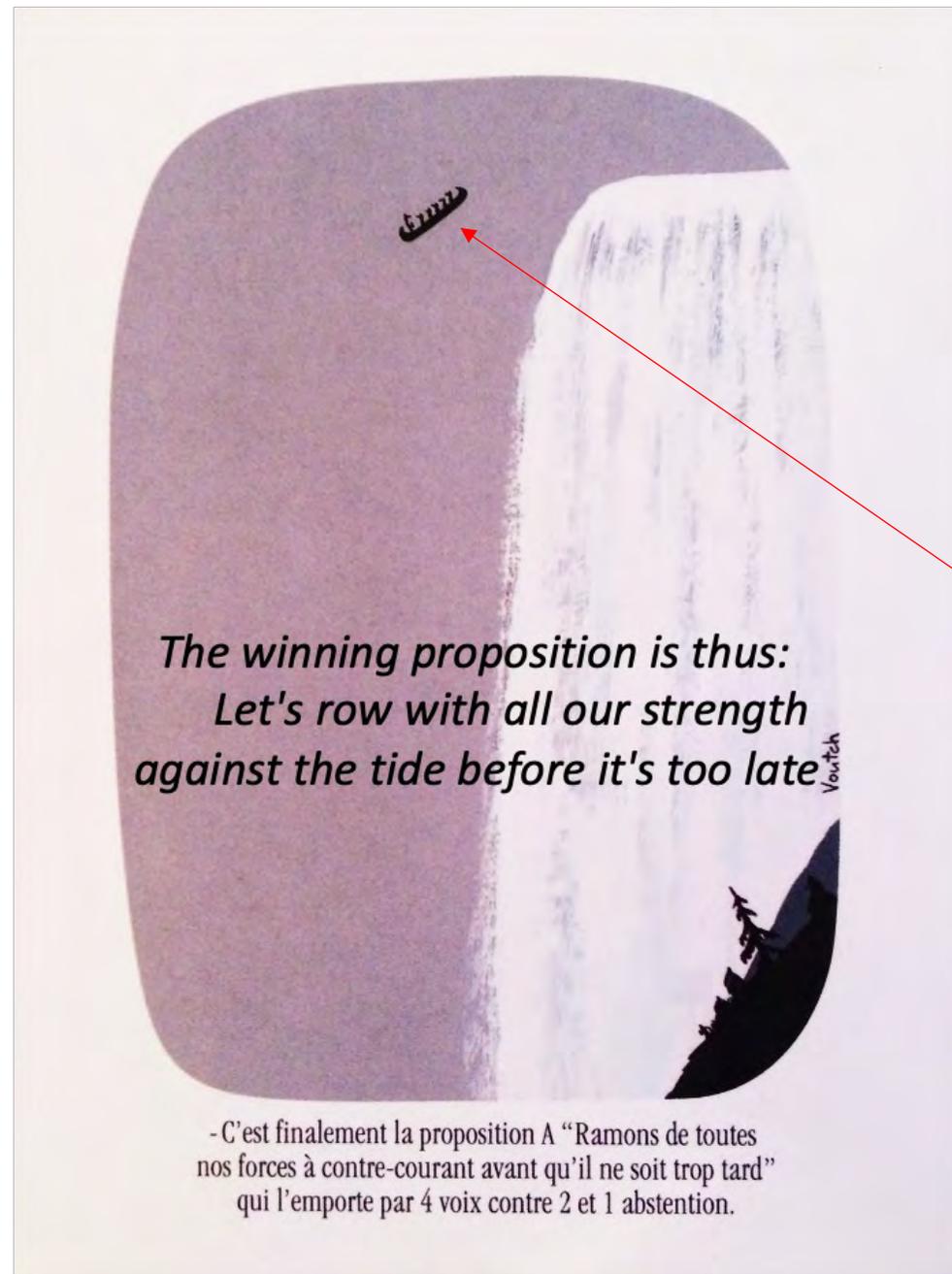
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- **Plant and soil science**, *Plant Soil*, 320, 1 (2009) , *J. Exp. Botany*, 58, 2513 (2007)
- **Non-destructive sensing**
- **Inertial Confinement Fusion**, *Opt. Express*, 28, 13978 (2020)



