Australian Government

ANSTO

The Invisible Revealed: Showcasing the application of neutrons in Heritage Research

Joseph Bevitt

Instrument Group Manager (3D Imaging & Residual stress)
Australian Centre for Neutron Scattering
ANSTO

Science. Ingenuity. Sustainability.

Australian Nuclear Science & Technology Organisation

Public research organisation

Operating over 60 years

Manages >$1 billion of scientific equipment

Main campus
Lucas Heights

NSW

OPAL Research Reactor

&

5 x Particle Accelerators

Clayton
Australian Synchrotron

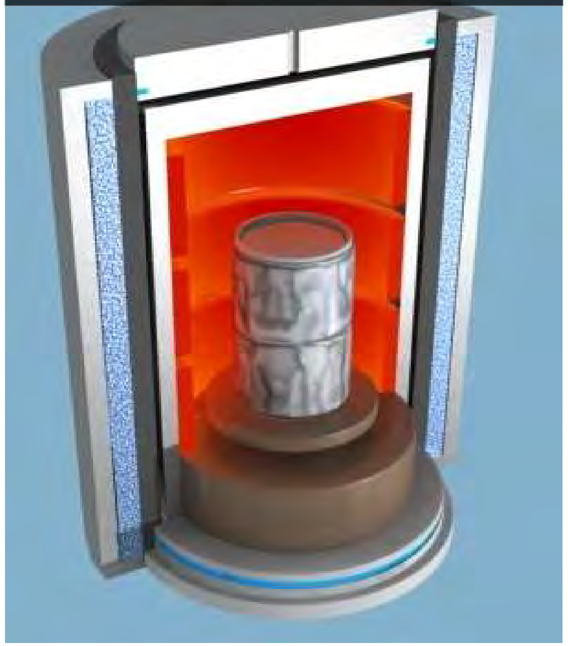
VIC

ANSTO

Nuclear Science & Technology Research Areas

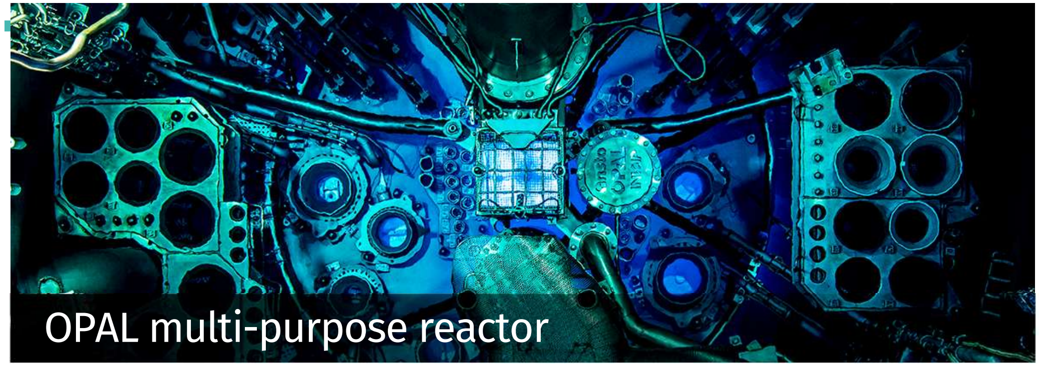
The Environment

Nuclear Fuel Cycle



Human Health

ANSTO's National Research Infrastructure



OPAL multi-purpose reactor

Australian Centre for Neutron Scattering

ANSTO Centre for Accelerator Science

Australian Synchrotron

National Deuteration Facility

NCRIS
National Research
Infrastructure for Australia
An Australian Government Initiative

Australian Government
Department of Education

ANSTO

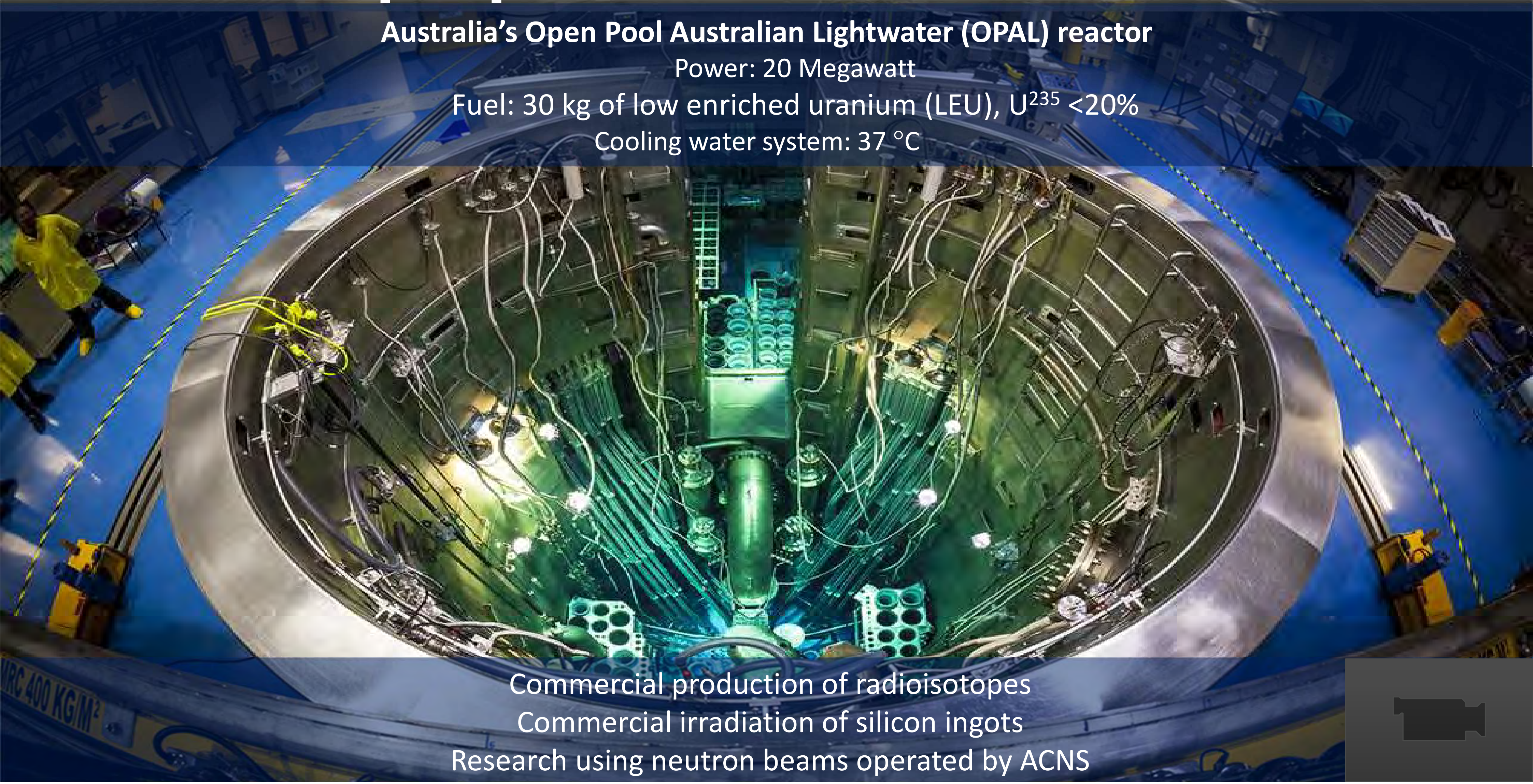
OPAL Multipurpose Research Reactor

Australia's Open Pool Australian Lightwater (OPAL) reactor

Power: 20 Megawatt

Fuel: 30 kg of low enriched uranium (LEU), U^{235} <20%

Cooling water system: 37 °C

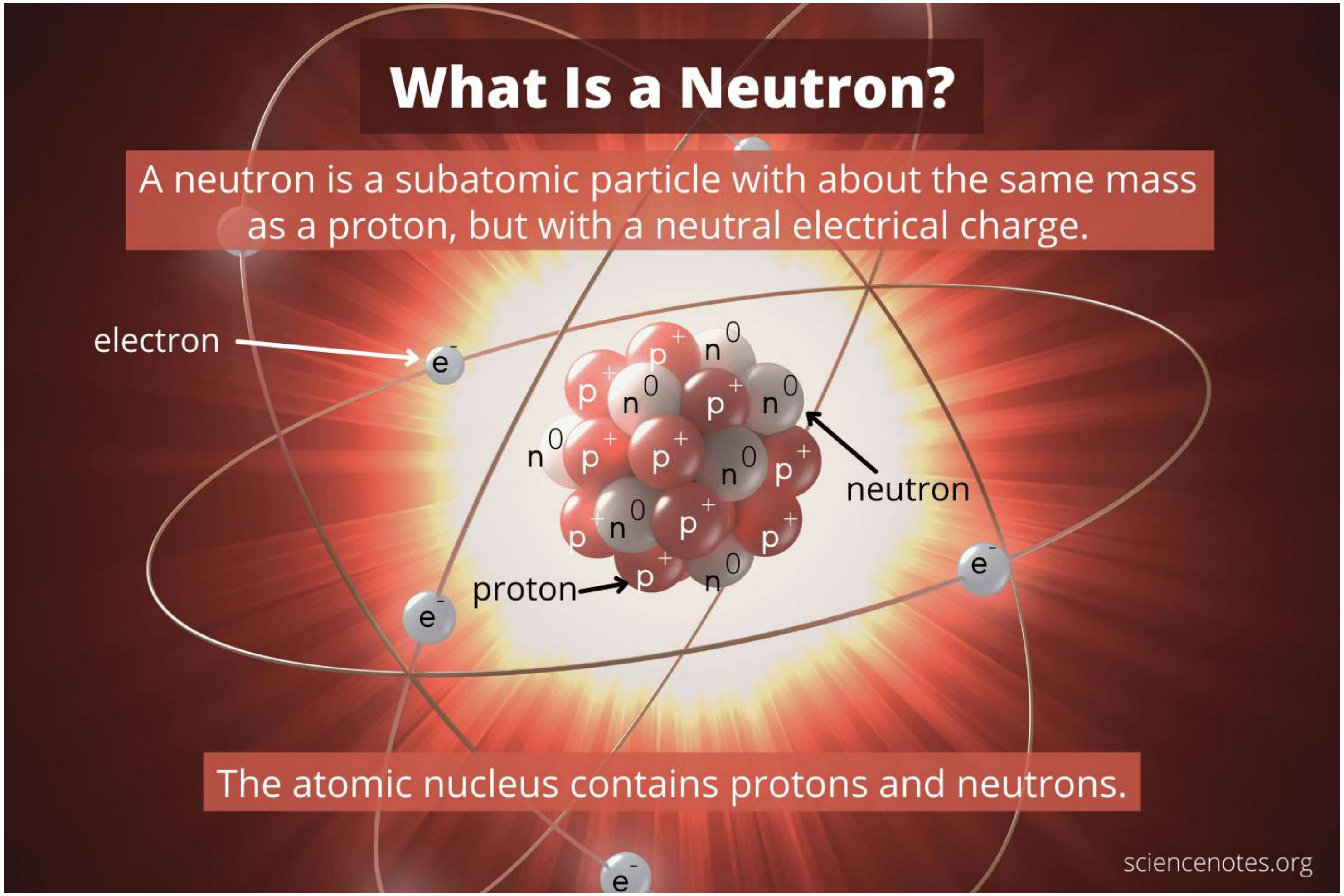


Commercial production of radioisotopes

Commercial irradiation of silicon ingots

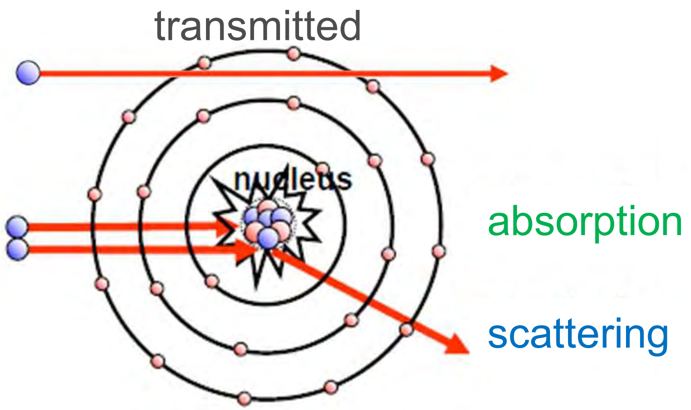
Research using neutron beams operated by ACNS

OPAL is a Neutron Factory



Australian Centre for Neutron Scattering

Neutron Beams for Materials Science



Imaging

Radiography
Tomography
Real-time imaging
Resonance capture analysis
Autoradiography
Energy-selective imaging

Diffraction

Full-pattern
Residual stress
Texture

Activation Analysis

Instrumental Neutron Activation Analysis (INAA)
Prompt Gamma Activation Analysis (PGAA)

Non-destructive analysis of materials from the micro- to macroscopic scale

Inelastic scattering


Taipan
Thermal triple axis


Sika
Cold triple axis


Pelican
Cold time-of-flight


Emu
Backscattering

Large scale structure


Quokka
Pinhole SANS


Platypus
Reflectometry


SPATZ
Reflectometry

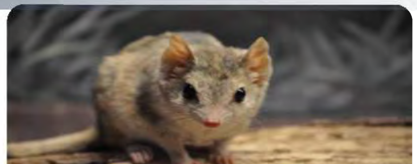

Kookaburra
Ultra-SANS


Bilby
II pinhole SANS

Diffraction


Echidna
High resolution powder


Wombat
High intensity powder


Kowari
Residual stress


Koala
Single crystals

Imaging


Dingo
Radiography & Tomography

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Neutron Radiography and Tomography

- DINGO Thermal-neutron radiography/tomography/imaging instrument

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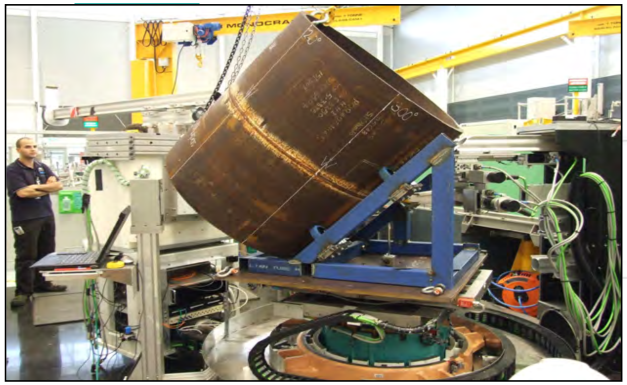
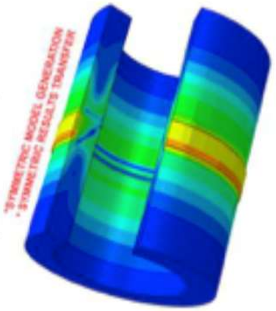
KOWARI: residual stress instrument





Characterisation and process development

Metals, alloys composites, plastic, liquids, glasses, concrete paints...

Materials consultancy and testing

Advanced manufacturing, welding/joining,

surface modification and enhancement

New materials development and optimisation

Alloy development,

Structural analysis and assessment

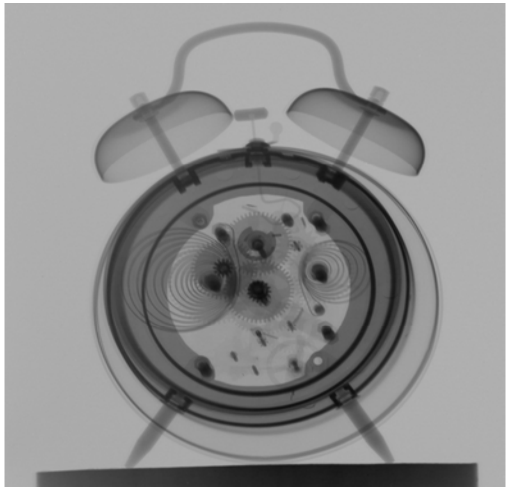
Pipelines, transport, defence, civil infrastructure

Residual stress and structural integrity

- Fracture
- Fatigue
- Distortion
- Stress corrosion cracking

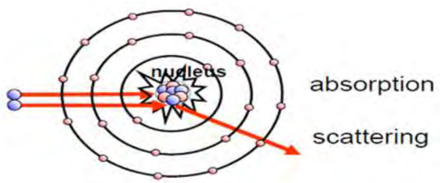
Radiography and Tomography

photograph	radiograph	tomograph
looking at	*looking through*	*looking inside*



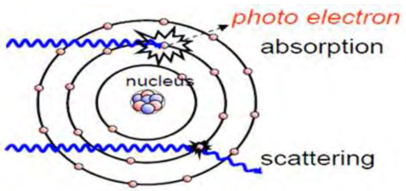
Neutrons Complement X-ray imaging

Neutrons

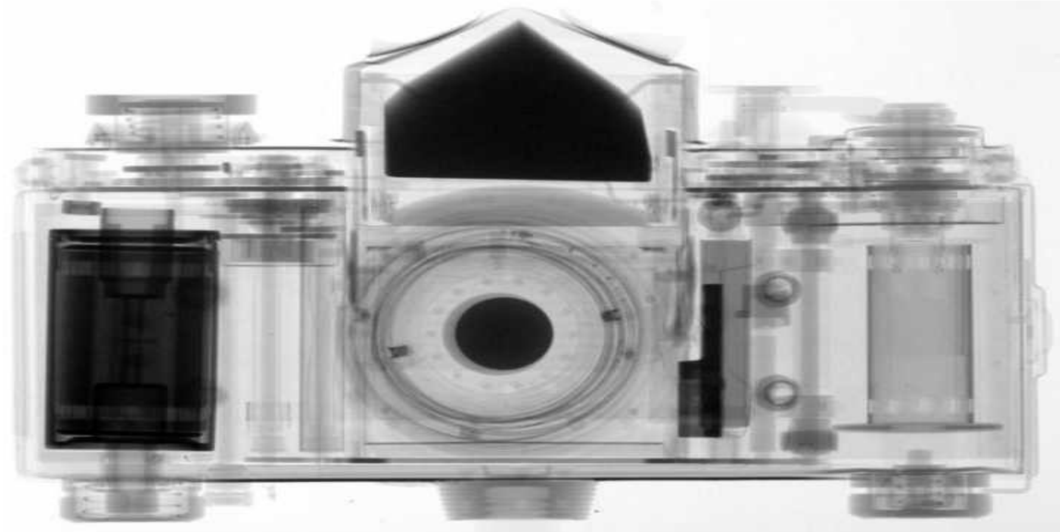


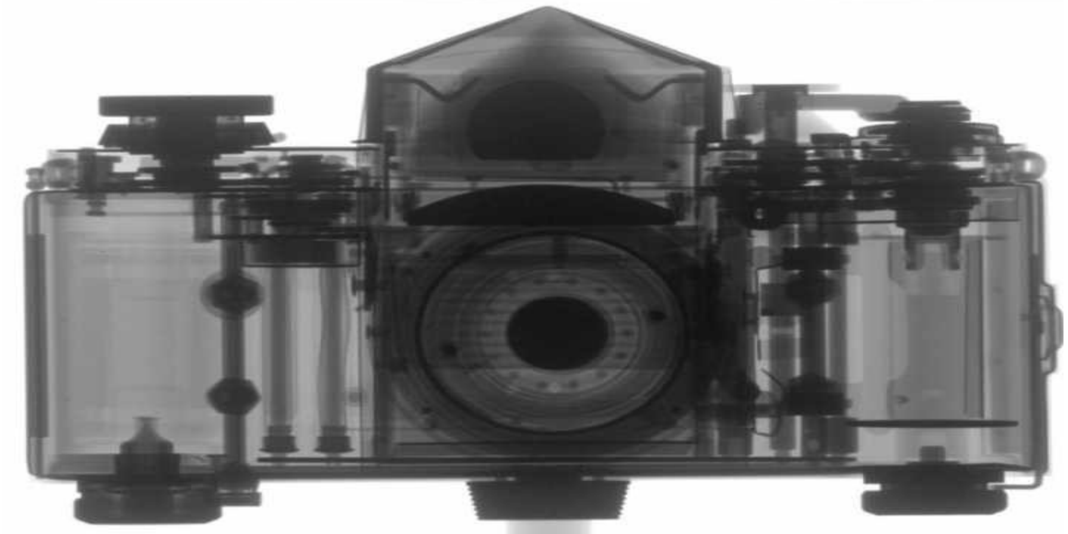
Pros	Cons
High penetration power	Acquisition time
High sensitivity to H	Resolution
Non-invasive method	Post-experiment radioactivity

