Australian Government

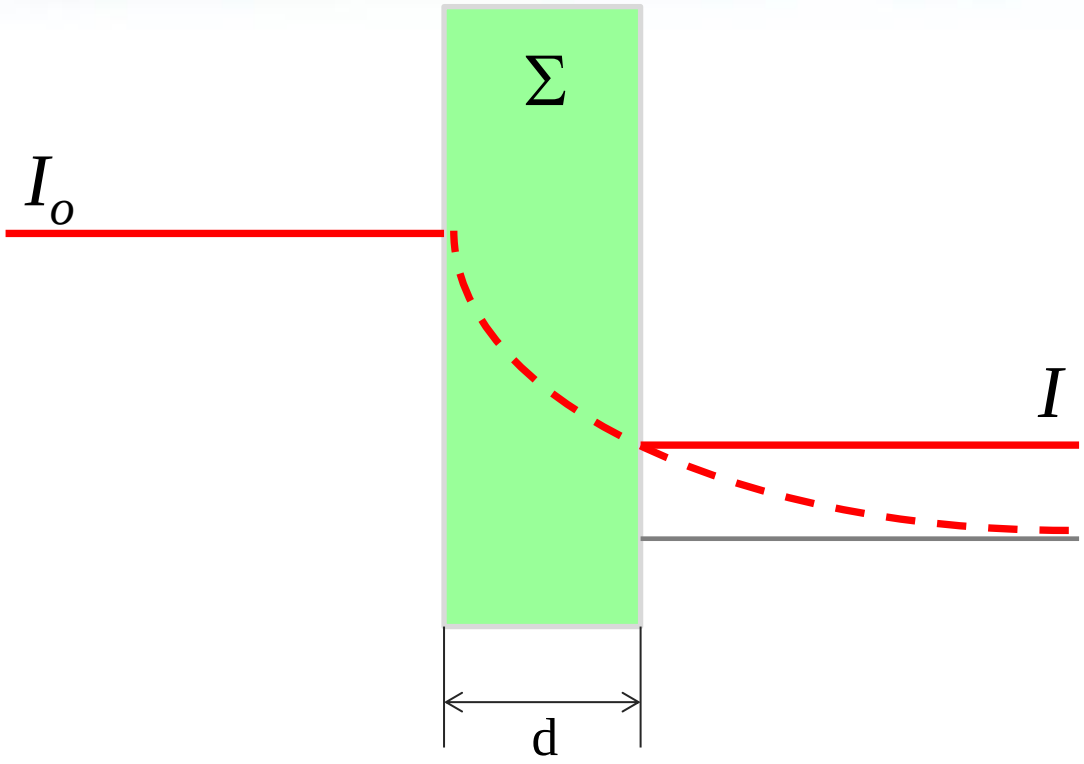
Ansto

Neutron Imaging

Floriana Salvemini

Instrument Scientist

Basic principle



$$I = I_0 e^{-\Sigma d}$$

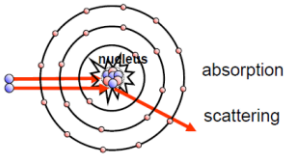
$$T = \frac{I}{I_0}$$

$$-\ln(T) = \Sigma d \quad \text{with} \quad \Sigma = \sigma n$$

Lambert-Beer law

Trasmittance

Contrast ∝ material (σ) & thickness (d)

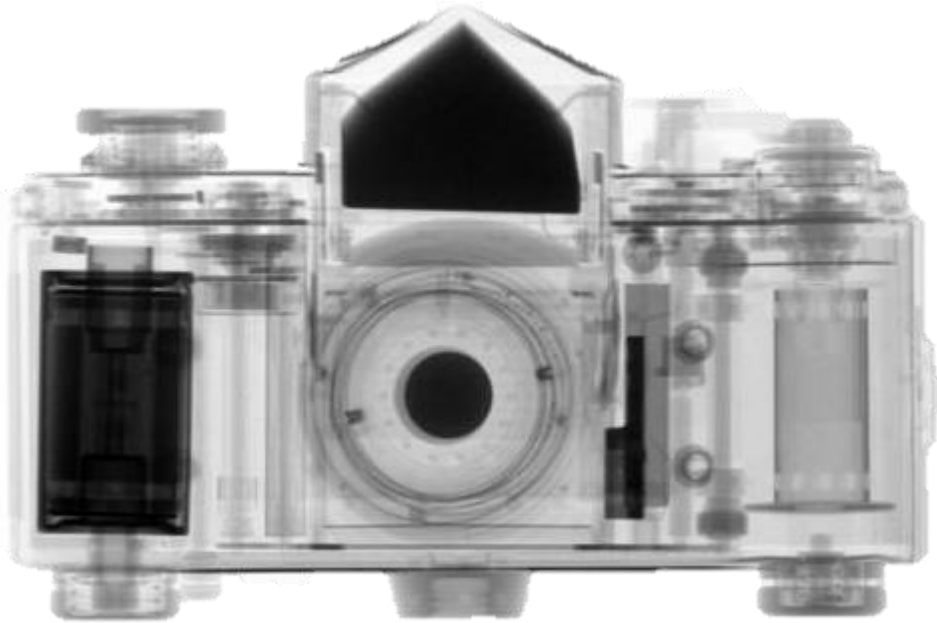


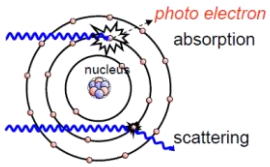
Neutrons

Attenuation coefficients for thermal neutrons [cm^{-1}]

1a	2a	3b	4b	5b	6b	7b	8			1b	2b	3a	4a	5a	6a	7a	0
H																	He
3.44																	0.02
Li	Be											B	C	N	O	F	Ne
3.30	0.79											101.60	0.56	0.43	0.17	0.20	0.10
Na	Mg											Al	Si	P	S	Cl	Ar
0.09	0.15											0.10	0.11	0.12	0.06	1.33	0.03
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
0.06	0.08	2.00	0.60	0.72	0.54	1.21	1.19	3.92	2.05	1.07	0.35	0.49	0.47	0.67	0.73	0.24	0.61
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
0.08	0.14	0.27	0.29	0.40	0.52	1.76	0.58	10.88	0.78	4.04	115.11	7.58	0.21	0.30	0.25	0.23	0.43
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
0.29	0.07	0.52	4.99	1.49	1.47	6.85	2.24	30.46	1.46	6.23	16.21	0.47	0.38	0.27			
Fr	Ra	Ac	Rf	Ha													
	0.34																

	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
*Lanthanides	0.14	0.41	1.87	5.72	171.47	94.58	1479.04	0.93	32.42	2.25	5.48	3.53	1.40	2.75
	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
**Actinides	0.59	8.46	0.82	9.80	50.20	2.86								