Building a Laser-based industrial solution

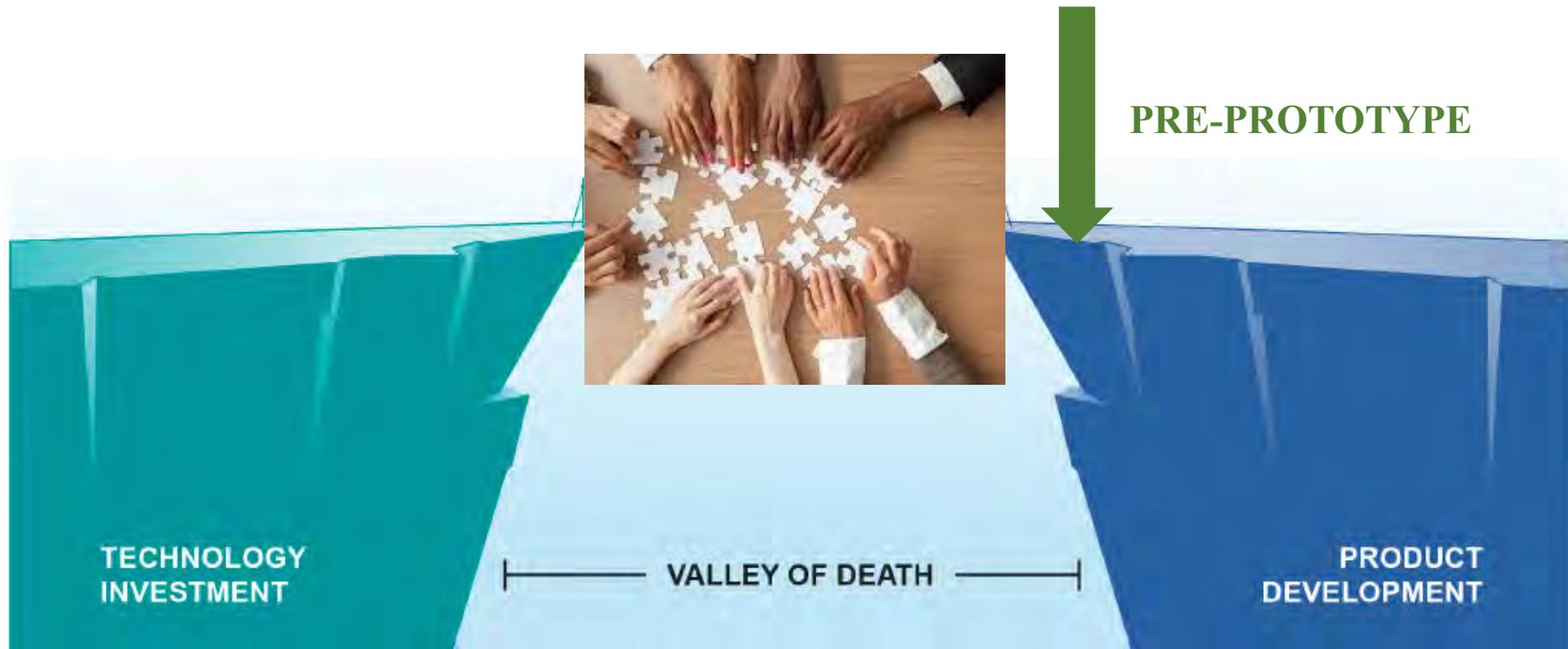
- 
- Can we do a new product?
 - How can it be manufactured ?
 - Does it work in its intended environment?
 - How will it be financed, marketed and distributed, and compete in the marketplace?