X-ray



Pros	Cons
Fast acquisition	High Z materials
High resolution	Lower material differentiation
No after-radiation	





Attenuation Coefficient (X-rays)

Group → / ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H 0.02																	He 0.02
2	Li 0.06	Be 0.22											B 0.28	C 0.27	N 0.11	O 0.16	F 0.14	Ne 0.17
3	Na 0.13	Mg 0.24											Al 0.38	Si 0.33	P 0.25	S 0.30	Cl 0.23	Ar 0.20
4	K 0.14	Ca 0.26	Sc 0.48	Ti 0.73	V 1.04	Cr 1.29	Mn 1.32	Fe 1.57	Co 1.78	Ni 1.96	Cu 1.97	Zn 1.64	Ga 1.42	Ge 1.33	As 1.50	Se 1.23	Br 0.90	Kr 0.73
5	Rb 0.47	Sr 0.86	Y 1.61	Zr 2.47	Nb 3.43	Mo 4.29	Tc 5.06	Ru 5.71	Rh 6.08	Pd 6.13	Ag 5.67	Cd 4.84	In 4.31	Sn 3.98	Sb 4.28	Te 4.06	I 3.45	Xe 2.53
6	Cs 1.47	Ba 2.73		Hf 19.70	Ta 25.47	W 30.49	Re 34.47	Os 37.92	Ir 39.01	Pt 38.61	Au 35.94	Hg 25.88	Tl 23.23	Pb 22.81	Bi 20.28	Po 20.22	At -	Rn 9.77
7	Fr -	Ra 11.80		Rf -	Db -	Sg -	Bh -	Hs -	Mt -	Ds -	Rg -	Uub -	Uut -	Uuq -	Uup -	Uuh -	Uus -	Uuo -
Lanthanides				La 5.04	Ce 5.79	Pr 6.23	Nd 6.46	Pm 7.33	Sm 7.68	Eu 5.66	Gd 8.69	Tb 9.46	Dy 10.17	Ho 10.17	Er 11.70	Tm 12.49	Yb 9.32	Lu 14.07
Actinides				Ac 24.47	Th 28.95	Pa 39.65	U 49.08	Np -	Pu -	Am -	Cm -	Bk -	Cf -	Es -	Fm -	Md -	No -	Lr -

[A. Kaestner, PSI]

Attenuation Coefficient (neutrons)

Group → / ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H 3.44																	He 0.02
2	Li 3.30	Be 0.79											B 101.6	C 0.56	N 0.43	O 0.17	F 0.20	Ne 0.10
3	Na 0.09	Mg 0.15											Al 0.1	Si 0.11	P 0.12	S 0.06	Cl 1.33	Ar 0.03
4	K 0.06	Ca 0.08	Sc 2.00	Ti 0.60	V 0.72	Cr 0.54	Mn 1.21	Fe 1.19	Co 3.92	Ni 2.05	Cu 1.07	Zn 0.35	Ga 0.49	Ge 0.47	As 0.67	Se 0.73	Br 0.24	Kr 0.61
5	Rb 0.08	Sr 0.14	Y 0.27	Zr 0.29	Nb 0.40	Mo 0.52	Tc 1.76	Ru 0.58	Rh 10.88	Pd 0.78	Ag 4.04	Cd 115.1	In 7.58	Sn 0.21	Sb 0.30	Te 0.25	I 0.23	Xe 0.43
6	Cs 0.29	Ba 0.07		Hf 4.99	Ta 1.49	W 1.47	Re 6.85	Os 2.24	Ir 30.46	Pt 1.46	Au 6.23	Hg 16.21	Tl 0.47	Pb 0.38	Bi 0.27	Po -	At -	Rn -
7	Fr -	Ra 0.34		Rf -	Db -	Sg -	Bh -	Hs -	Mt -	Ds -	Rg -	Uub -	Uut -	Uuq -	Uup -	Uuh -	Uus -	Uuo -
Lanthanides				La 0.52	Ce 0.14	Pr 0.41	Nd 1.87	Pm 5.72	Sm 171.47	Eu 94.58	Gd 1479.0	Tb 0.93	Dy 32.42	Ho 2.25	Er 5.48	Tm 3.53	Yb 1.40	Lu 2.75
Actinides				Ac -	Th 0.59	Pa 8.46	U 0.82	Np 9.80	Pu 50.20	Am 2.86	Cm -	Bk -	Cf -	Es -	Fm -	Md -	No -	Lr -

[A. Kaestner, PSI]

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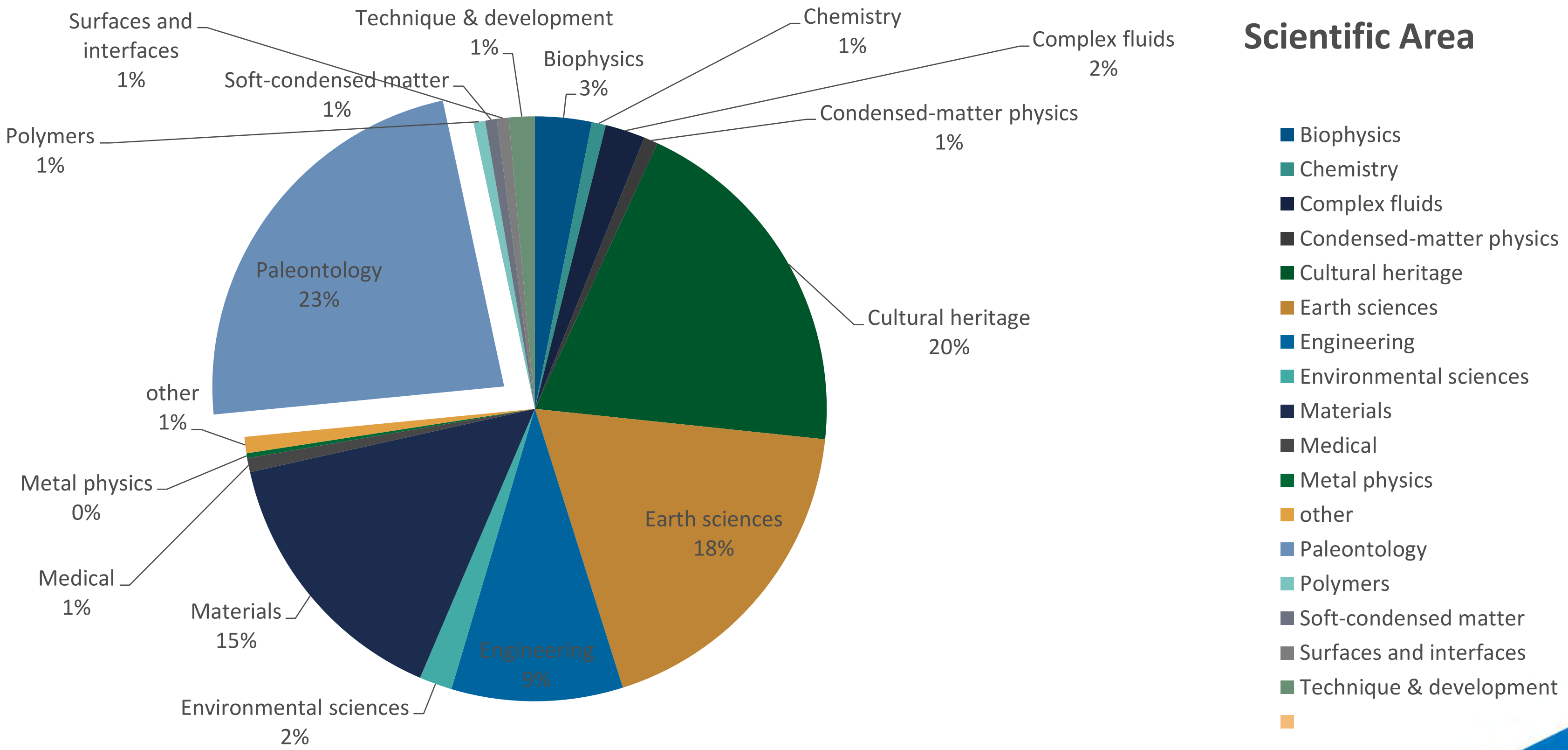
Merit-based Dingo Utilisation



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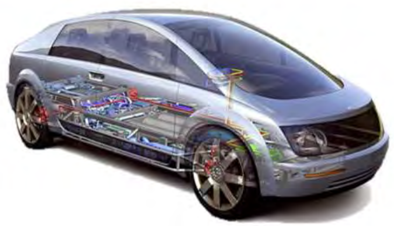
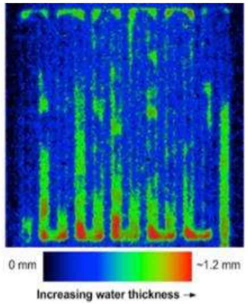
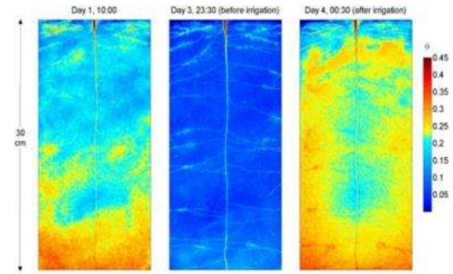
Applications overview

Energy

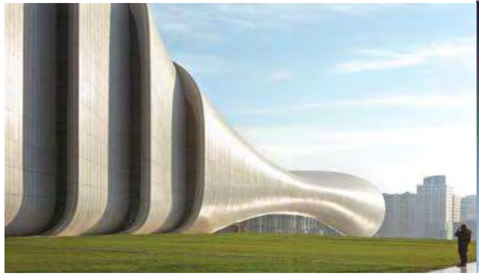


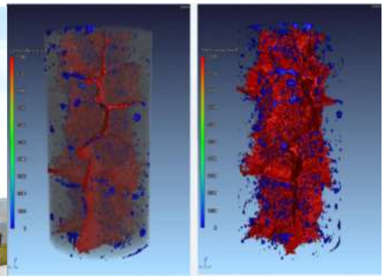


Agriculture & Food

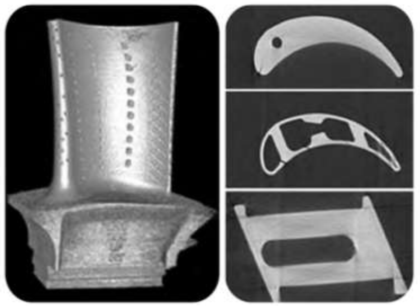


Civil engineering

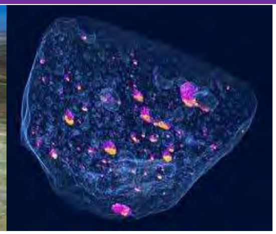




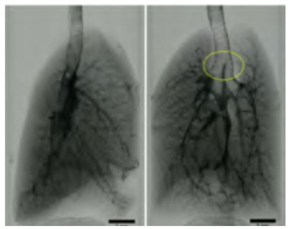
Industrial manufacturing



Earth & Planetary Science



Biology and Medicine



Discovery via Palaeontology

National Youth Science Forum

A 12 DAY RESIDENTIAL PROGRAM FOR STUDENTS ENTERING YEAR 12 WHO ARE PASSIONATE ABOUT SCIENCE, TECHNOLOGY, ENGINEERING AND MATHS.

Outreach = Opportunity

AUSTRALIAN AGE OF DINOSAURS
WINTON Q.
www.australianageofdinosaurs.com

Student volunteer tour guide and preparator

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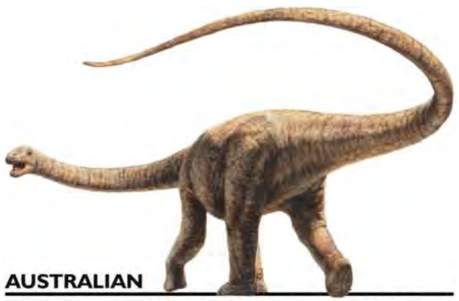
AAOD: First Fossil Samples on Dingo



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www.australianageofdinosaurs.com

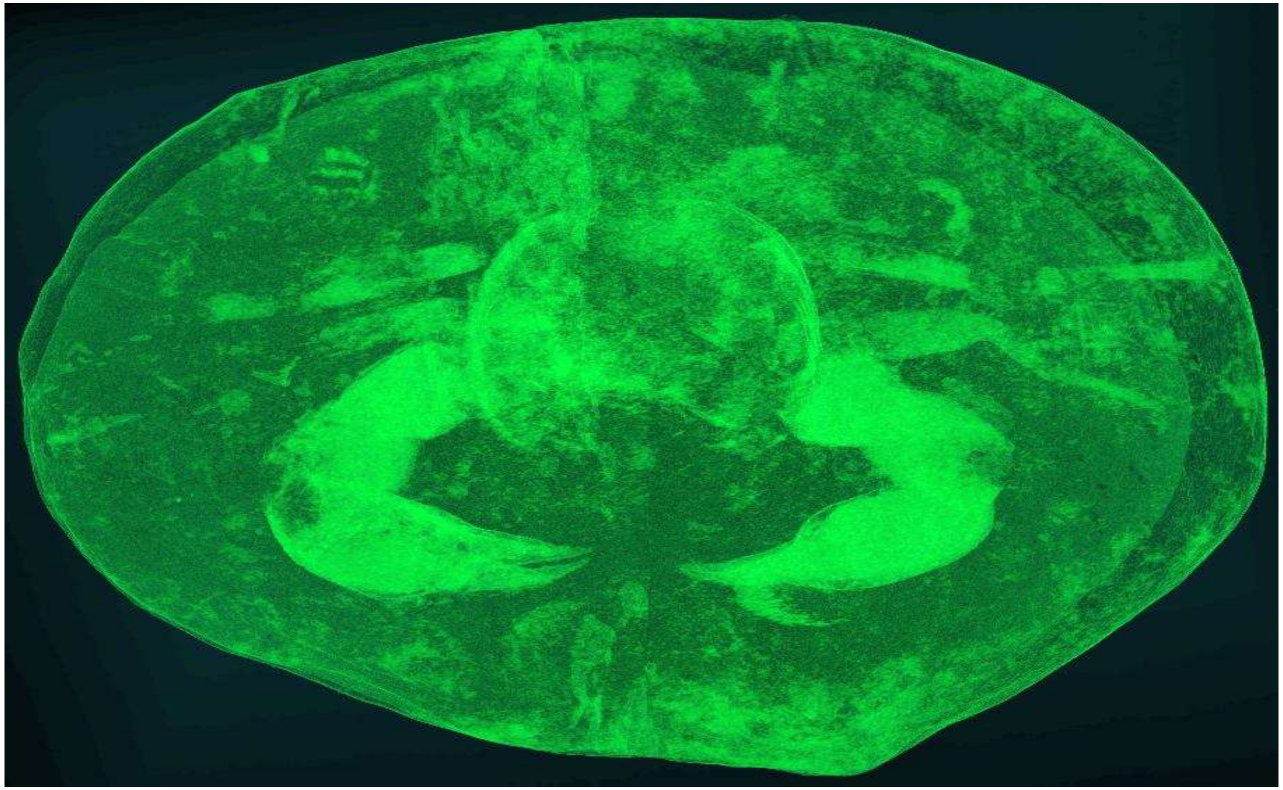
First Test Samples

ANSTO

AAOD: First Fossil Samples on Dingo

Neutrons: achieve contrast between organic remains (H-atoms in chitin) and limestone.

X-rays: very limited contrast



Ilfracombe Crab *Torynomma quadrata*. 112 MYO

AAOD: First Fossil Samples on Dingo

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AGE OF DINOSAURS
WINTON Q.
www.australianageofdinosaurs.com

NeutronCT is a means of guiding physical preparation of specimens for study or display

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X-rays: Imaging and Medical Beamline @ Australian Synchrotron