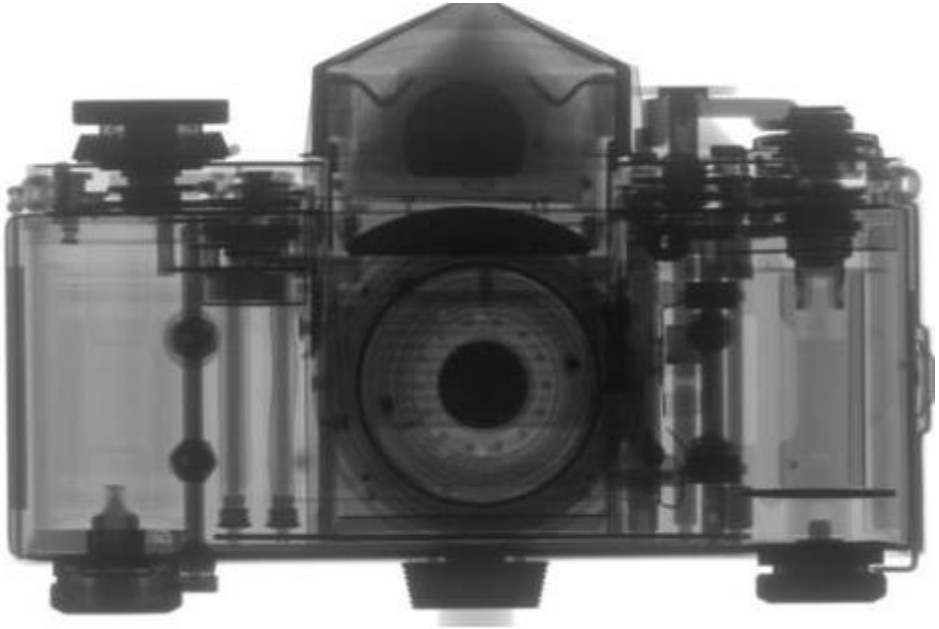


X-ray

Attenuation coefficients for X-ray [cm^{-1}] (150kV)

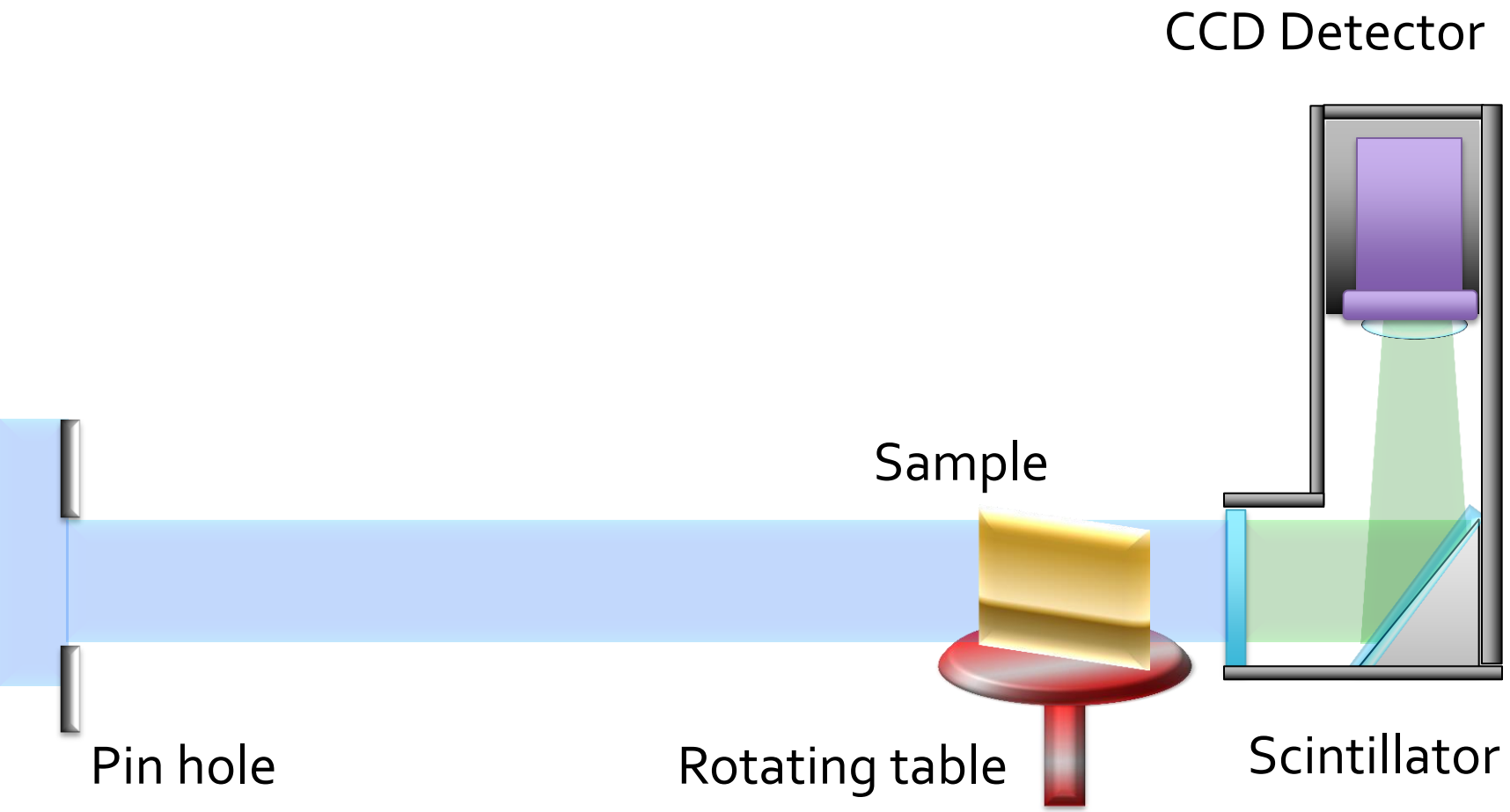
1a	2a	3b	4b	5b	6b	7b	8			1b	2b	3a	4a	5a	6a	7a	0
H																	He
0.02																	0.02
Li	Be											B	C	N	O	F	Ne
0.06	0.22											0.28	0.27	0.11	0.16	0.14	0.17
Na	Mg											Al	Si	P	S	Cl	Ar
0.13	0.24											0.38	0.33	0.25	0.30	0.23	0.20
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
0.14	0.26	0.48	0.73	1.04	1.29	1.32	1.57	1.78	1.96	1.97	1.64	1.42	1.33	1.50	1.23	0.90	0.73
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
0.47	0.86	1.61	2.47	3.43	4.29	5.06	5.71	6.08	6.13	5.67	4.84	4.31	3.98	4.28	4.06	3.45	2.53
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
1.42	2.73	5.04	19.70	25.47	30.49	34.47	37.92	39.01	38.61	35.94	25.88	23.23	22.81	20.28	20.22		9.77
Fr	Ra	Ac	Rf	Ha													
	11.80	24.47															