Building



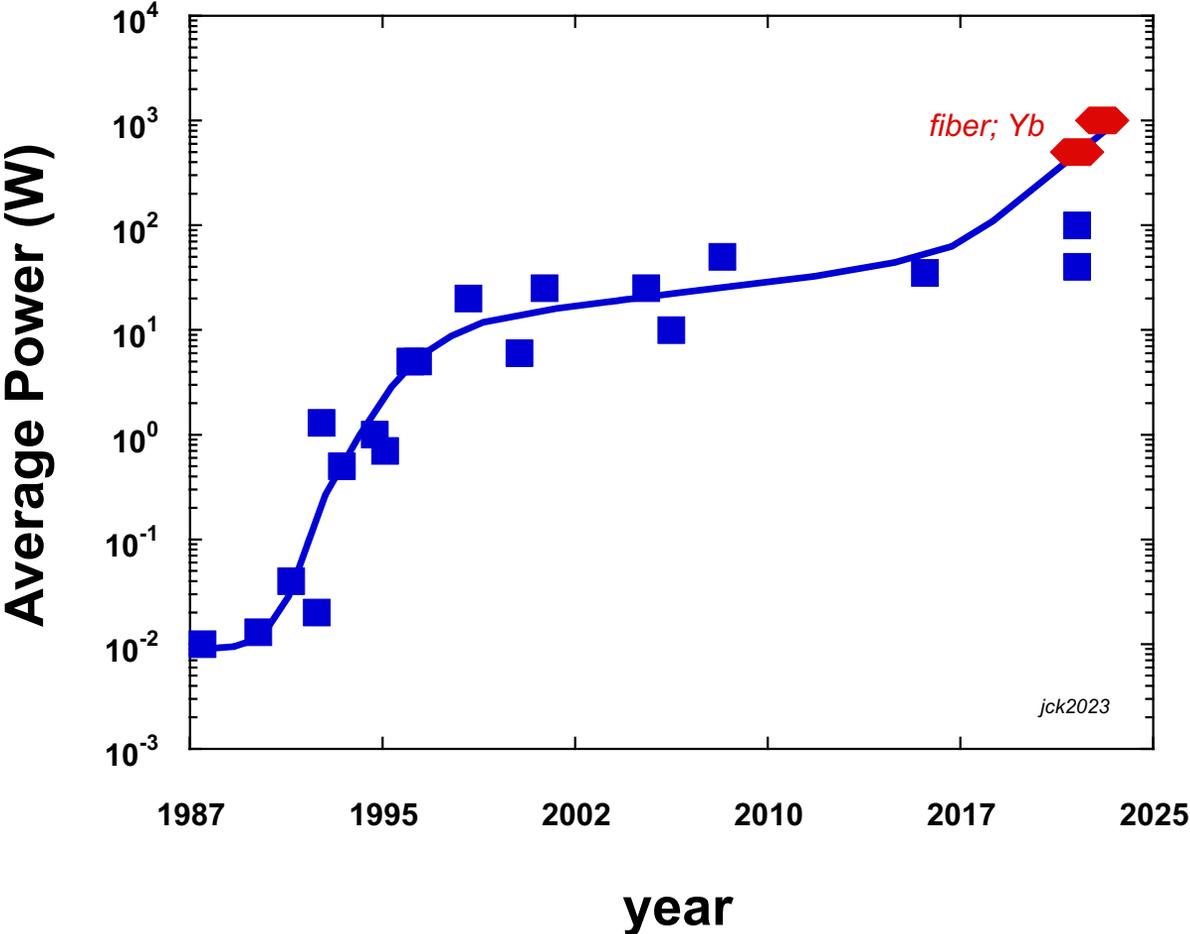
Me

Building a Laser-based industrial solution



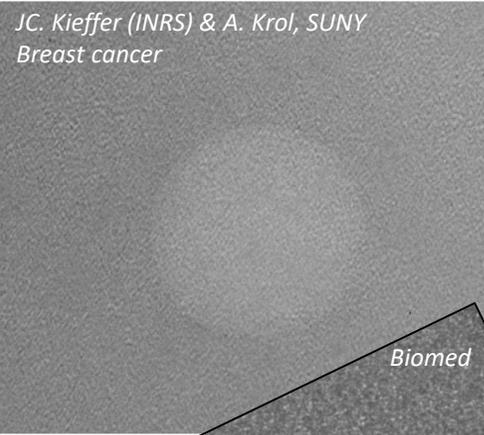
Source: GAO review of DOD information. | GAO-23-105868

A POSSIBLE HOPE ON THE K-ALPHA X-RAY SOURCE FRONT



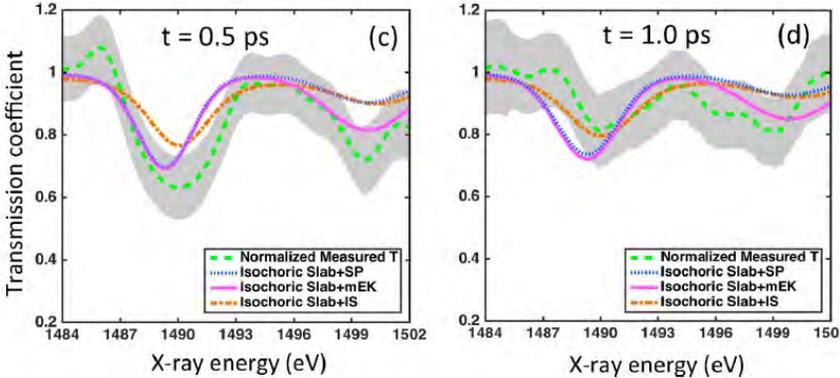
A fantastic possibility with LWFA-based X-ray source