Permian (~280 MYO) Amphibians & Reptiles

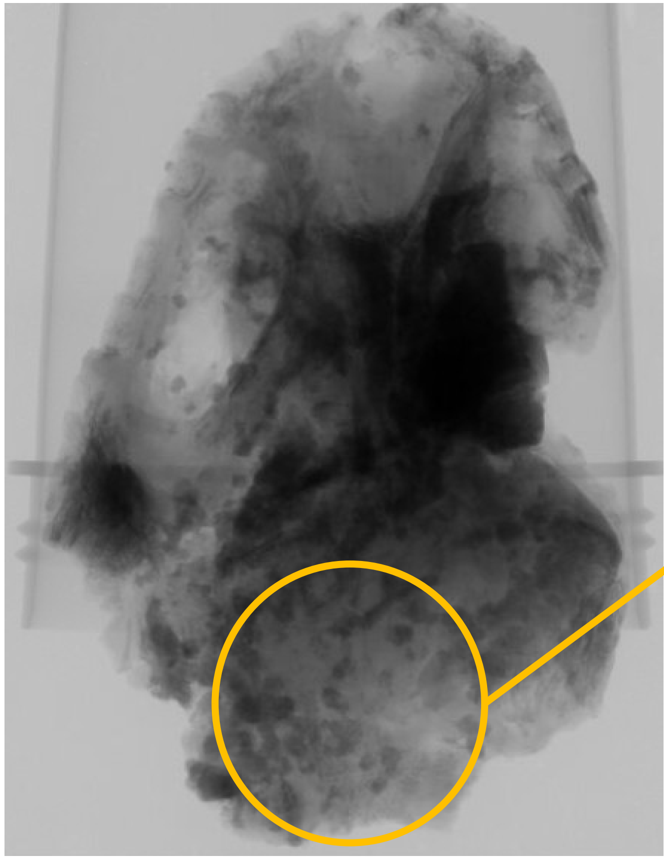
Prof Robert Reisz

UNIVERSITY OF TORONTO

ANSTO

Neutron Vs Synchrotron X-rays

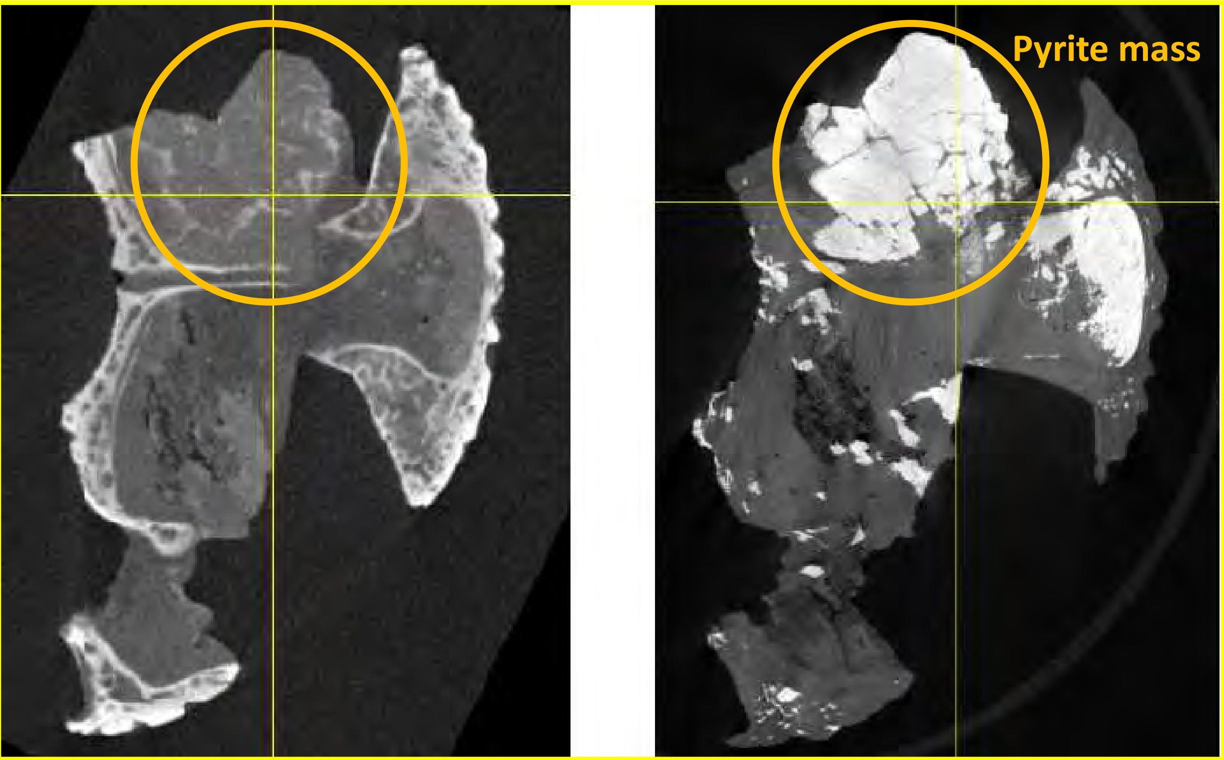
Dingo, neutrons



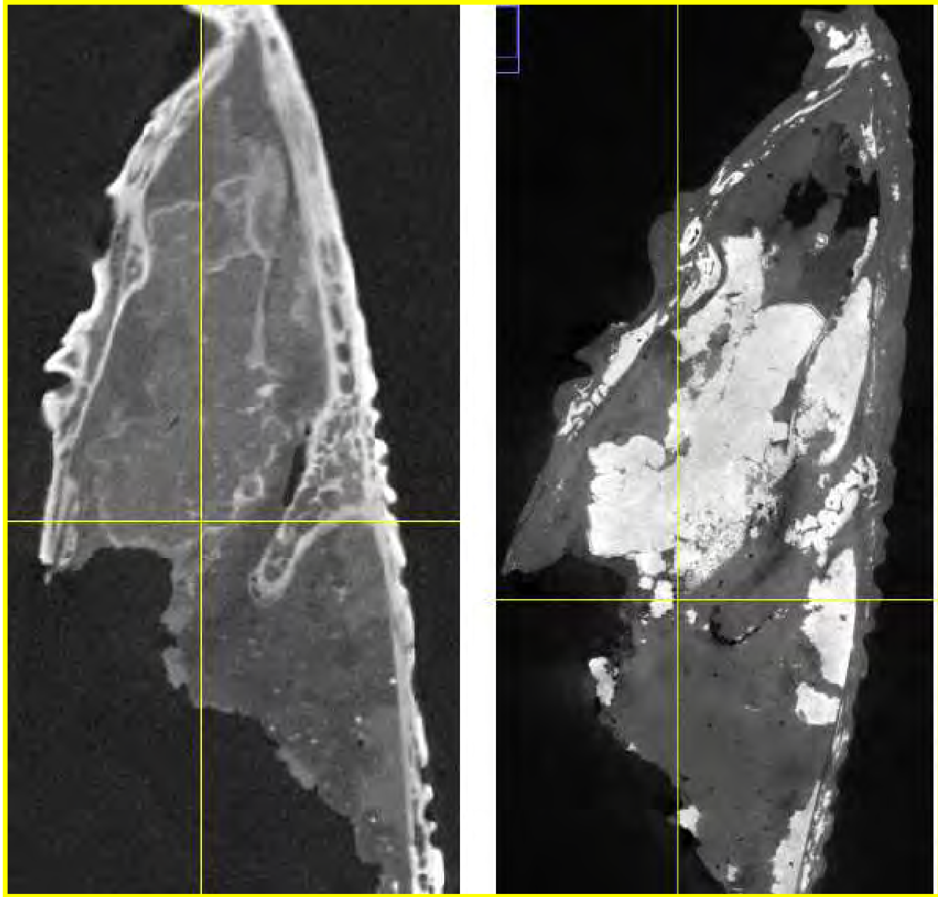
Australian Synchrotron IMBL

Spots = **Fool's gold** (iron pyrite) which causes interference with X-rays

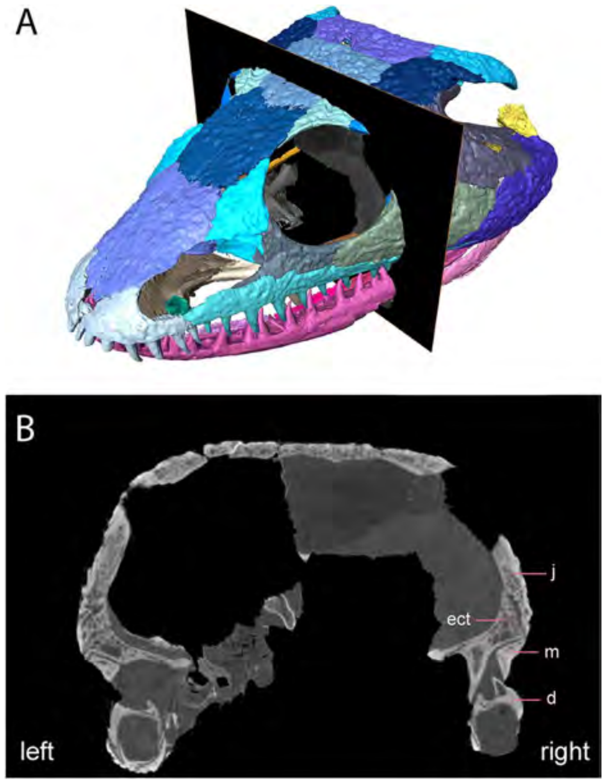
Neutron Vs Synchrotron X-rays

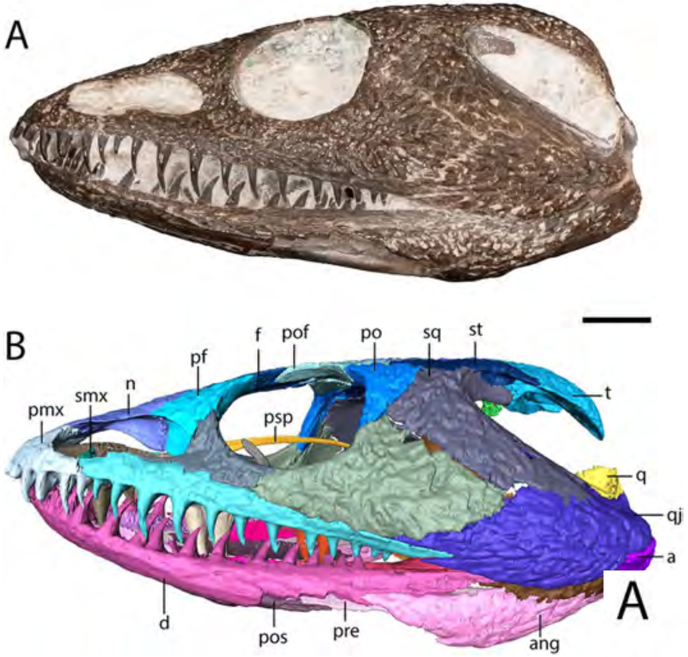


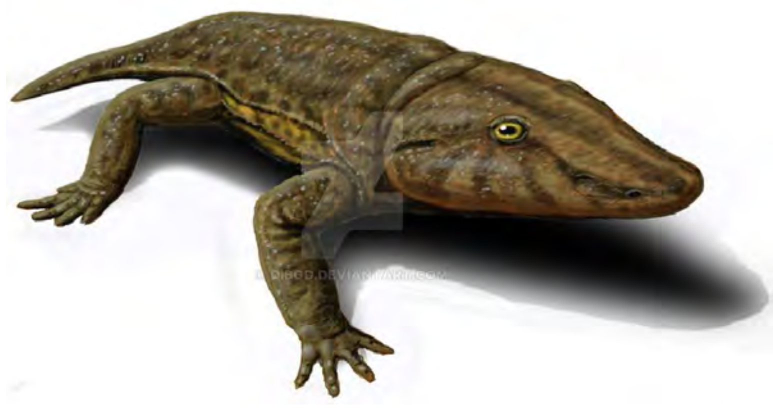
Neutrons X-rays

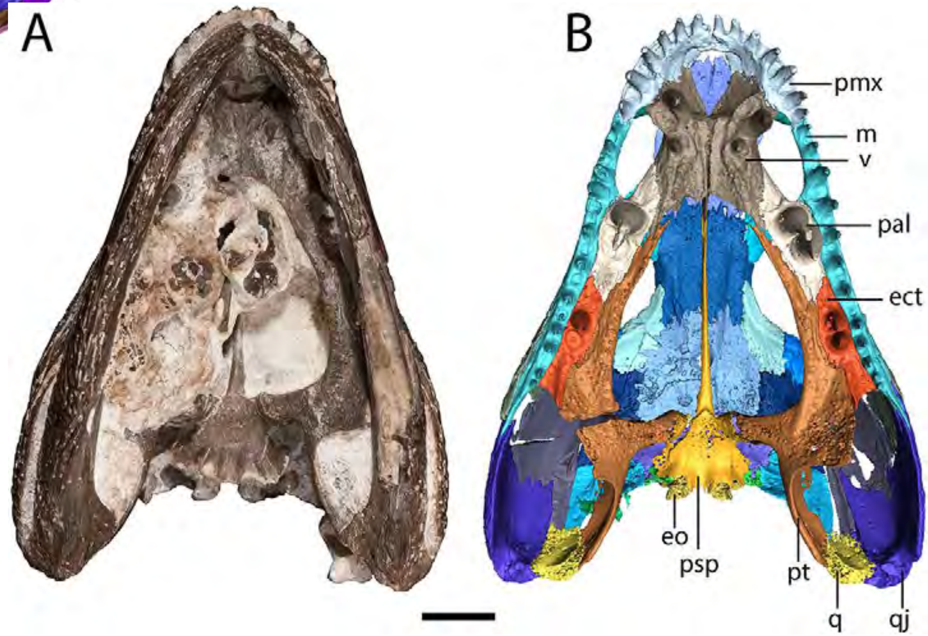


Acheloma

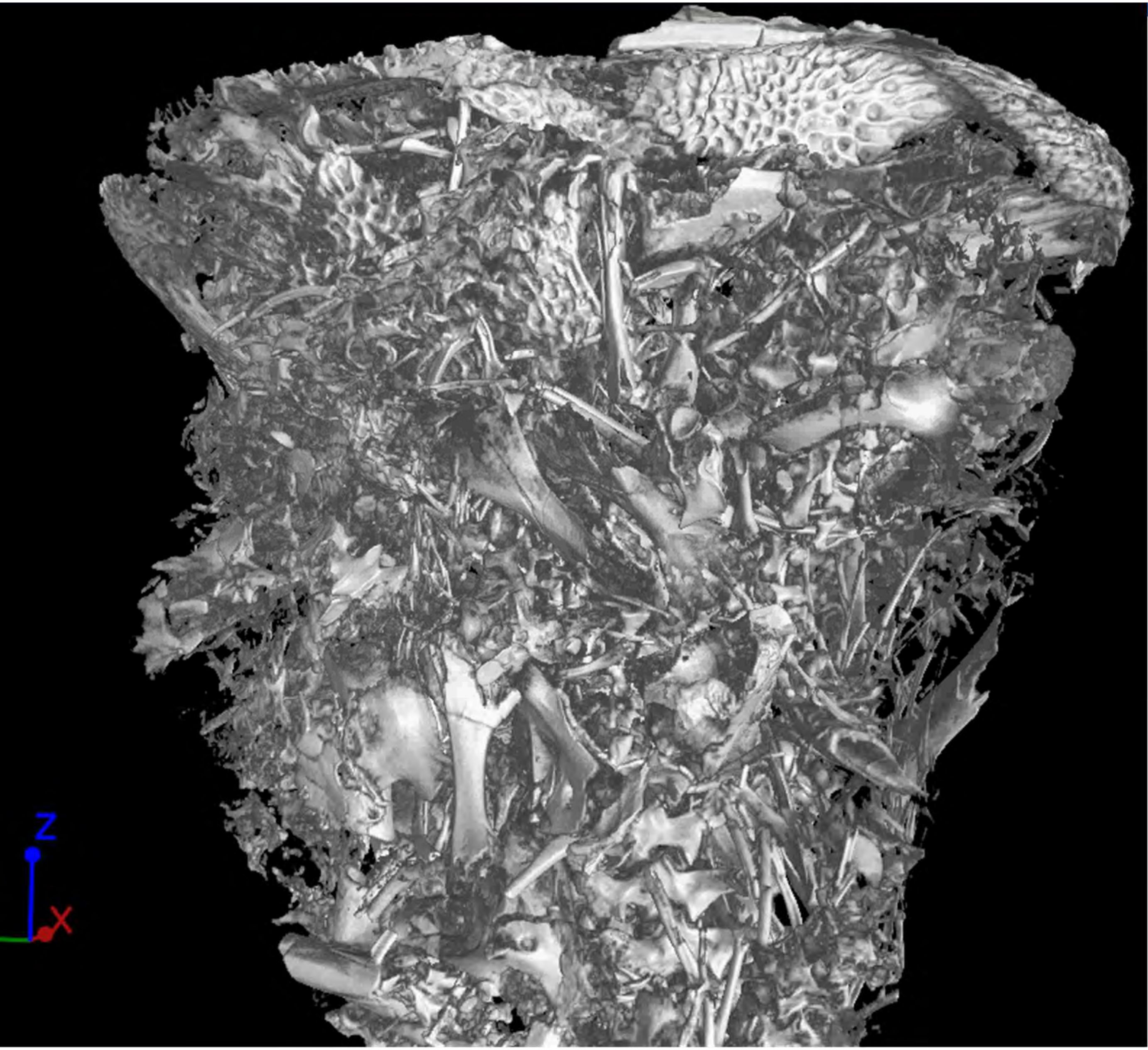






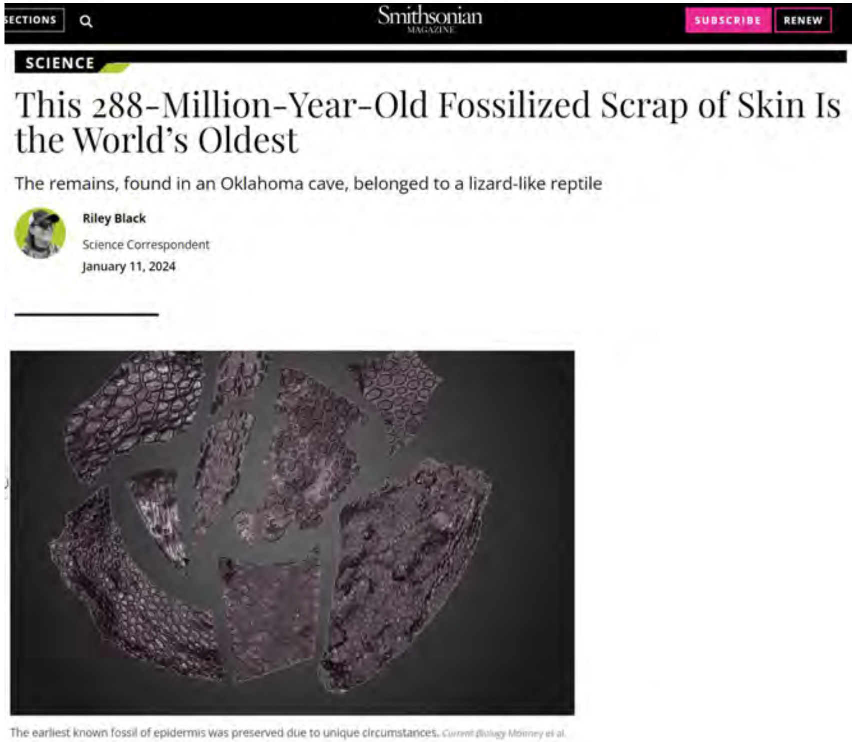


Gee, Bevitt, & Reisz, *A juvenile specimen of the trematopid Acheloma*, *Frontiers in Earth Science*, 7 (38), 2019.



A cave deposit death assembly currently being segmented by the Reisz group.

Dimensions: 20 x 20 x 16 cm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SCIENCE

This 288-Million-Year-Old Fossilized Scrap of Skin Is the World's Oldest

The remains, found in an Oklahoma cave, belonged to a lizard-like reptile

Riley Black
Science Correspondent
January 11, 2024

The earliest known fossil of epidermis was preserved due to unique circumstances. *Current Biology Mooney et al.*

A New Cretaceous Australian Crocodilian
Combining Neutron AND Synchrotron X-ray CT

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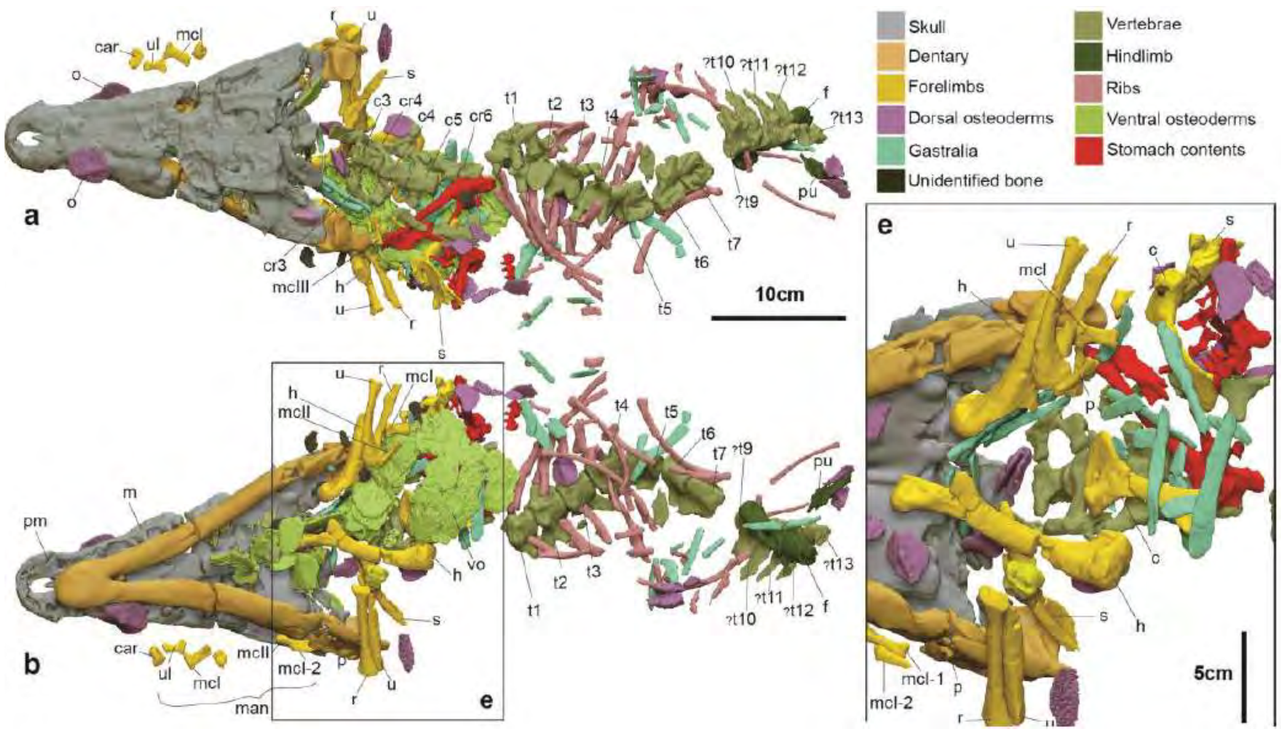