	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
*Lanthanides	5.79	6.23	6.46	7.33	7.68	5.66	8.69	9.46	10.17	10.91	11.70	12.49	9.32	14.07
	Th	Pa	U	Np	Pu	Am	Cm	Bk	Vf	Es	Fm	Md	No	Lr
**Actinides	28.95	39.65	49.08											

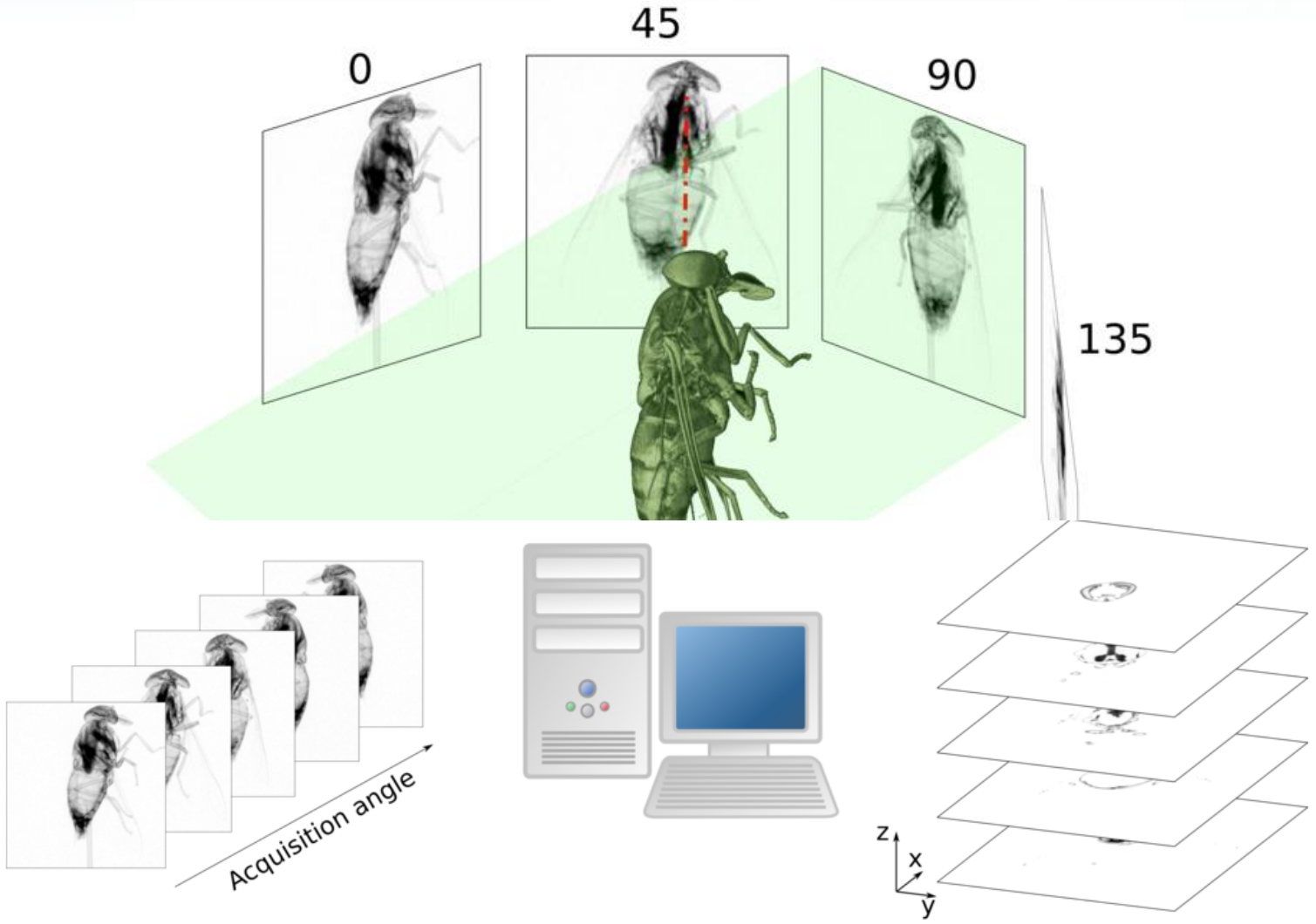


Source: http://www.psi.ch/niag/what-is-neutron-imaging

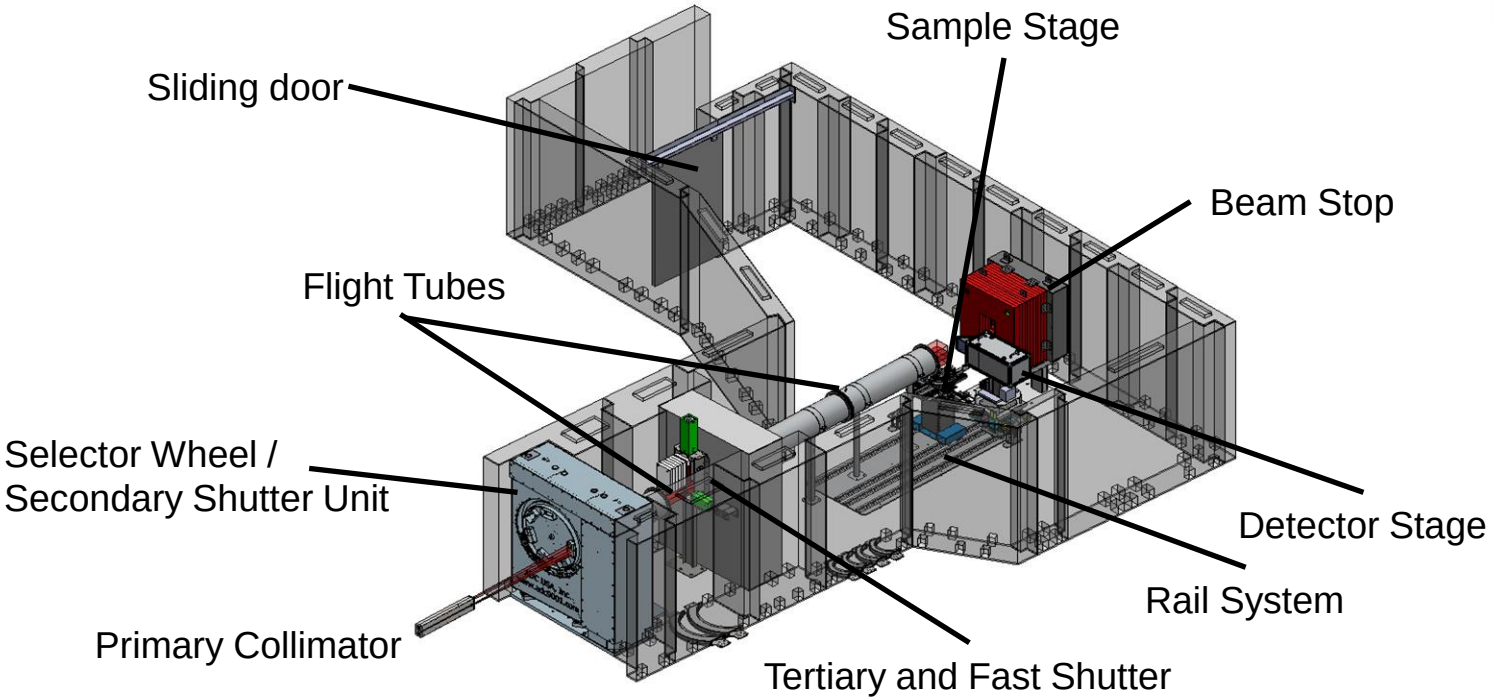
Instrument set-up



Computer tomography reconstruction



DINGO layout

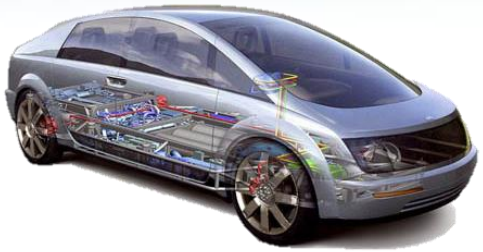


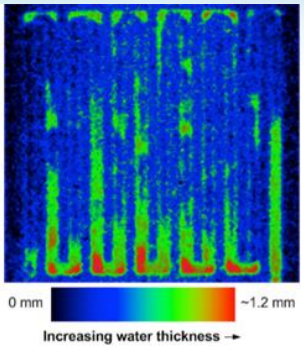
Technical details

- Ikon-l CCD, NEO CMOS camera
- Two Zeiss macro lens (50mm and 100mm)
- Three beam sizes 200 x 200, 100 x 100 and 50 x 50 mm^2
- Pixel size 20 – 100 µm
- 25fps fast imaging under development