JC. Kieffer (INRS) & A. Krol, SUNY
Breast cancer

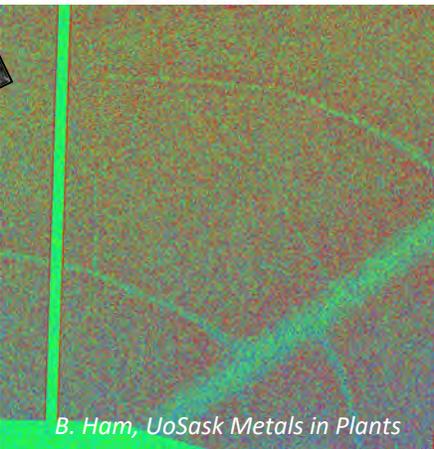
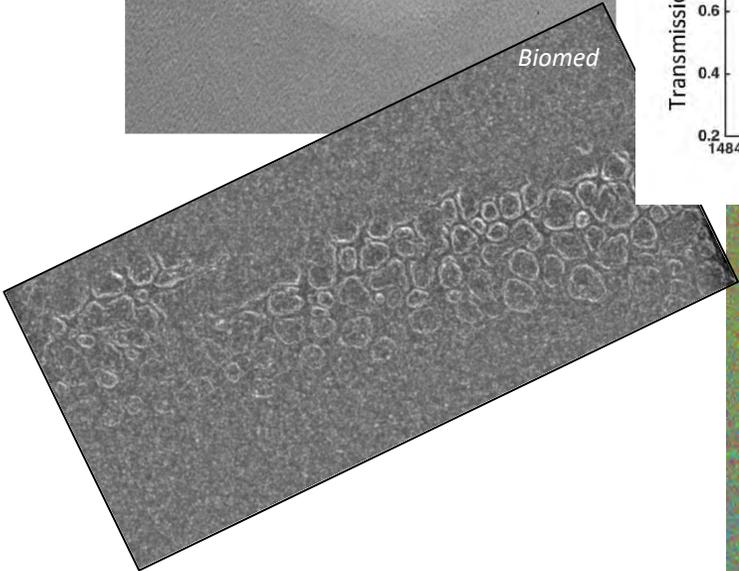
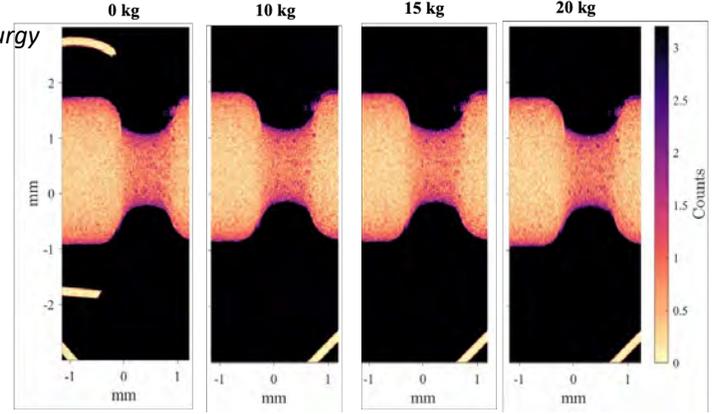


Biomed

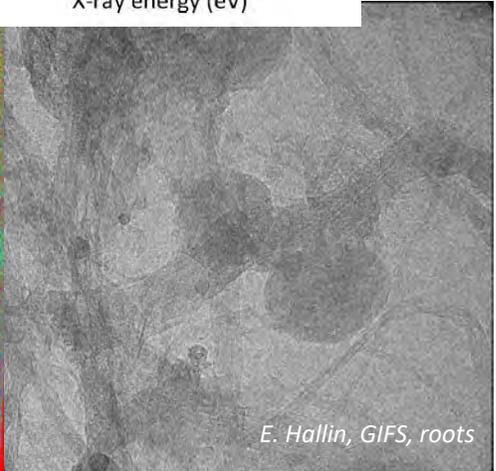
R. Fedosejevs, UoA, WDM time resolved



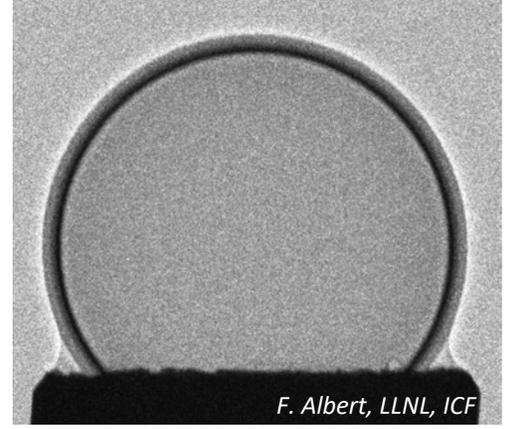
A. Hussein, UoA, Metallurgy



B. Ham, UoSask Metals in Plants



E. Hallin, GIFS, roots



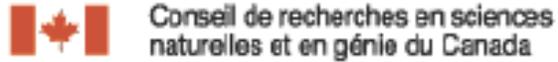
F. Albert, LLNL, ICF

Building a Laser-based industrial solution

- Financial Engineering to develop a prototype
 - *Fast positioning*
 - *Large cost integrating industrialization aspects*
- Industrial engineering
 - *The technology Transfer model*
 - *The JV model (industrial actors)*
- Market positioning
 - *A machine is a compromise between complexity and efficiency at*
THE LOWEST COST



THANK YOU



Natural Sciences and Engineering
Research Council of Canada

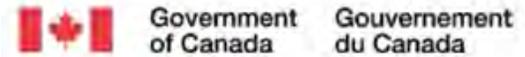


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prompt