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Confractosuchus sauroktonos

White, MA, *et al., Abdominal contents reveal Cretaceous crocodyliforms ate dinosaurs*, Gondwana Res. 106, 281-302 (2022)

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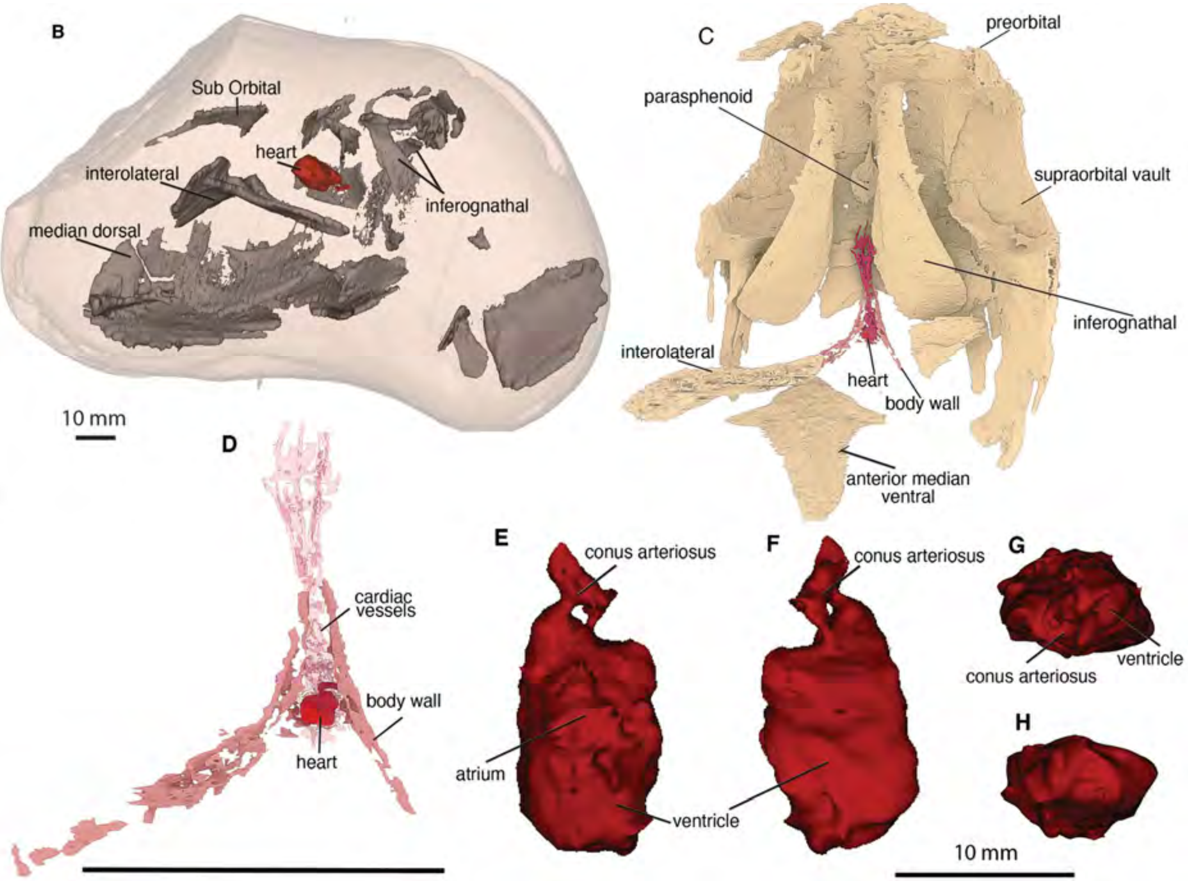
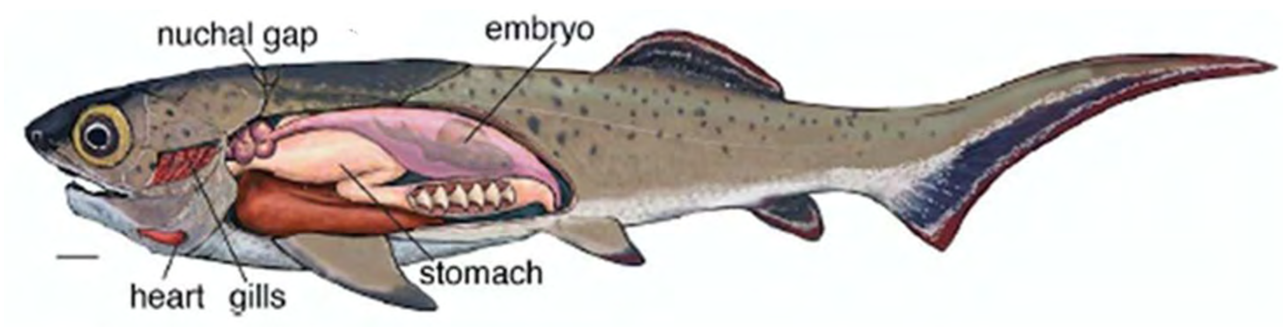
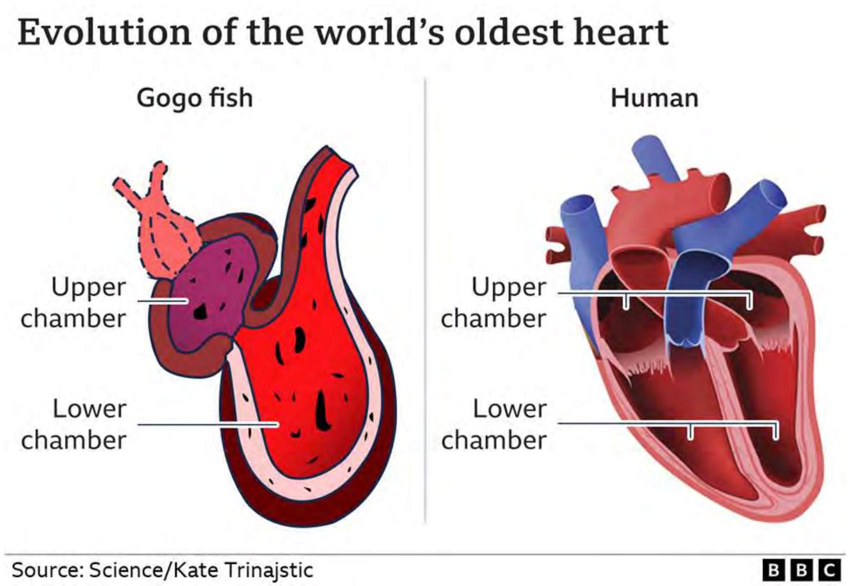
World's oldest fossil heart!



Compagopiscus



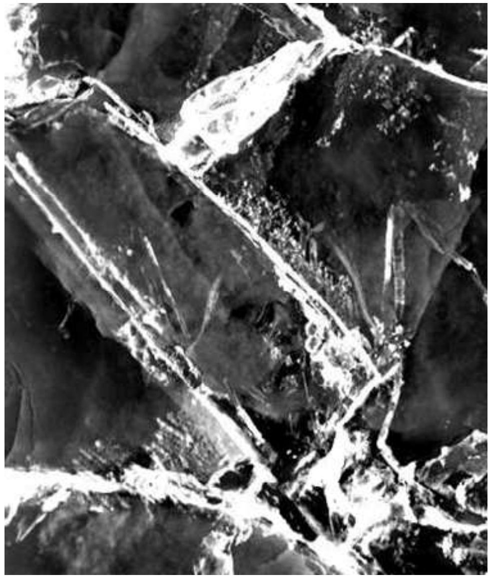


SCIENCE 15 Sep 2022, 377 (6612), 1311-1314; DOI: 10.1126/science.abf3289

Authenticity, Repairs & Fraud

吉林大学 恐龙演化研究中心
THE DINOSAUR EVOLUTION RESEARCH CENTER OF JILIN UNIVERSITY

- A potential new species of Enantiornithine
- Neutron sensitivity to hydrogen revealed repair and/or restoration or replacement of the head. XRF verified it was sourced from another fossil
- Opportunity to publish remains, albeit with a new focus



Neutrons

XRF - Strontium

ANSTO

Prime Benefits of Neutrons

- Alternative contrast to X-rays
- Increased penetration through steel and iron-based minerals.
- Large samples
- Sensitivity to hydrogen & water

Disadvantages

- Residual (temporary) radioactivity
- Long scan times for high-resolution studies
- Samples need to come to neutron facilities

Cultural Heritage

Cultural Heritage Project @ ANSTO

Heritage materials and technologies

Non-destructive approach

Synergy of Nuclear techniques

Material technology

Analytical science

Archaeometry & Conservation science

Cultural Heritage Project Applications and materials

- Documentation ✔
- Detection of hidden features and objects ✔
- Structural and morphological bulk analysis ✔
- Identification of ancient manufacturing technology ✔
- Authentication, provenance ✔
- Assessment of the conservation status ✔
- Identification of past interventions ✔
- Evaluation of new conservation methods ✔

MATERIALS

Metals

Paintings

Rock and ceramic

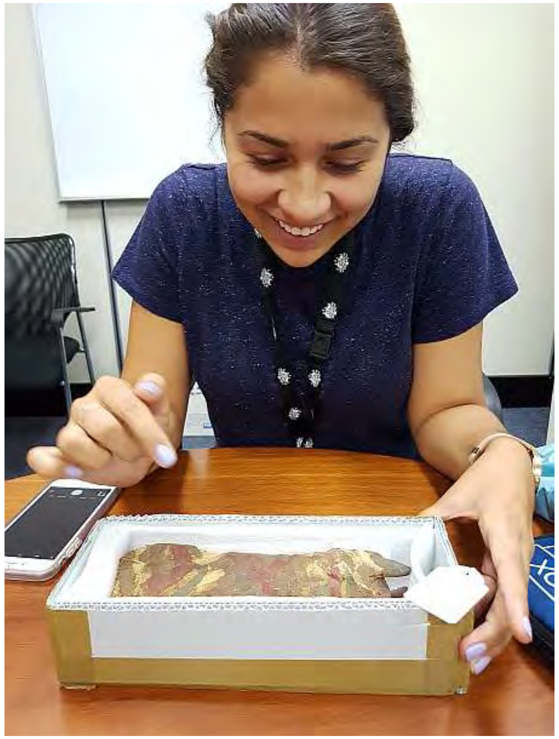
Wood

Organic polymers

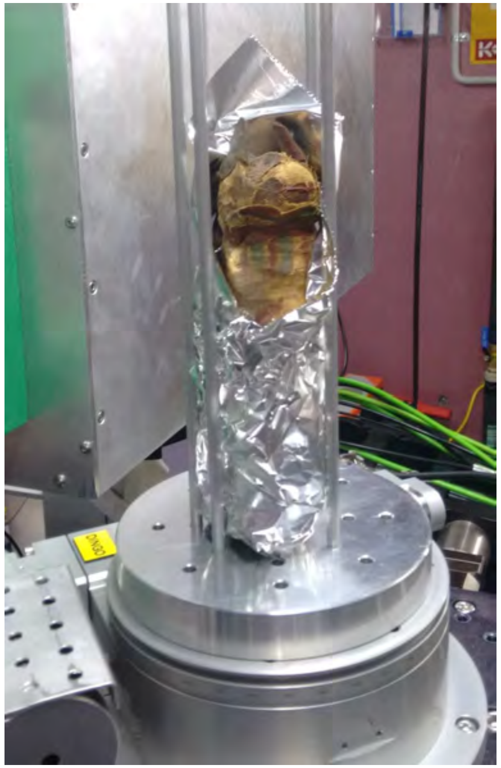
Composite

ANSTO

First Evidence of Recycling of Mummified Egyptian Votive Offerings



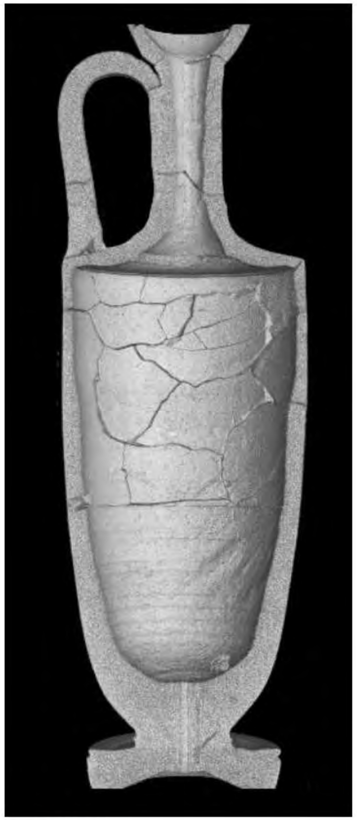
IA. 2402



Raymond, C.A. *et al*, Recycled blessings: an investigative case study of a re-wrapped Egyptian votive mummy using novel and established 3D imaging techniques, *Archaeometry* (2019). DOI: https://doi.org/10.1111/arcm.12477

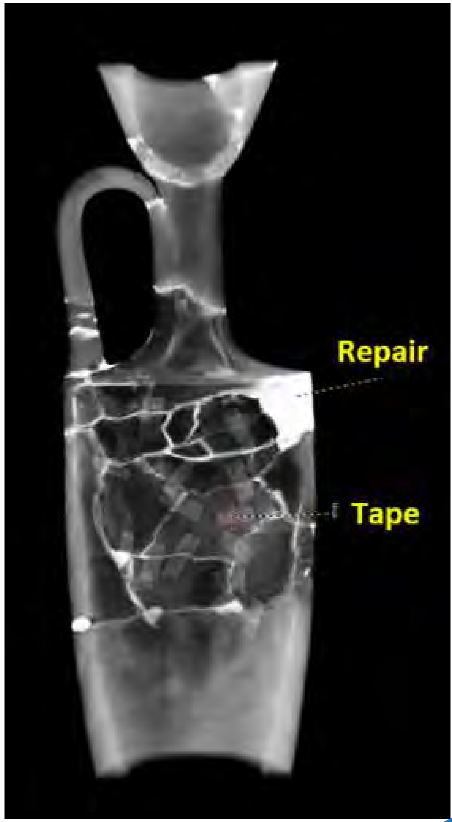
MU 4489: White-Ground Lekythos ~500 BCE

- Hidden organic components (tape) revealed with neutrons, but not with X-rays



X-ray CT

Neutron CT



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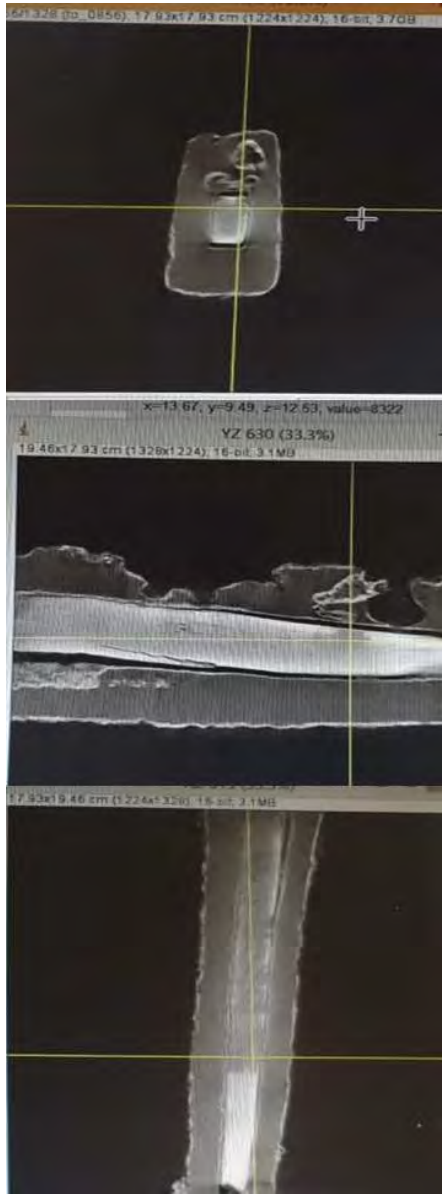
Neutrons can image through lead!

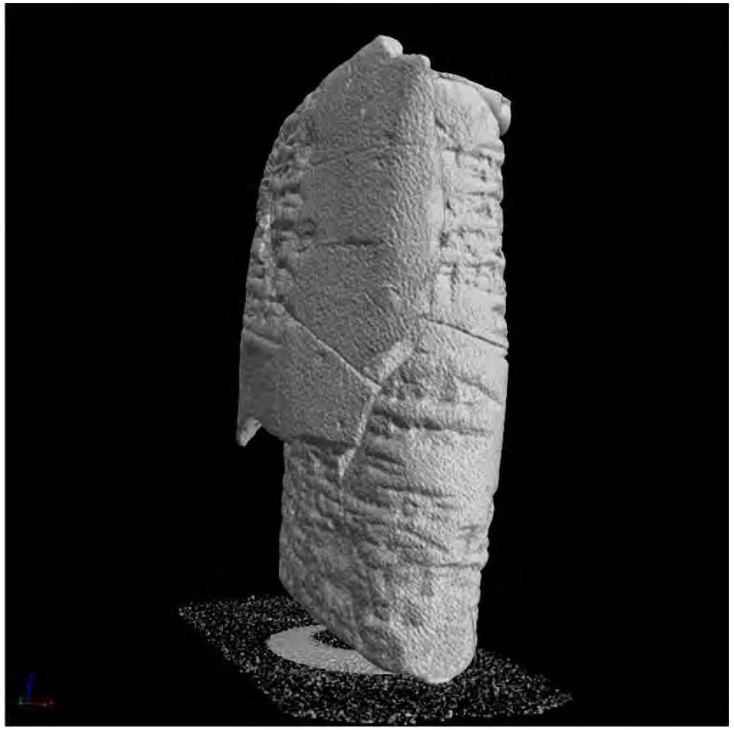


- Imaging an ancient Roman lead anchor reveals wood support and manufacturing method.
  Carla Raymond, PhD Thesis (unpublished).