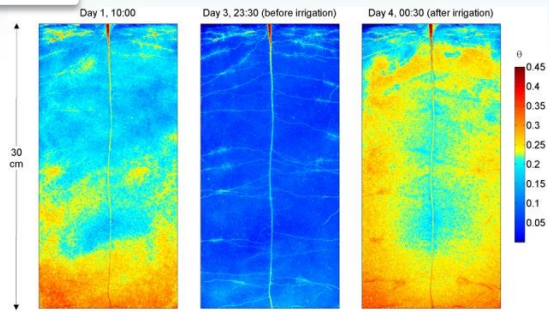
Applications Overview

Energy

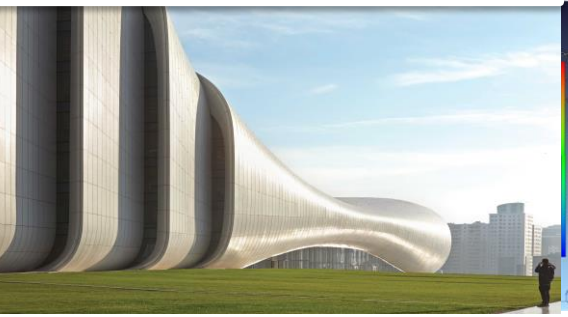


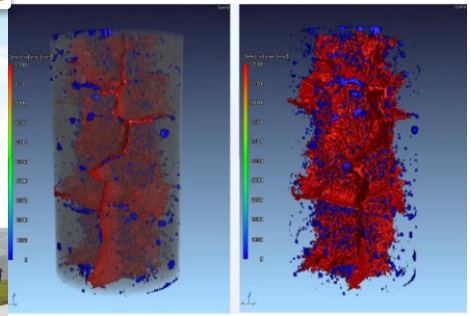


Agriculture & Food

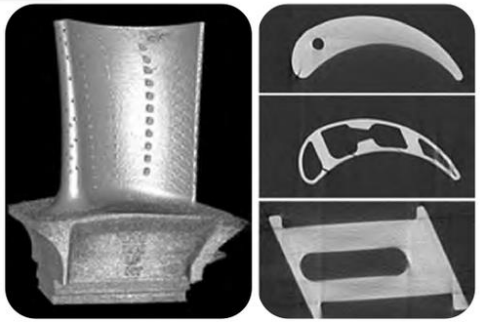


Civil Engineering

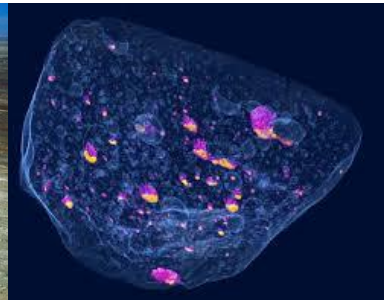




Industrial Manufacture

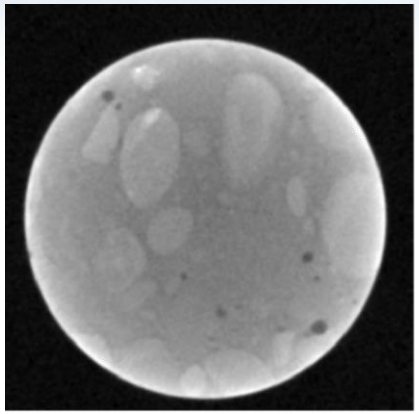


Geo & Planetary Science

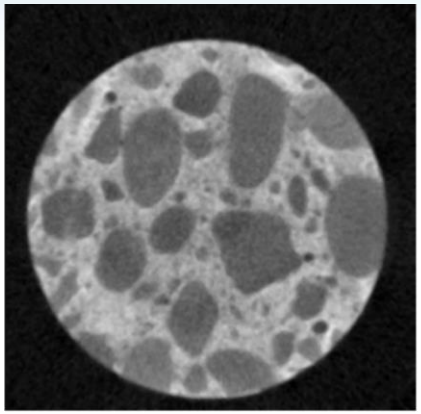


Biology

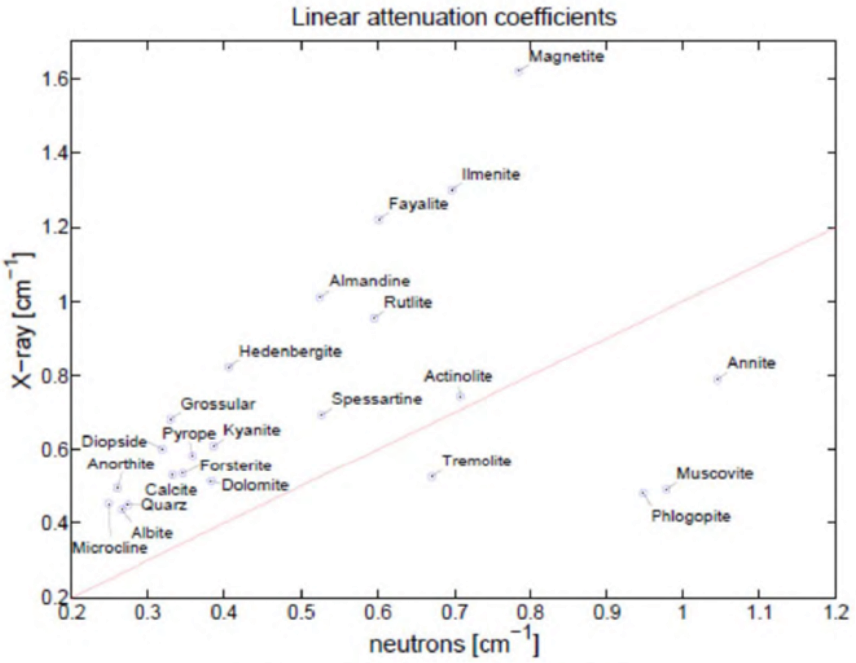
Civil engineering: Concrete

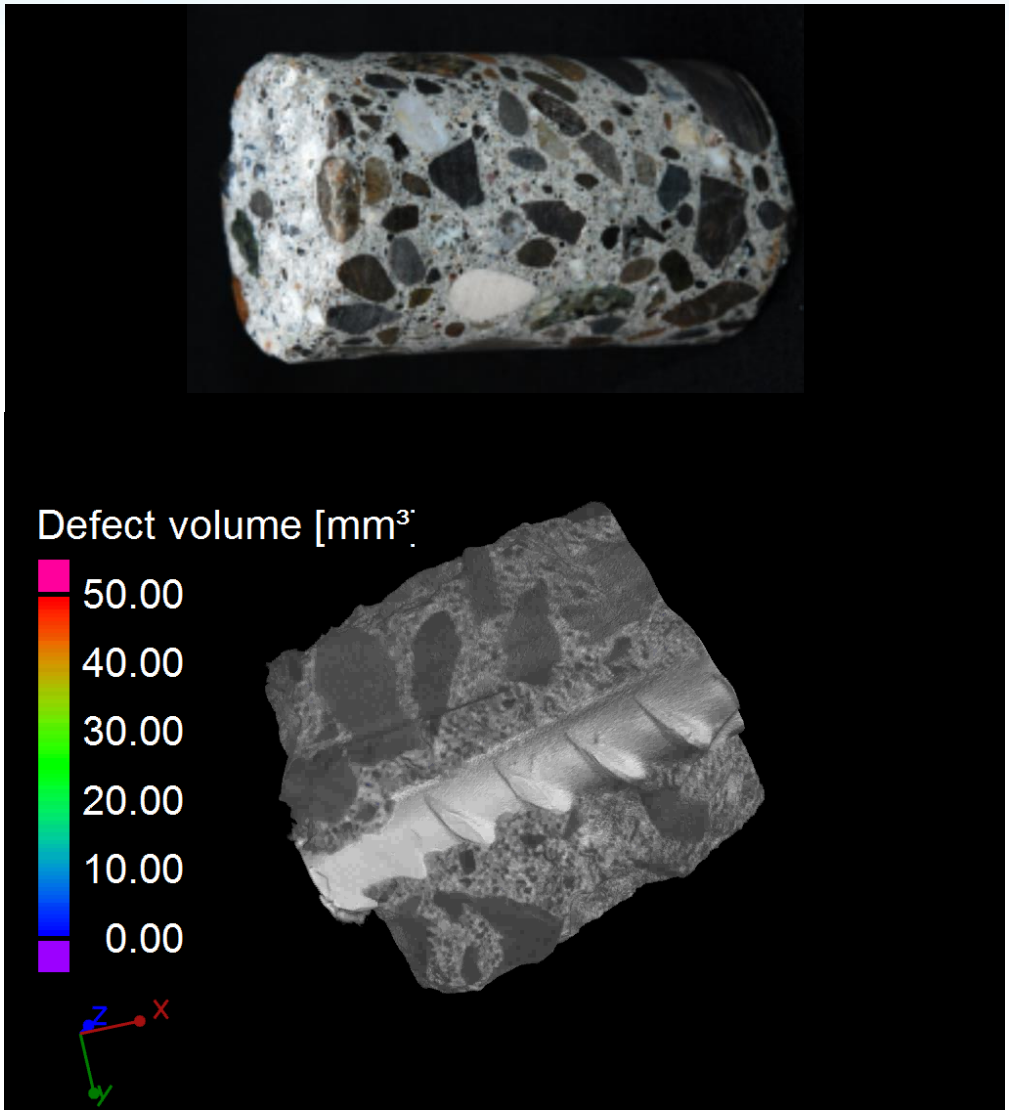


X-rays 250 kV

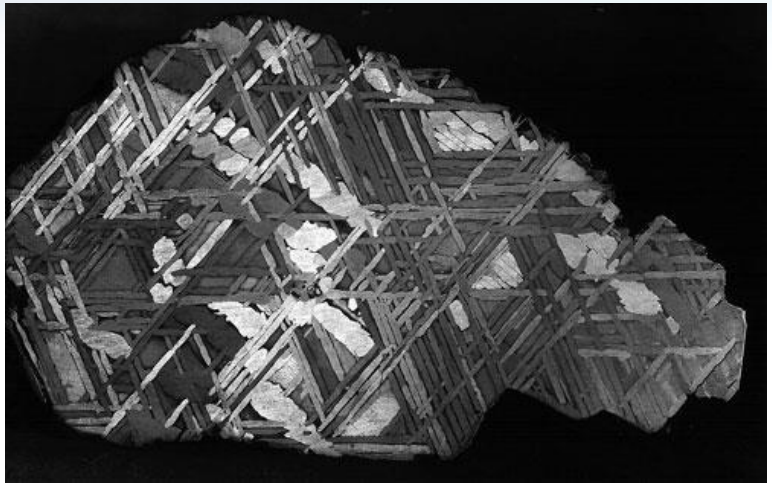


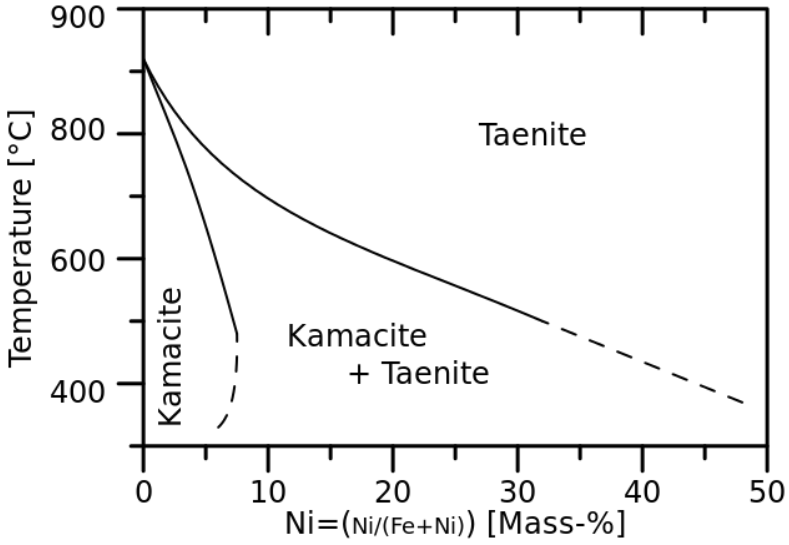
Thermal neutrons