High-throughput Artefact Scanning

Rapid NCT reduced radioactivation of museum samples, permitting rapid return (<3 days)

- 20 min NCT scan
- Raw data 0.013mm
- Effective voxel 0.026mm

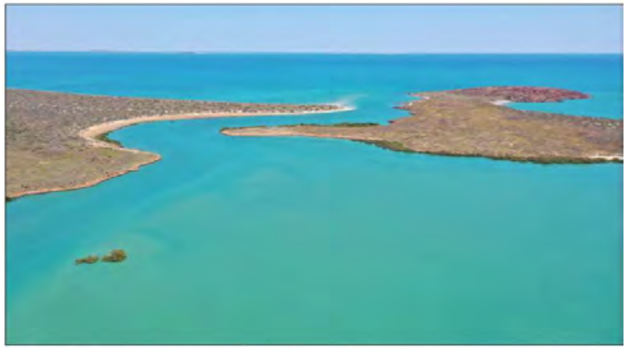


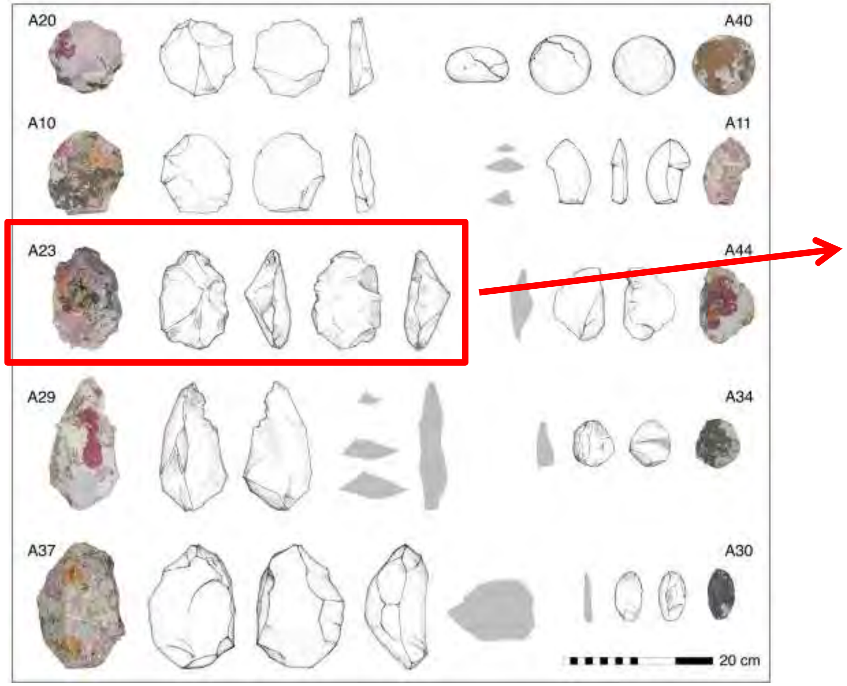
Centre for Ancient Cultural Heritage and Environment

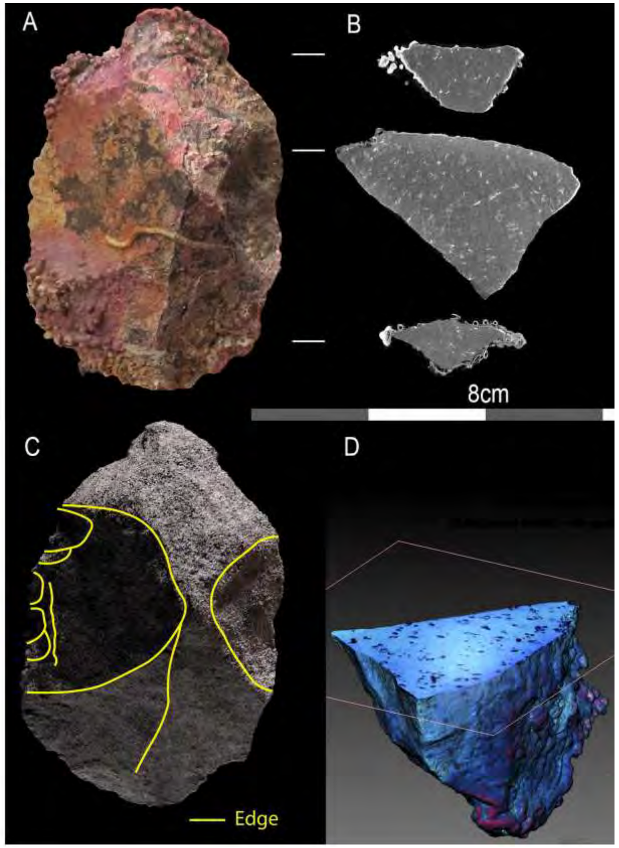
MACQUARIE University

ANSTO

Australia's 1st Ancient Underwater Archaeological Site







PLoS ONE 15(7): e0233912

The Invisible Revealed

Nuclear Methods Applied to the Powerhouse Museum Collection

POWERHOUSE

Australian Government | ANSTO

UNSW SYDNEY

Powerhouse Museum

Powerhouse Ultimo, located next to Sydney CBD

Powerhouse Parramatta

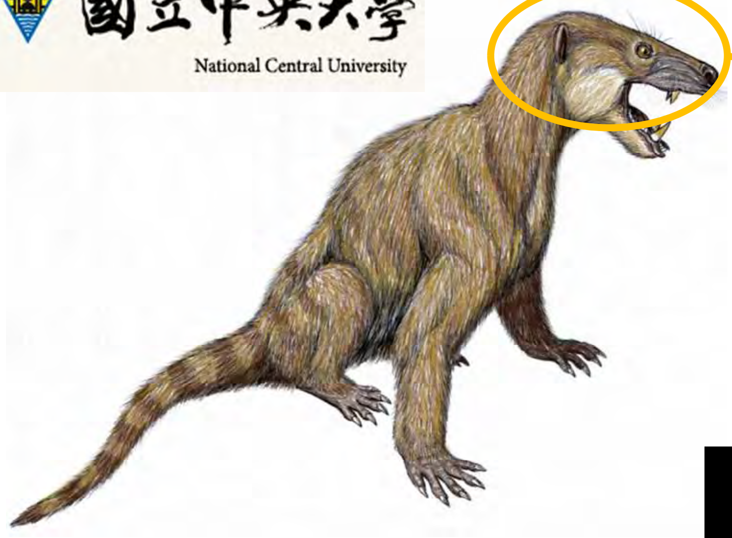
Powerhouse Castle Hill

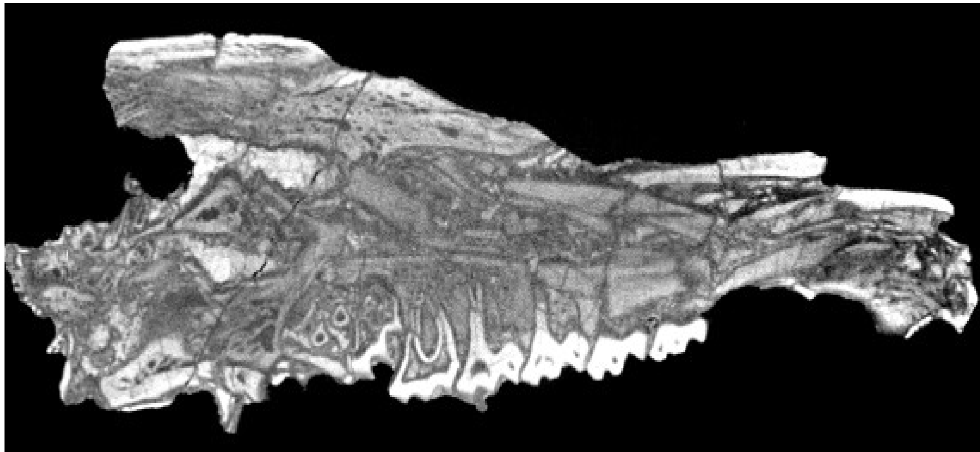
Sydney Observatory

ANSTO

Bienotherium: An Early Jurassic Stem Mammal

國立中央大學
National Central University





- Neutron contrast achieved due to selective uptake of rare earths in biological tissue.
- High energy X-rays needed for penetration = no contrast

ANSTO

3D Printed Neutron-CT Jigsaw Puzzle

NeutronCT data were converted to 3D prints for museum display (Powerhouse Museum, Sydney)

MAAS Exhibition : The Invisible Revealed

https://www.maas.museum/event/the-invisible-revealed/

- 12 November 2021 – 6 March 2022

Image: Figure, Mahasiddha Catrapa, Tibet, 1400–1599, Powerhouse Collection

Concept

"The Australian Nuclear Science and Technology Organisation (ANSTO) uses a combination of its state-of-the-art nuclear reactor, synchrotron and other particle accelerator based technologies to scan artefacts from the Powerhouse Collection. These world-class facilities provide insights into how these artefacts were manufactured, and how they be better conserved for future generations, by revealing their atomic- and microscopic-level structures and composition.

This exhibition will illustrate the discoveries of these age-old artefacts made using ANSTO's scientific instruments by presenting a selection of the original artefacts alongside computer-generated 3D (tomographic) visualisations and other imagery that reveal their structural secrets. Scale models and details of the sophisticated ANSTO facilities will be exhibited to give an appreciation of the achievements of Australia's diverse scientific and technical talent. To date, collaborative studies have been completed on items such as four Samurai swords spanning the period 1346–1800, a Chinese Shang dynasty (1600–1046 BCE) bronze wine vessel and three Tibetan Buddhist sculptures (1200–1600 CE)….

ANSTO

MUSEUM OF APPLIED ARTS AND SCIENCES

ANSTO Proposal for MAAS collection objects for analysis

Dr Deborah Lawler-Dormer, Research Manager, MAAS
Matthew Connell, Director Curatorial, Collections and Exhibitions, MAAS
March 2021

Museum of Applied Arts & Sciences

Sampling of Initial MAAS ideas

MUSEUM OF APPLIED ARTS AND SCIENCES

Conservation Research statement:

Identification of early synthetic dyes in the MAAS textile collection

MAAS has a large collection of early synthetic dyes (c.1903) store in glass jars (registration numbers H1996 through to H2015). In collaboration with ANTSO, we could undertake a study comparing our collection of early synthetic dyes with textiles of the same time period. The Smithsonian undertook a similar project. Powerhouse, for example, could analyse all pink/red dyes in the collection then compare them with the following items:

- 86/610 Evening dress, womens, Australia, c. 1910
- A9897 Evening dress, womens, silk chiffon / silk velvet / tulle / metal / resin, by Voila, England / France, c. 1910

Example

Best done elsewhere via IR, Raman

MAAS.MUSEUM

Proposal Submissions –March 2021

ACNS Neutron Beam Instrument Proposal

ID DB10004
Title ANSTO-MAAS Powerhouse MOU Beamtime Request: Neutron imaging of MAAS Collection objects for analysis and exhibit
Round Discretionary Beamtime

- Overview
- exhibition statement
- aim of proposal
- need for rapid neutronCT
- detail around specific objects

a) Marine Chronometer; Object Number: *H3940*
b) Wehrmacht (German army) type cipher machine in oak carry case; Object Number: *94/90/1*
c) Miniature Hit camera made by TougodoCompany; Object Number: 2004/44/10
d) Miniature Demon camera designed by Walter O'Reilly c. 1889; Object Number: 2004/44/1
e) Pocket watch by John Ellicott, London. Made 1771; Object Number: A4387
f) Chronometer designed by Marc Newson. Made 1999; Object Number: 2008/97/1
g) Curta calculator. Made c.1954; Object Number: 89/662
h) Padlock made for Postmaster Generals Department 1920 – 1970; Object Number: 98/2/43-1

Table 1: Selection of objects to be exhibited and neutron imaged using DINGO

Beamtime request: A total of 3 days of Dingo beamtime is requested to ensure safe handling of these objects on Dingo with curatorial assistance.

45 Objects, 9 Nuclear or Synchrotron Methods

- Over a 6-month period the following methods were used:

  - Accelerator Mass Spectrometry (^{14}C dating)
  - Proton Induced X-ray Emission
  - Neutron radiography and tomography
  - Synchrotron X-ray tomography
  - Neutron activation/Gamma spectroscopy
  - X-ray Fluorescence
  - Neutron powder diffraction
  - Neutron residual stress analysis
  - Neutron texture analysis

Access to instruments and staff time =

ANSTO's In-kind contribution to exhibition

  - A digital twin / virtual reality of the Dingo instrument & Gamma spectrometer

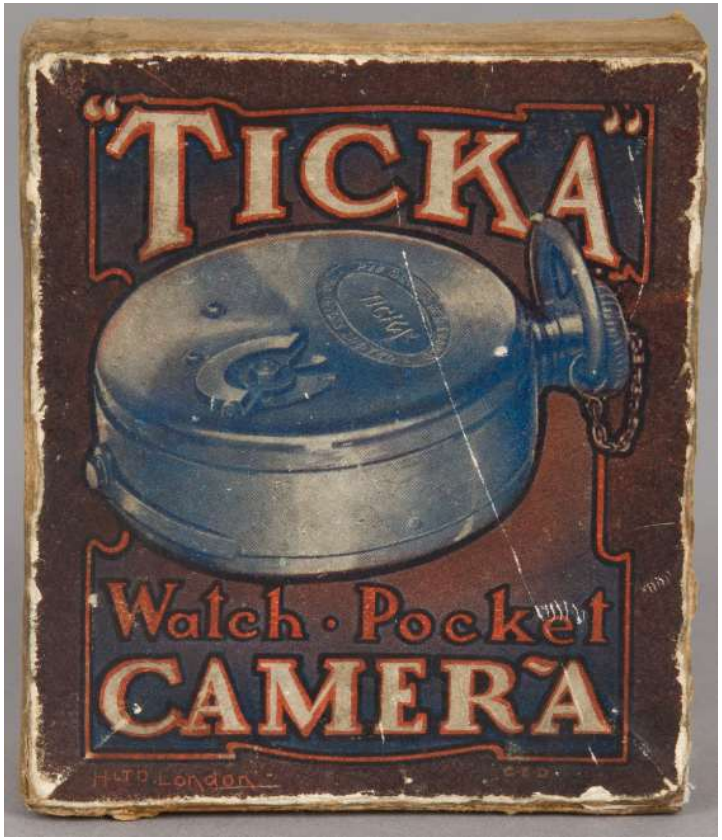
ANSTO

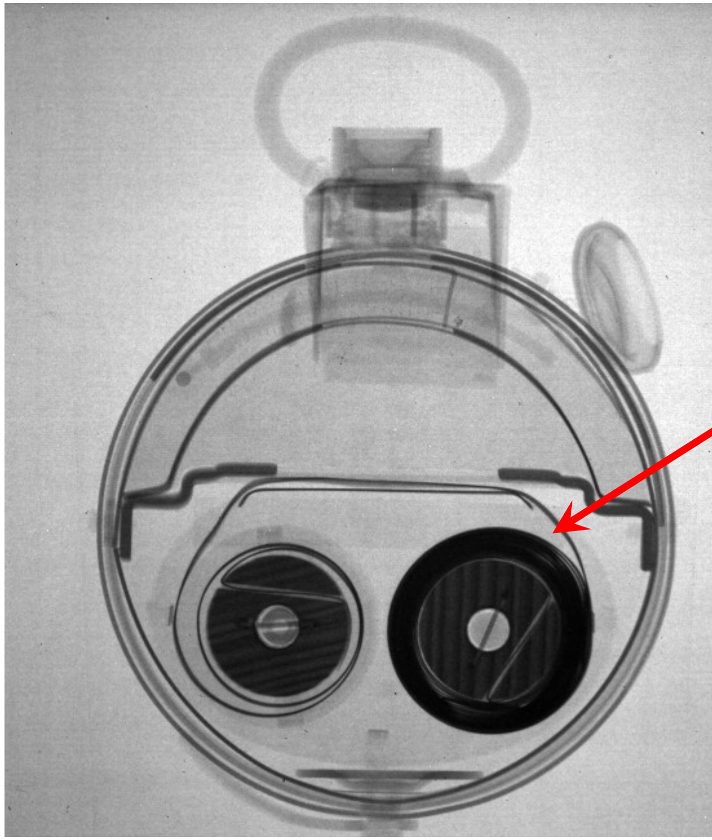
Delivery to Neutron Guide Hall - May 2021

ANSTO

Neutron Radiography

‘Ticka’ pocket watch camera





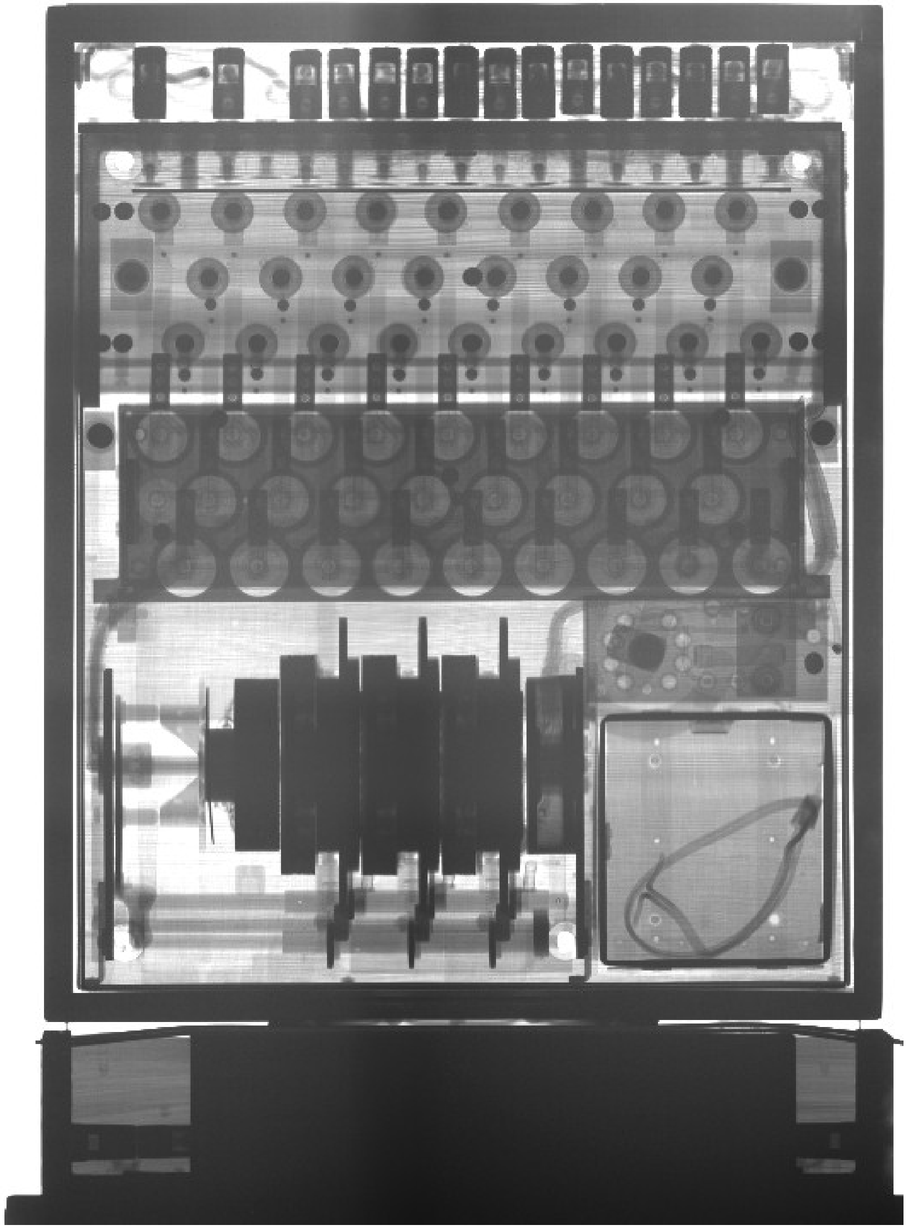
Original film within

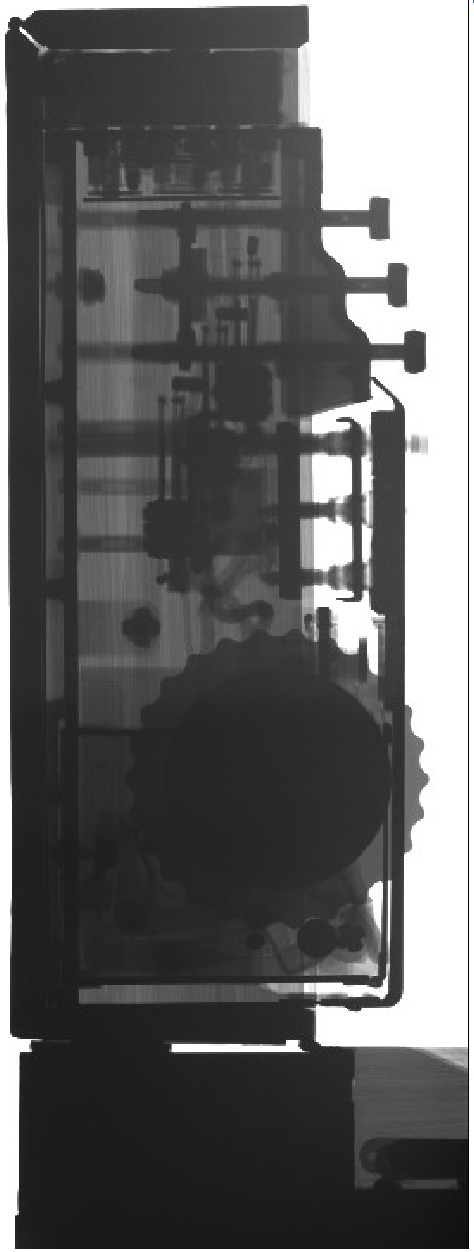
Pocket camera and viewfinder, 'Ticka', pocket watch shape, nickel / metal / glass, Houghtons Ltd, London, England, 1905-1914

ANSTO

German Cipher Machine “Enigma”