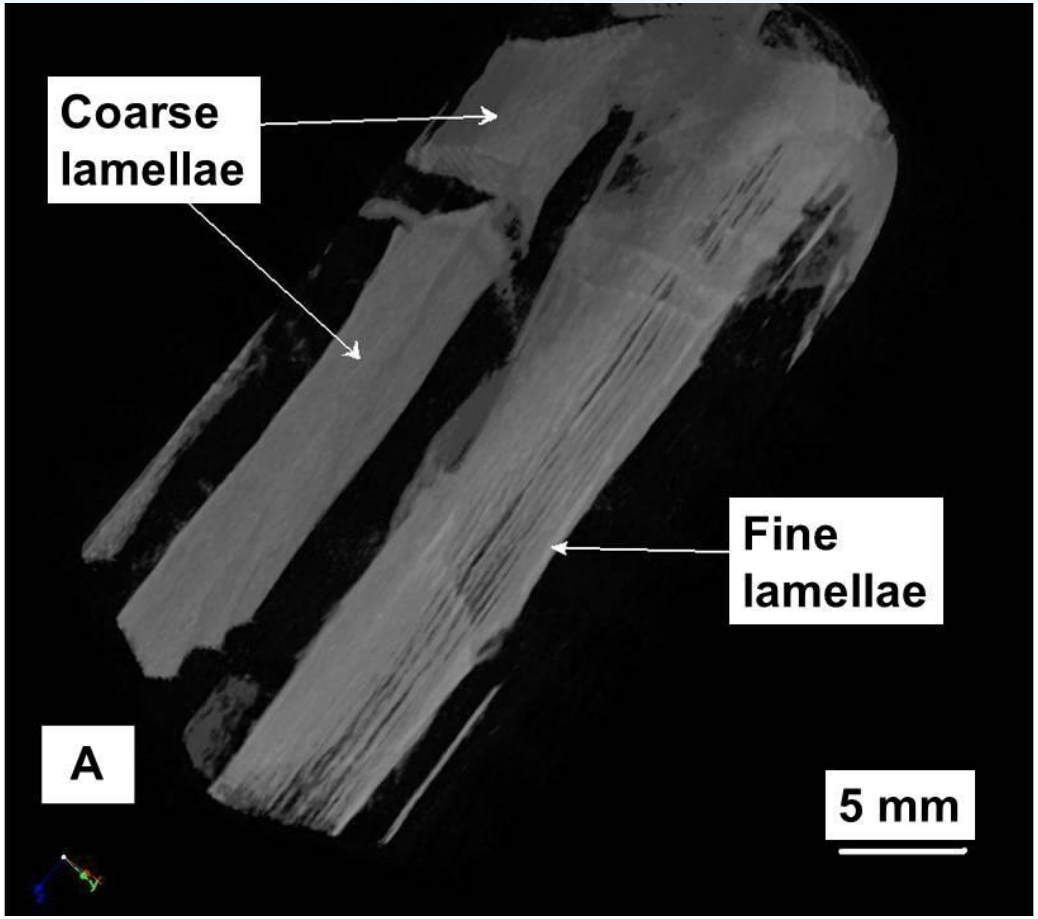




Planetary Science: Iron meteorites







Catalogue number	Meteorite Name	Chemical group	Structural group
MSN-RI3218	Seymchan	Pallasite	Coarse octahedrite (Og)

UNIVERSITÀ DEGLI STUDI FIRENZE

Cultural Heritage: The incuse coinages

600 B.C. 540 B.C. 440 B.C.

Asia Minor: first recognize coins
Shortly after – all over Magna Graecia.

Unique incuse technique developed by some Greek colonies in South Italy

The technique disappears

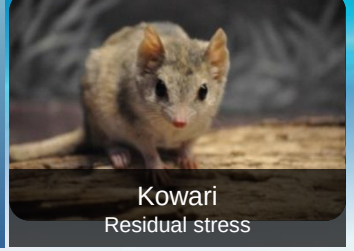
non-incuse

incuse

Still no commonly accepted explanation about manufacture process