ANSTO





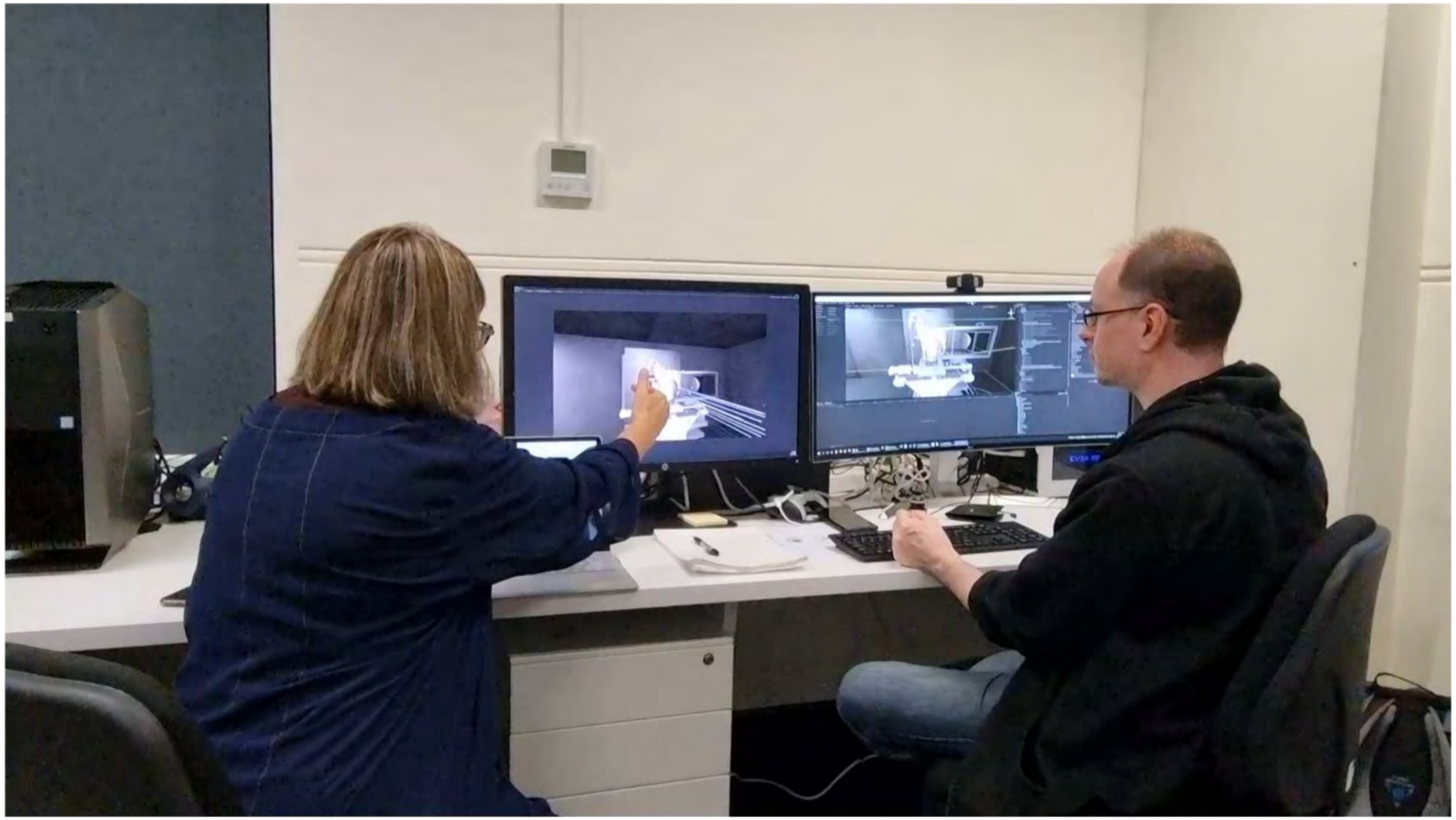
Enigma Cipher machine, front and side view neutron radiographs.

T'ang Dynasty Horse

Epicentre: Expanded Perception & Interaction Centre

ANSTO

Neutron CT Virtual Reality (Digital Twin)



EPICentre: Expanded Perception and Interaction Centre

Neutron CT Virtual Reality (Digital Twin)

EPICentre: Expanded Perception and Interaction Centre

ANSTO

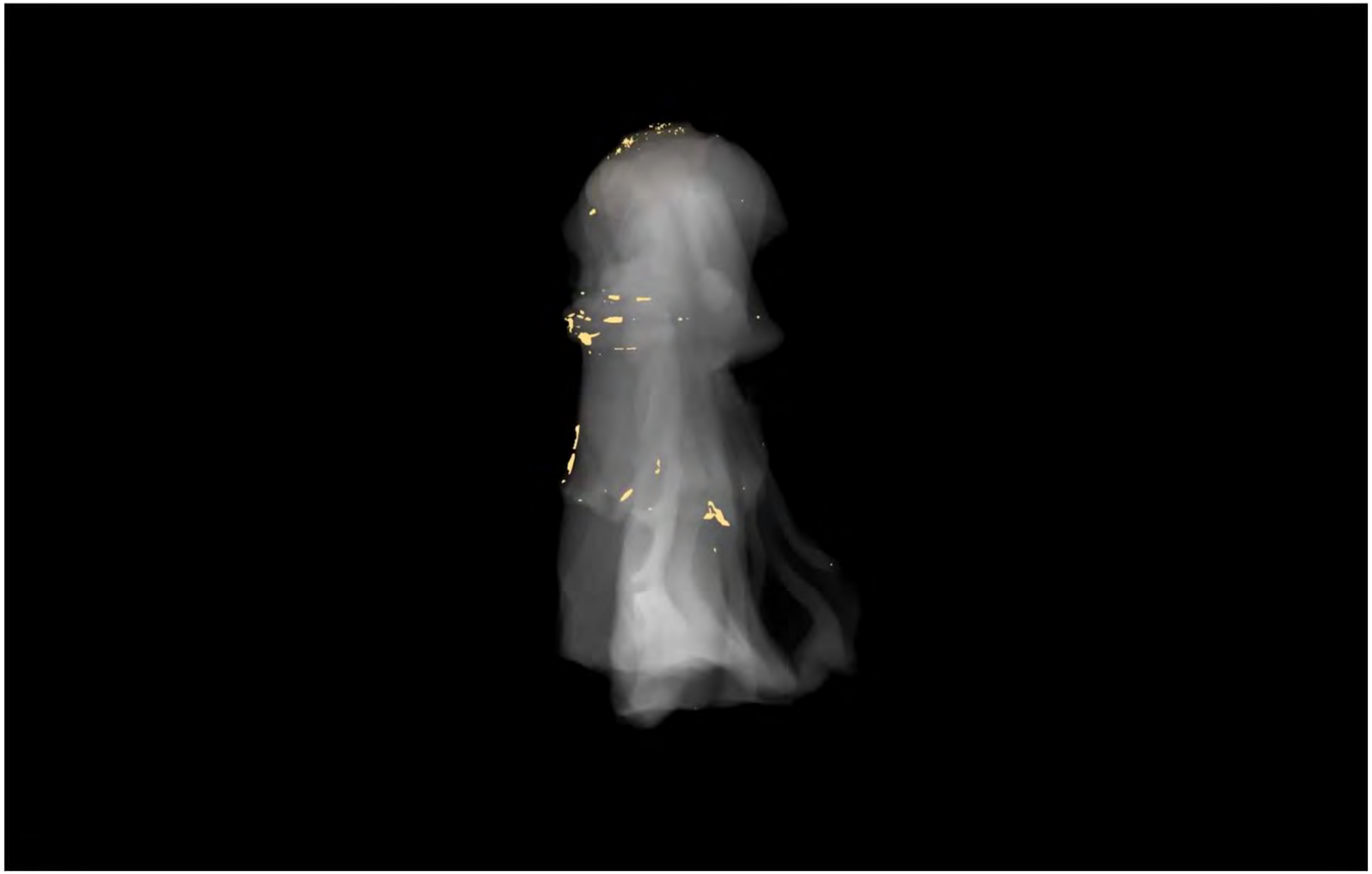
Neutron Tomography

Ancient Figure of Artemis

Research question:

- Can we identify the distribution of original pigment?
- Neutron tomography is very sensitive to traces of organic material
- Let’s try rapid (20 min) NCT scan!

Figure of Artemis



ANSTO

MUSEUM OF APPLIED ARTS AND SCIENCES

Sampling of Initial MAAS ideas

Object statement:

Curta calculator. Made c.1954

Mechanical calculator with case, Curta, System Curt Herzstark, metal, made by Contina Ltd, Mauren, Liechtenstein, c, 1954

"Compact hand held calculating machine built with watch making technology. Subtraction is performed by lifting the hand crank. Multiplication and division are done by lifting and turning the accumulator assembly to effect a shift.“ (Bromley note)

Object Number: 89/662

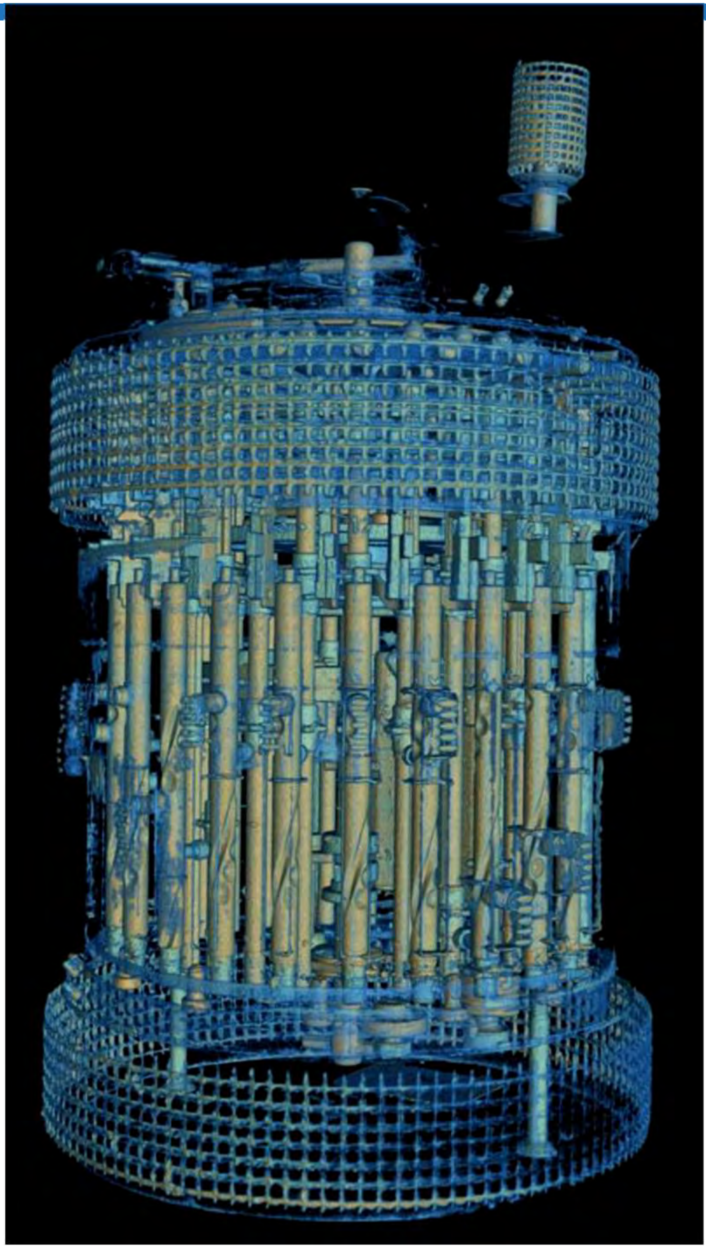
Research question:

Can we show the inner workings of this object?

2010/1/199
24/04/2014

Neutron or synchrotron CT

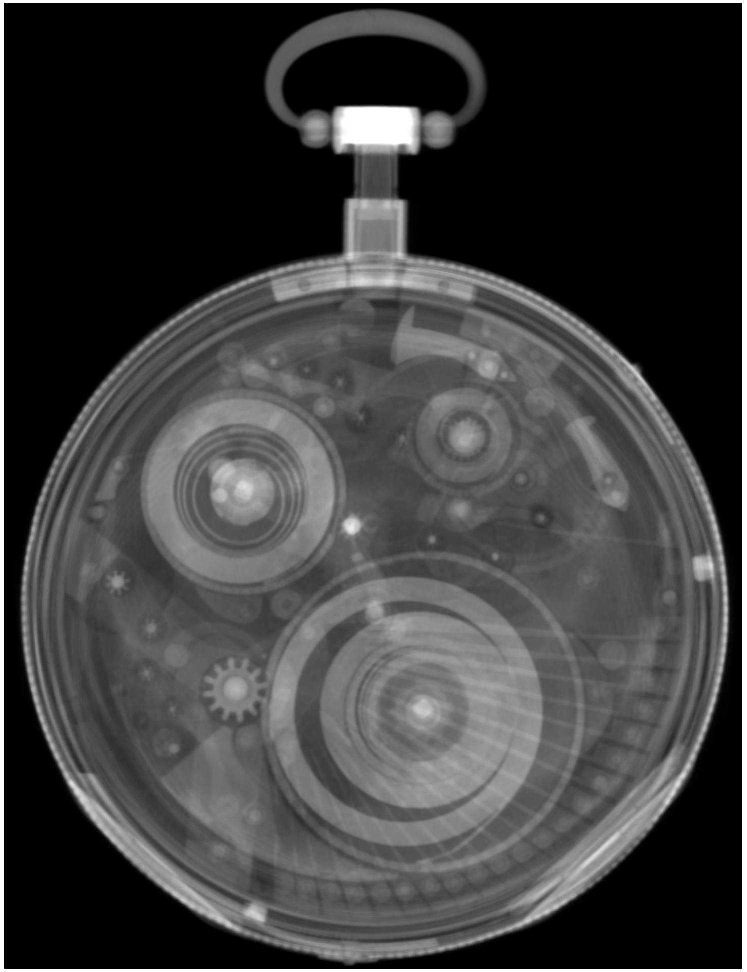
MAAS.MUSEUM



Curta Calculator

Musical rose gold pocket watch c1810

K971
05/01/2010



Musical rose gold pocket watch c1810

K971
05/01/2010

Textiles: Flat Objects and the challenges for Synchrotron X-ray CT

ANSTO

Clavus. Object A6168, Egypt 550–610CE

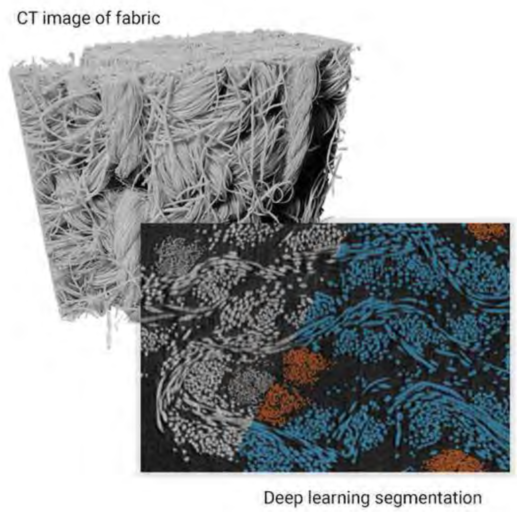
A 3rd-century fresco from the Hypogeum of the Aurelii in Rome, showing Roman senators in their striped togas.
Source: Dr. Dorothy King, http://phdiva.blogspot.com/2011/08/aurelii-and-third-century-rome.html

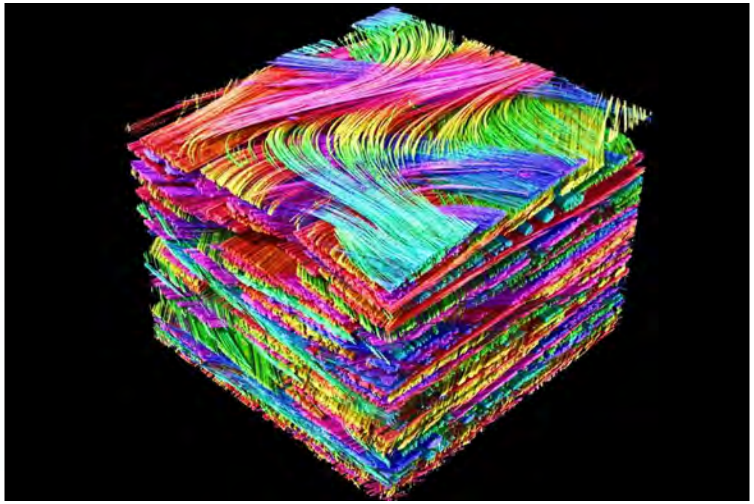
Laticlave, or clavus

A longitudinal band worn on a tunic. Purple bands on woollen tunics were worn by Roman senators as an emblem of office.

They later came to be adopted as a fashion statement in Greco-Roman Egypt.

Concept – Synchrotron X-ray CT



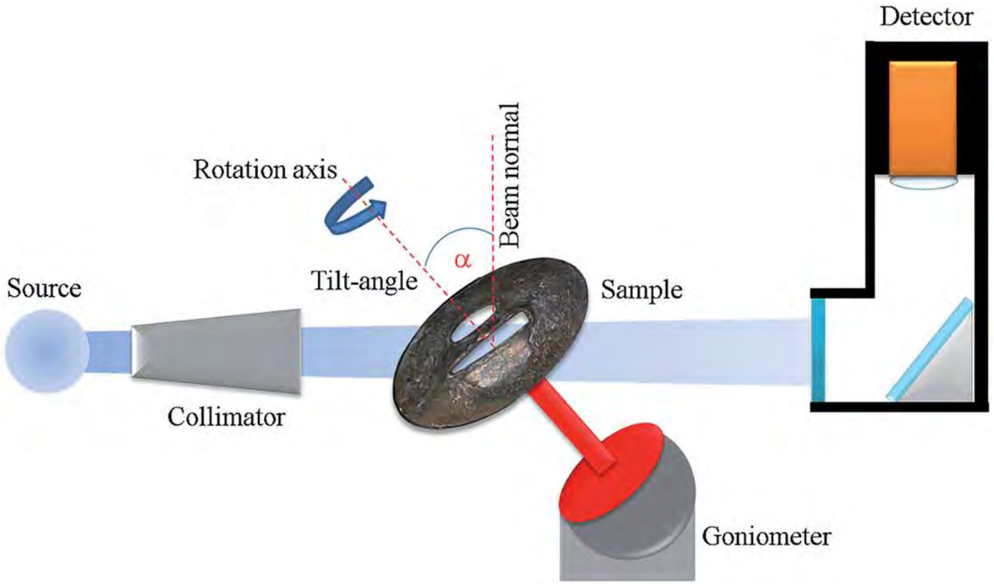


- High resolution scan of a VERY large, FLAT object to view and track every fibres
- Technically difficult as 3D imaging is best used for CYLINDRICAL (SOLID) objects
- Huge datasets = visualisation challenge

ANSTO

Laminography

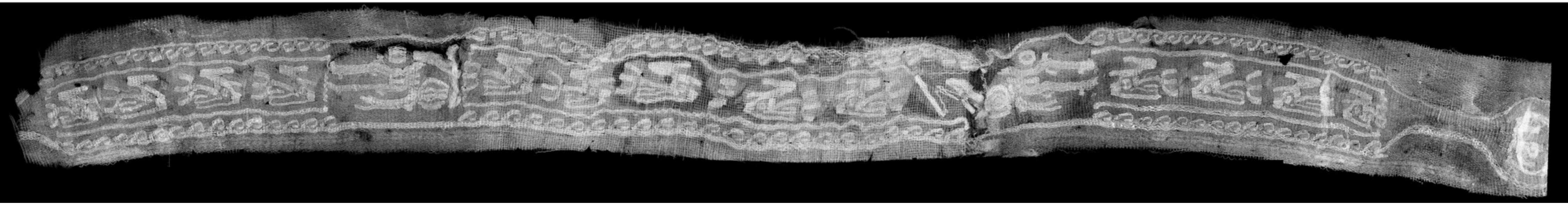
- Features above and below the plane of interest are blurred out but show a specific area more clearly