K. Sheedy, V. Luzin, S. Olsen, U. Garbe, F. Salvemini, T. Knowles, and P. Munroe, *Strange Objects and Strange Explanations: understanding the incuse coinages of South Italy by non-destructive neutron diffraction and tomography*, **Studies in Mediterranean Archaeology** (submitted to SIMA).

Texture Analysis



Kowari
Residual stress

Tomography

Dingo
Radiography & Tomography

Phase Analysis

Echidna
High resolution powder

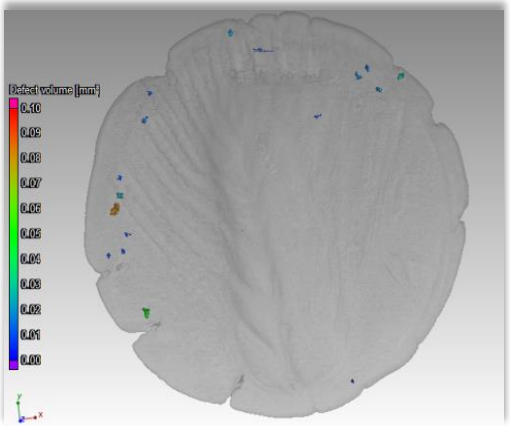
Incuse stater - Metapontum c. 550-500 BC

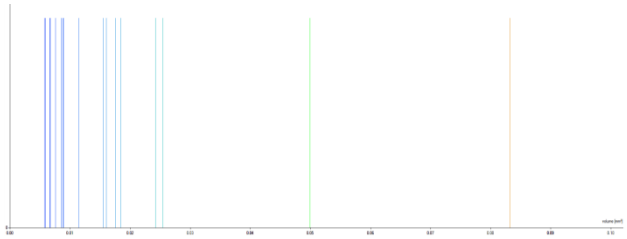
Incuse stater - Sybaris c. 550-500 BC

Non incuse stater - Naxos c. 550-500 BC

Manufacturing: hammering silver into a sheet, cutting off blanks and stamping the image.

Metapontum ACANS 525

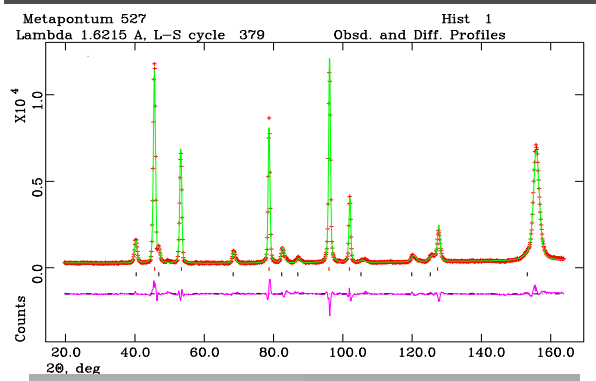


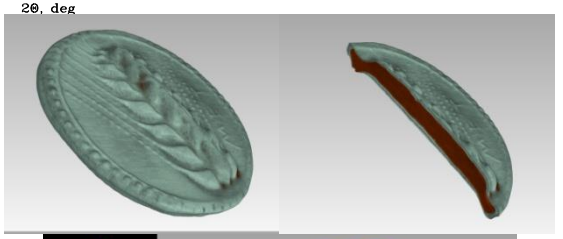


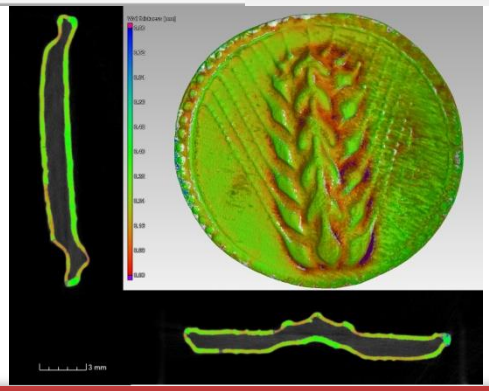
Voids	
Σ Voids Volume	0.38 mm³
Voids / Coin Volume	0.05%

Mint date 550-510 B.C.
Weight 7.43 g
Diameter 29 mm
Incuse

Metapontum ACANS 526







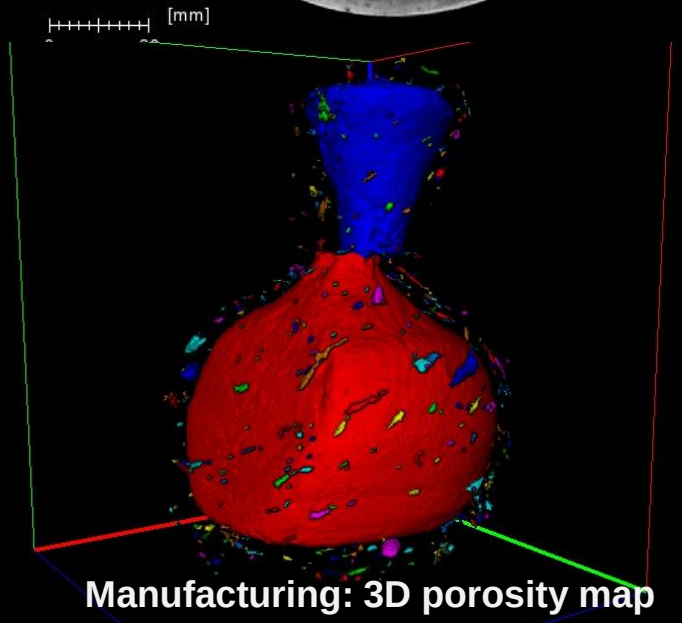
Mint date 510-470 B.C.
Weight 8.07 g
Diameter 24 mm
Incuse