ANSTO

Clavus A6168

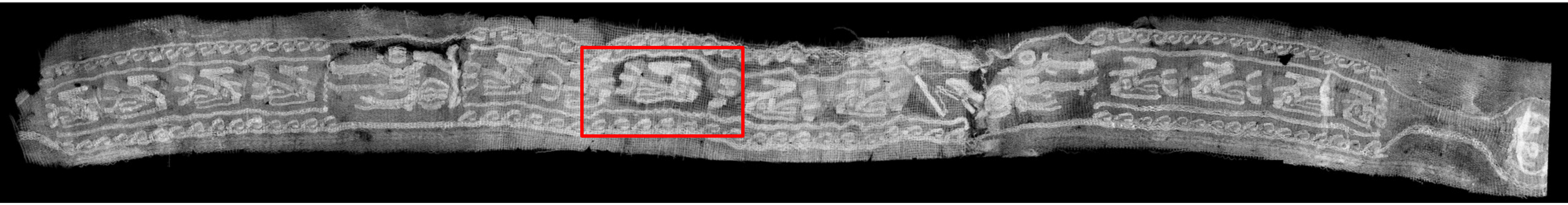
- Raw data : 1.34TB
- Final 3D reconstruction: 70GB



- Final 2D image = 30,704 x 3938 pixels

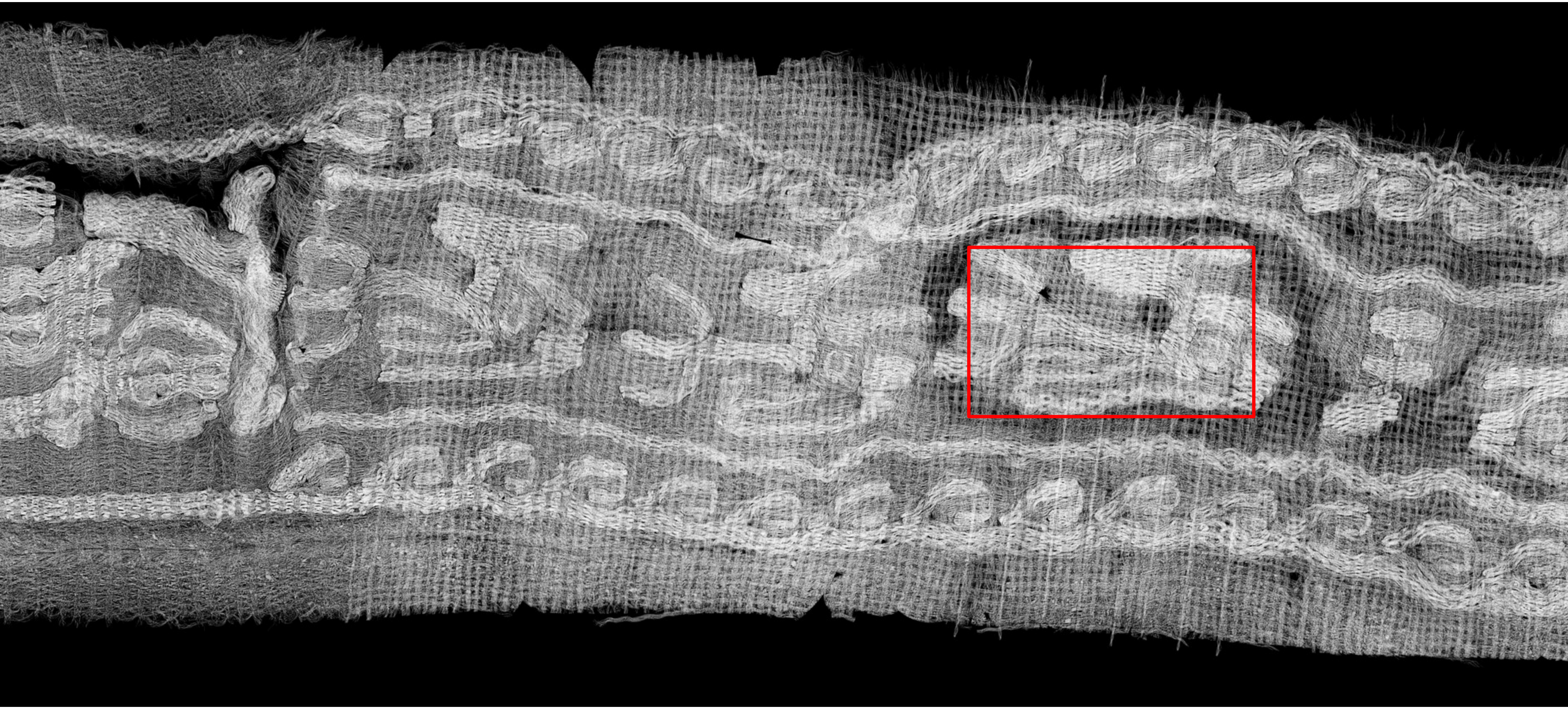
ANSTO

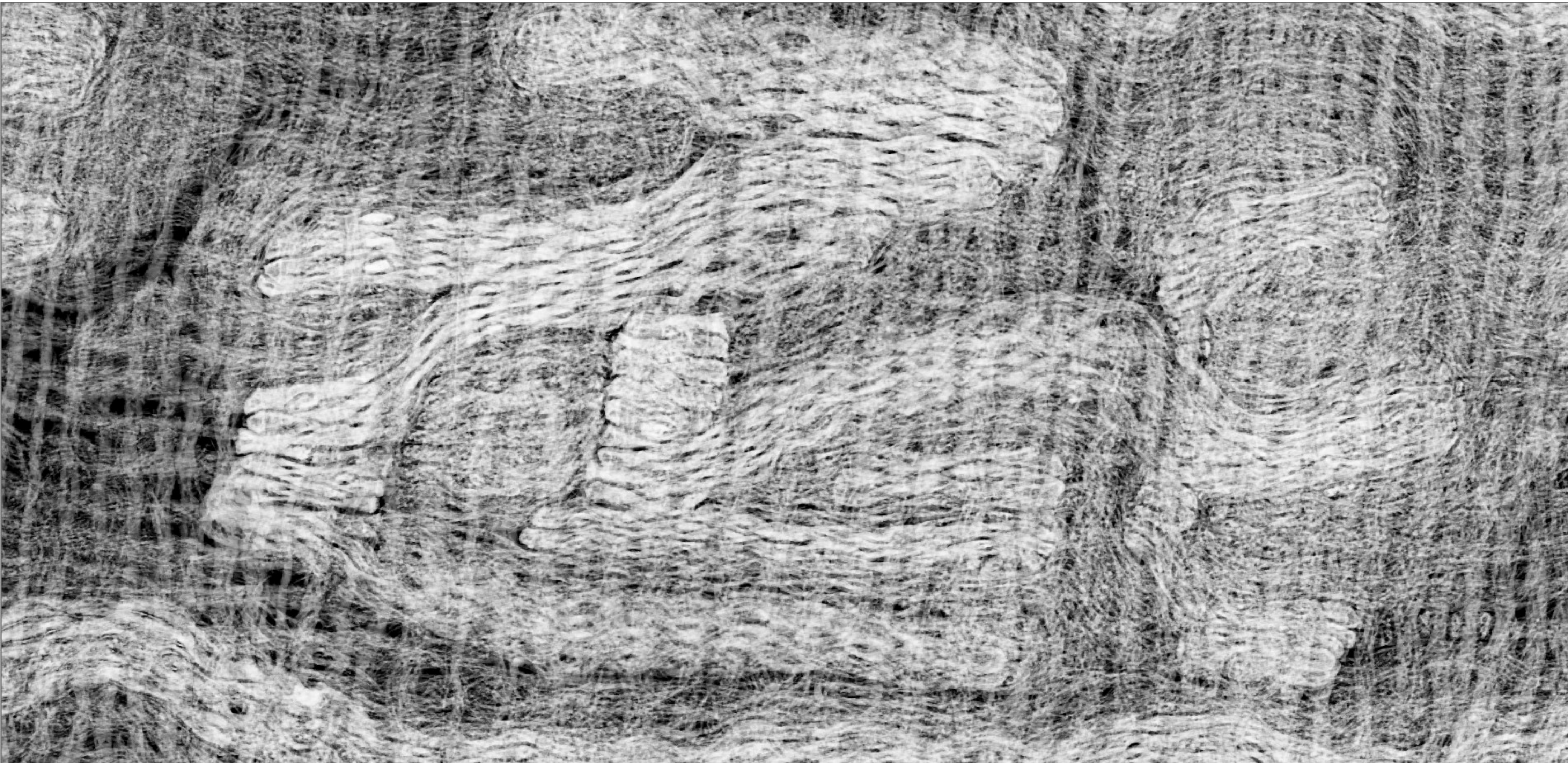
Clavus A6168



- Final 2D image = 30,704 x 3938 pixels

Clavus A6168





Multimodal CT: Combining Neutron and other imaging methods

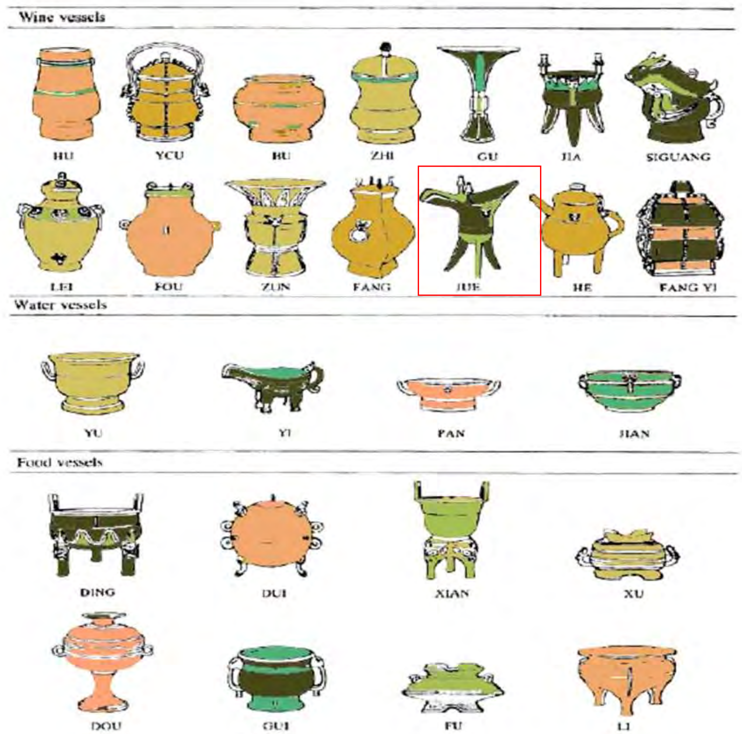
ANSTO

Authentication study of a Shang dynasty bronze vessel

2100 B.C. | 1600 B.C. | 1050 B.C.

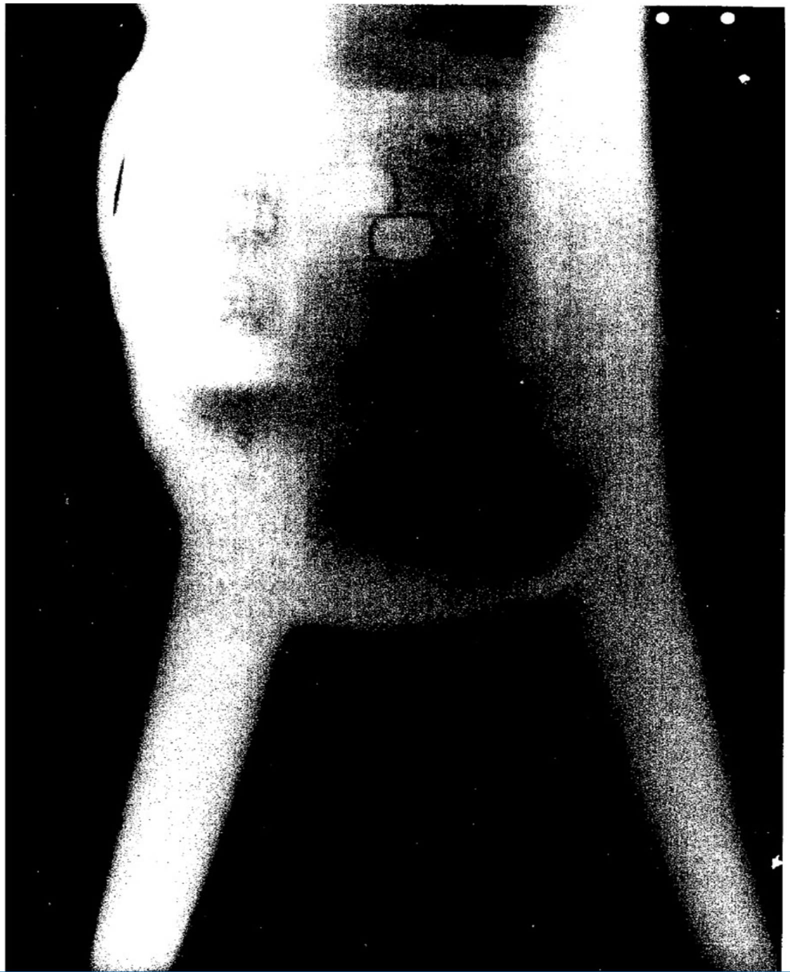
Xia dynasty | Shang dynasty | Zhou dynasty

Bronze wine vessel, Shang dynasty, China



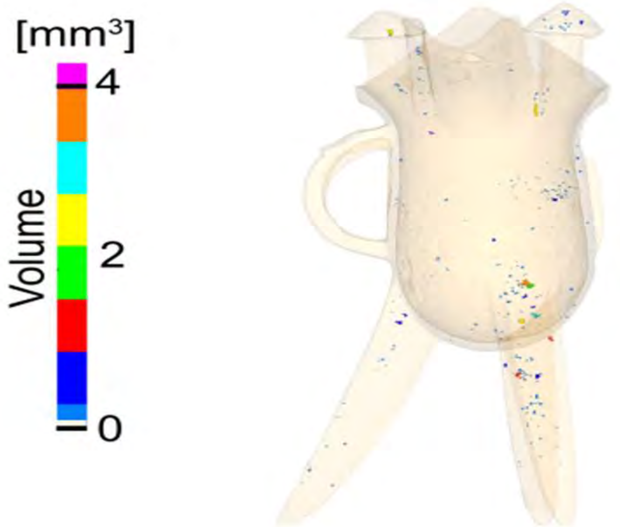
Typologies of bronze ritual vessel *

Previous investigation by conventional X-ray radiography

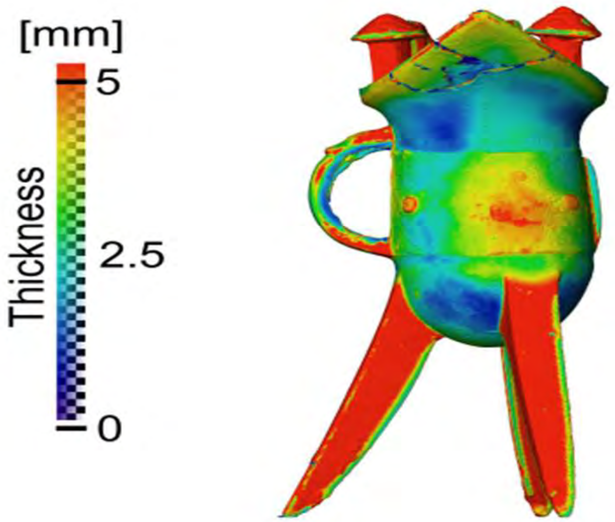


Evaluation of tomographic data

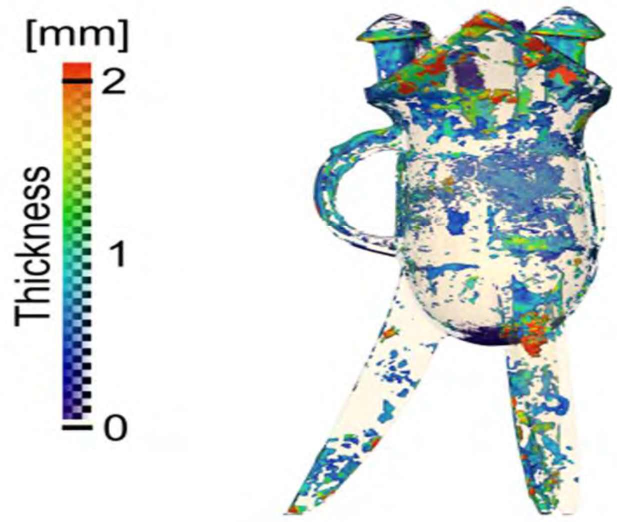
Porosities



Wall thickness

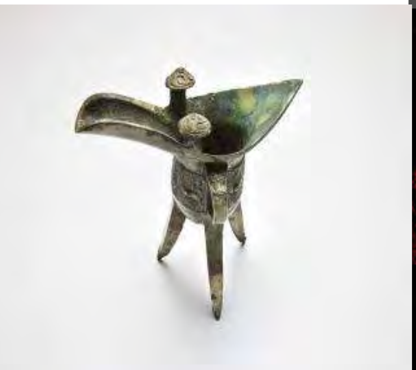


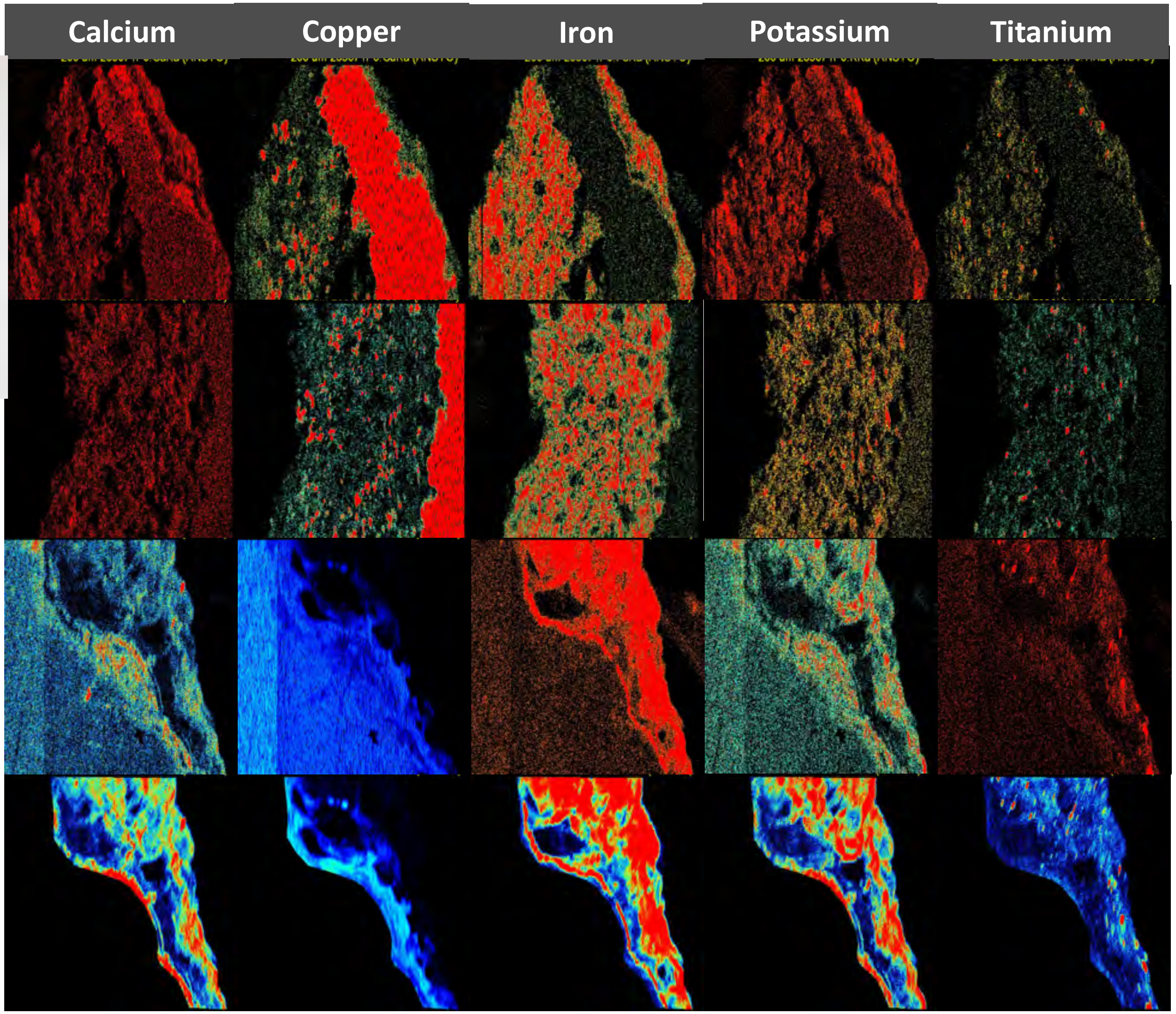
Mineralisation



Past restoration

“Jue” wall PIXE Corrosion Study





Jue –

- extraordinary bronze vessels
- to hold wine and food in rituals
- cast using multiple ceramic moulds – unparalleled technology in the ancient world
- China, Shang Dynasty, 1600-1046 BC

.