Characterization of an Ancient Thai doll

Thailand Institute of
Nuclear Technology

Pottery,
1500 A.C. Thailand

Hidden component

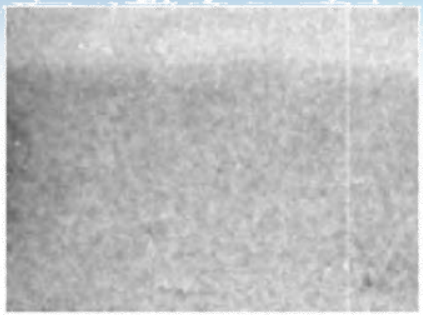


Manufacturing: 3D porosity map

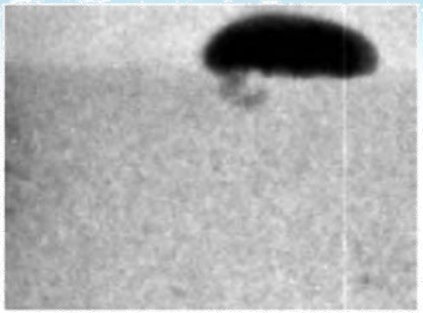
Past restoration

Isosurface extraction for 3D print

Dynamic process

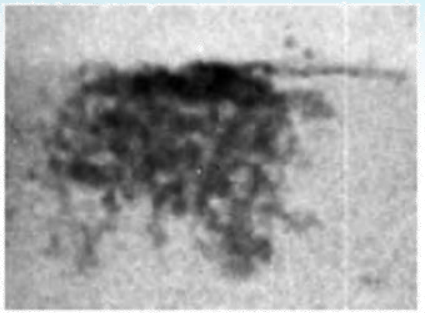


t=0 s



0.25 s

1.25 s



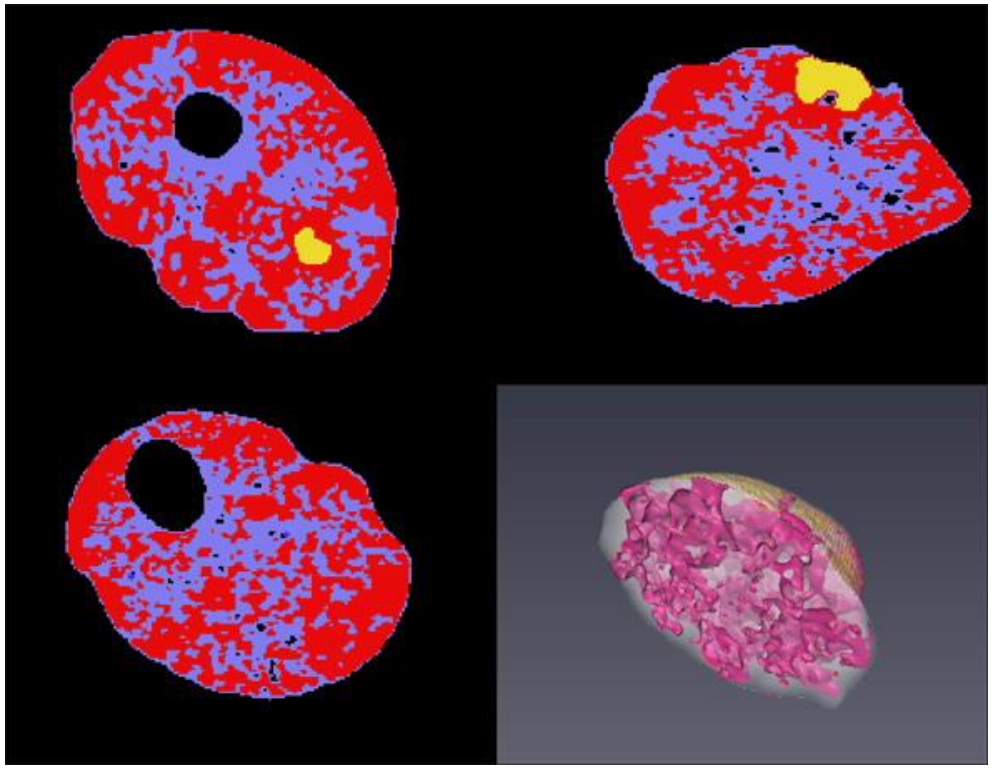
2.75 s

Curiosity

Non-invasive three-dimensional reconstruction of ancient opalised pearls reveals structure

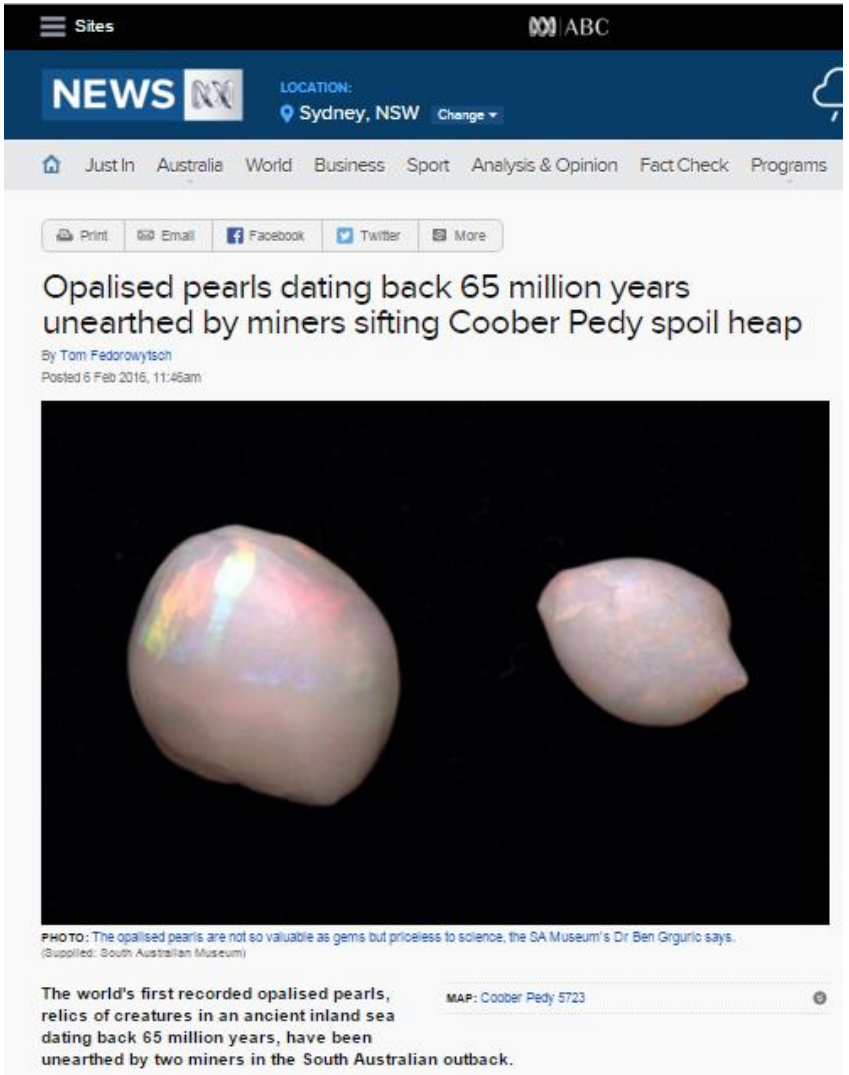
South Australian Museum

The world's first recorded opalised pearls, relics of creatures in an ancient inland sea dating back 65 million years, were unearthed by two miners in the South Australian outback, and have been studied, by means of neutron imaging in collaboration with Dr. Ben Grguric (South Australian Museum).



Cross sections along three directions of an opalised pearl 3D tomographic reconstruction appears in lower right corner.

[ABC Media Release]



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Opalised pearls dating back 65 million years unearthed by miners sifting Coober Pedy spoil heap

By Tom Fedorowytsch

Posted 6 Feb 2016, 11:46am

PHOTO: The opalised pearls are not so valuable as gems but priceless to science, the SA Museum's Dr Ben Grguric says. (Supplied: South Australian Museum)

The world's first recorded opalised pearls, relics of creatures in an ancient inland sea dating back 65 million years, have been unearthed by two miners in the South Australian outback.

MAP: Coober Pedy 5723

Conclusions

Neutron imaging

Technical advantages

- High penetration power
- Complementary contrast
- Non-invasive method

Materials

- Metals
- Ceramics
- Rocks
- Fossils
- Organic materials

Typical Investigations

- Civil Engineer
- Material Science
- Geoscience
- Planetary science
- Biology
- Medicine
- Palaeontology
- Cultural Heritage
- …..

Outcome

- Structural and Morphological bulk analysis
- Porosity, inclusions and defects evaluation
- Volume segmentation and quantification
- 3-D modelling

Proposal Deadline 15/09/2016

Nuclear-based science benefiting all Australians

Dingo Team:

Floriana Salvemini
Ulf Garbe
Joseph Bevitt
Klaus-Dieter Liss

https://neutron.ansto.gov.au/Bragg/proposal/index.jsp