Multimodal Neutron + X-ray CT scanning to resolve internal material composition

Concept

- Objects are CT scanned with neutrons and X-rays in a total of 3 different settings.

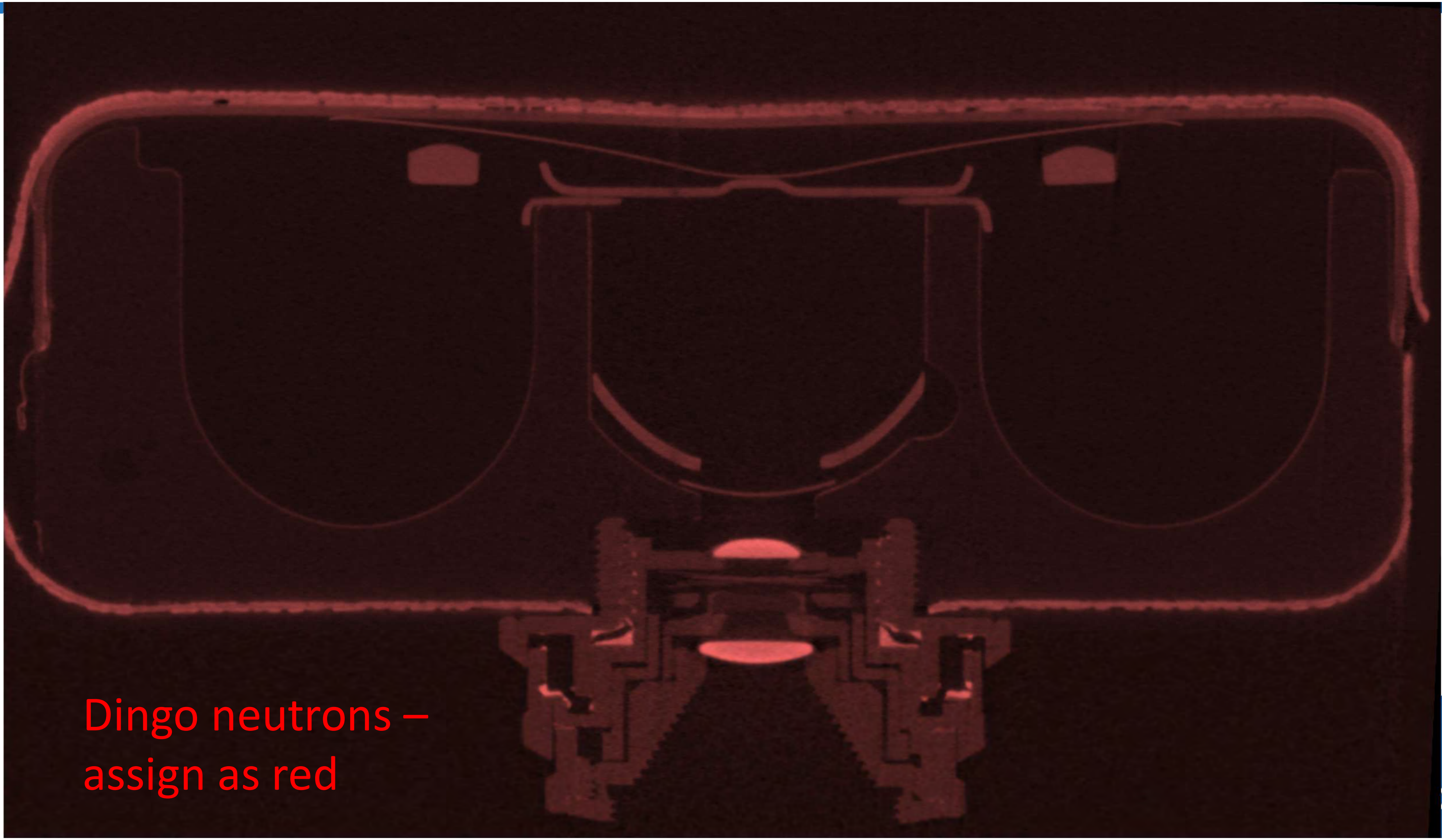
Benefit

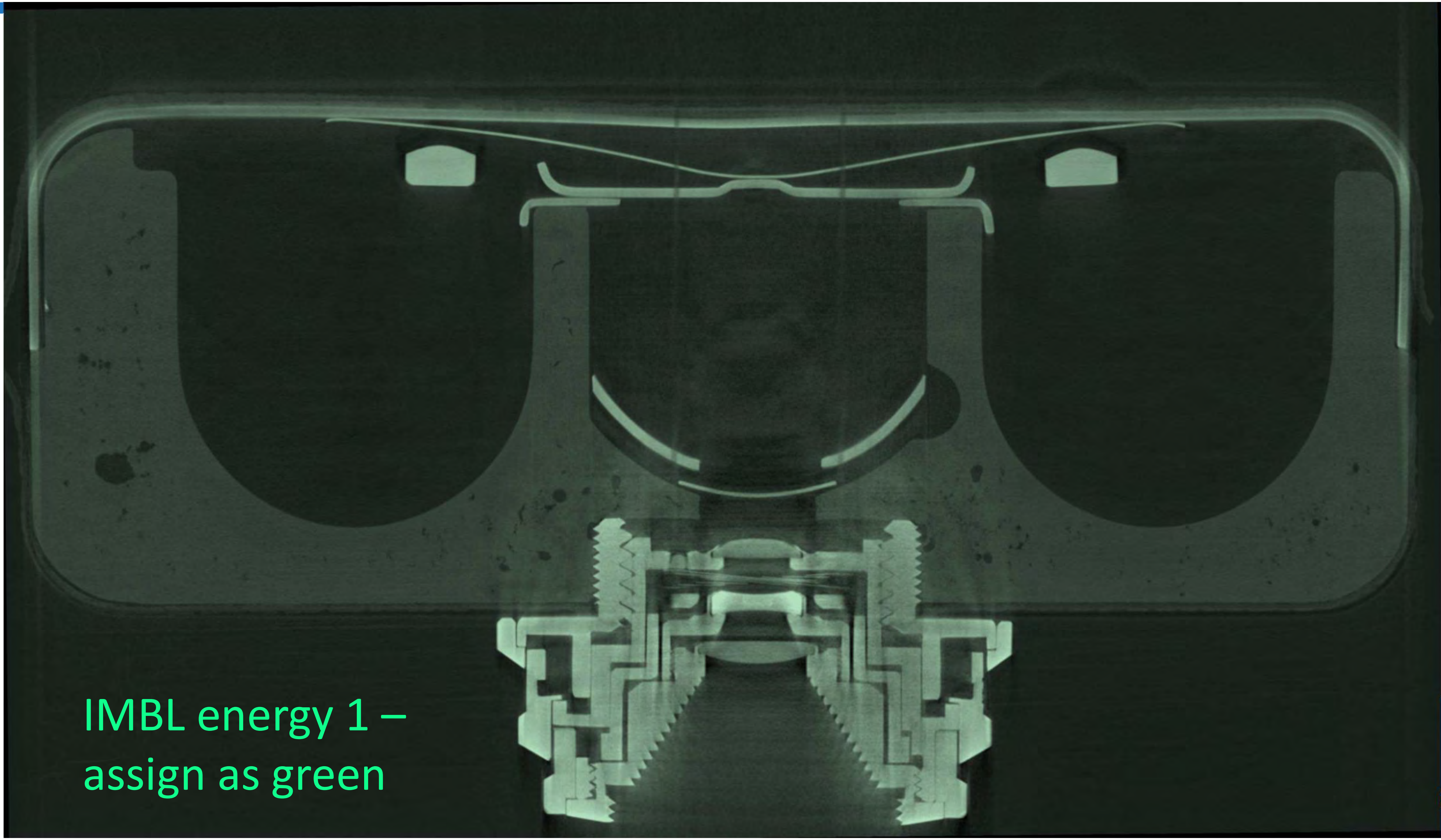
- CT scans are typically grey-scale data.
- These new datasets are in RGB colour = ease of material visualisation and material identification

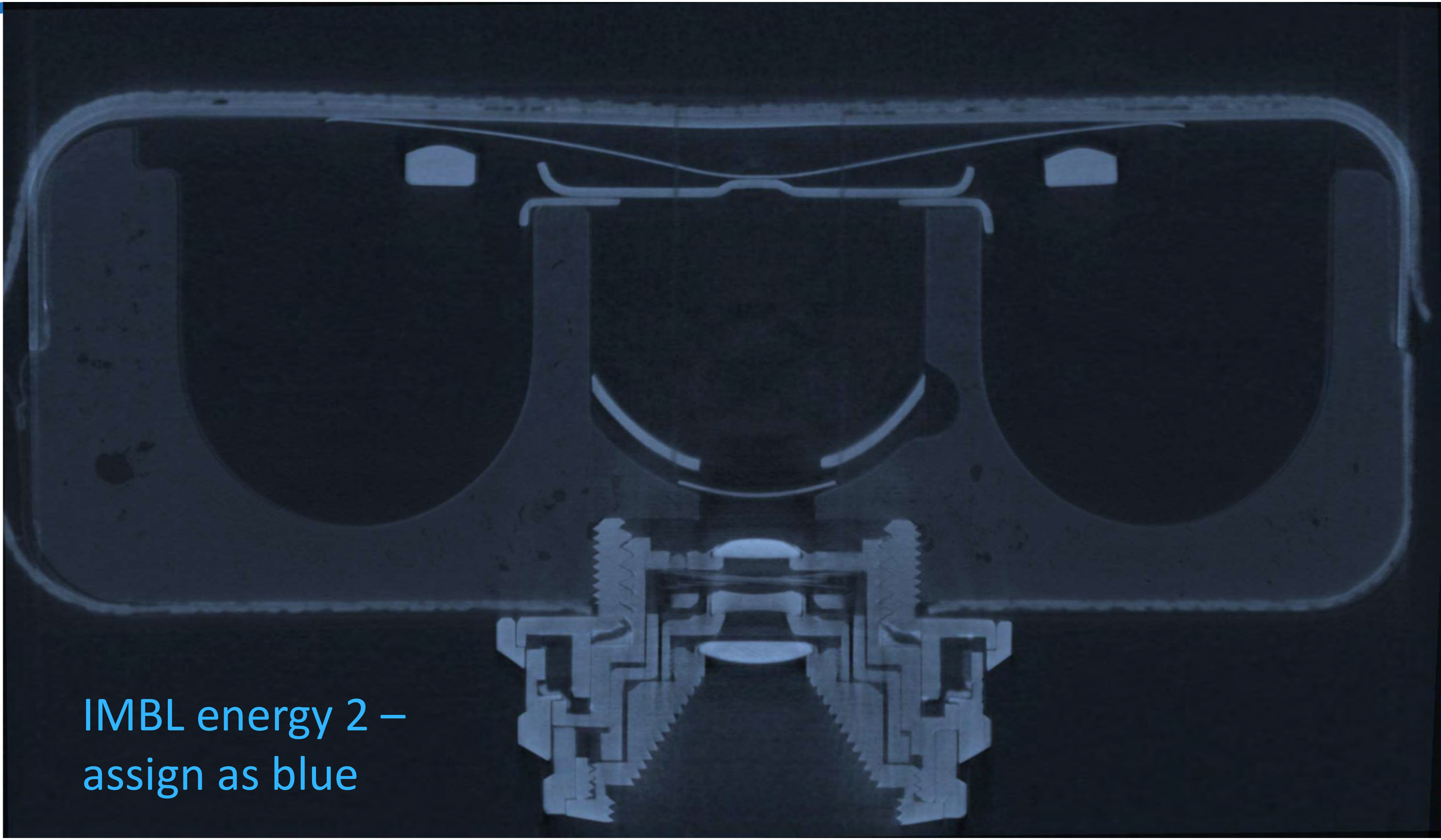
Demonstrate a new ANSTO capability: trimodal CT = colour CT imaging

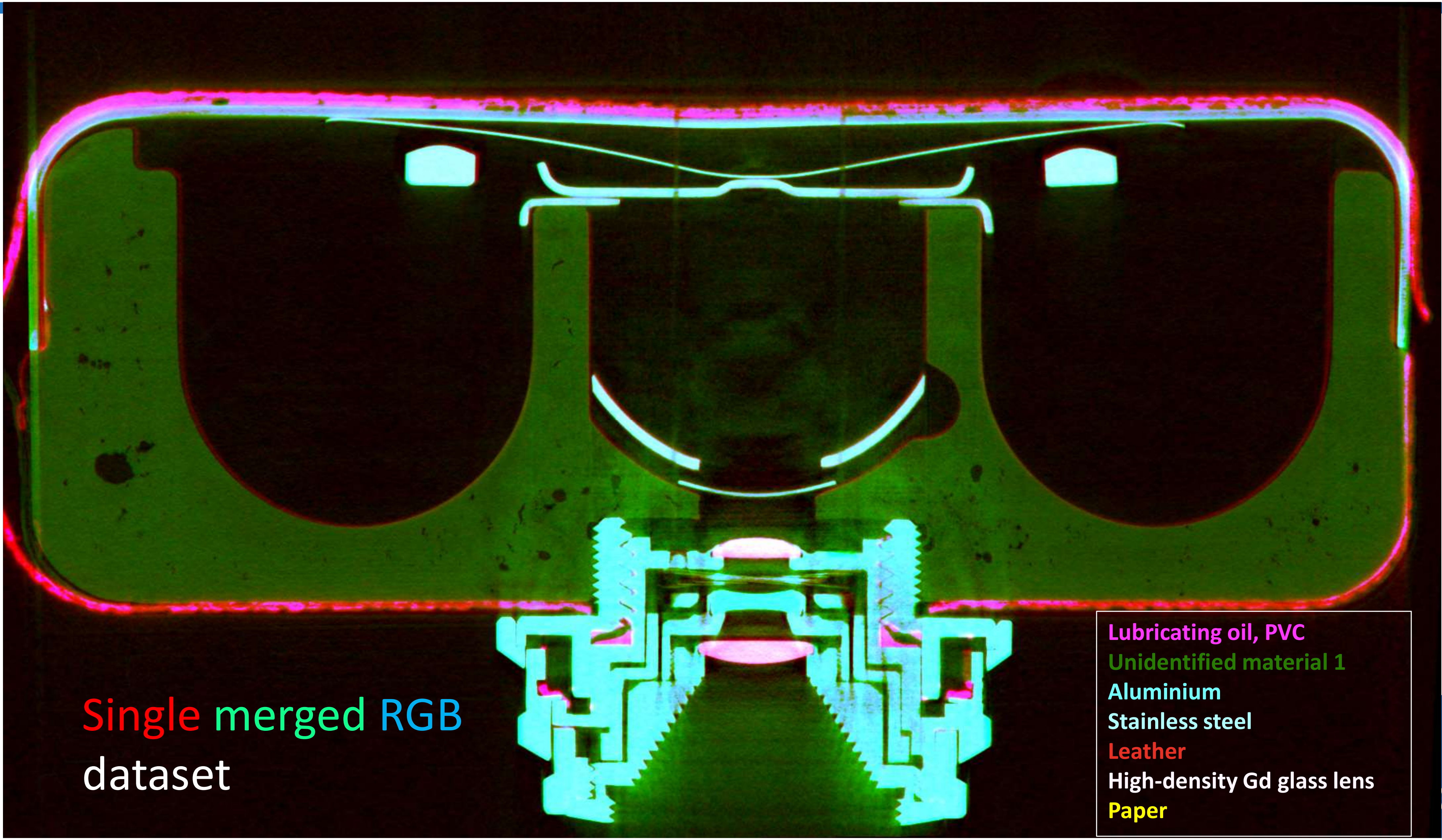
Miniature "Mikroma II' camera made by the Meopta company of Prague, Czechoslovakia in 1957

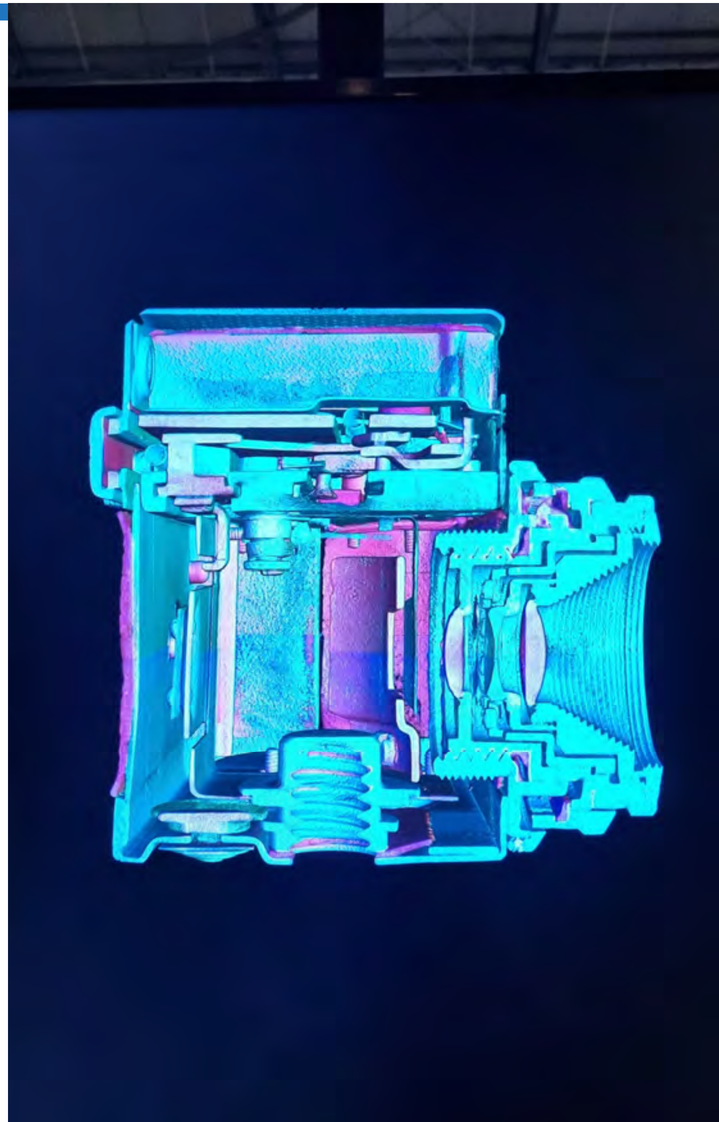
ANSTO


Dingo neutrons –
assign as red


IMBL energy 1 –
assign as green

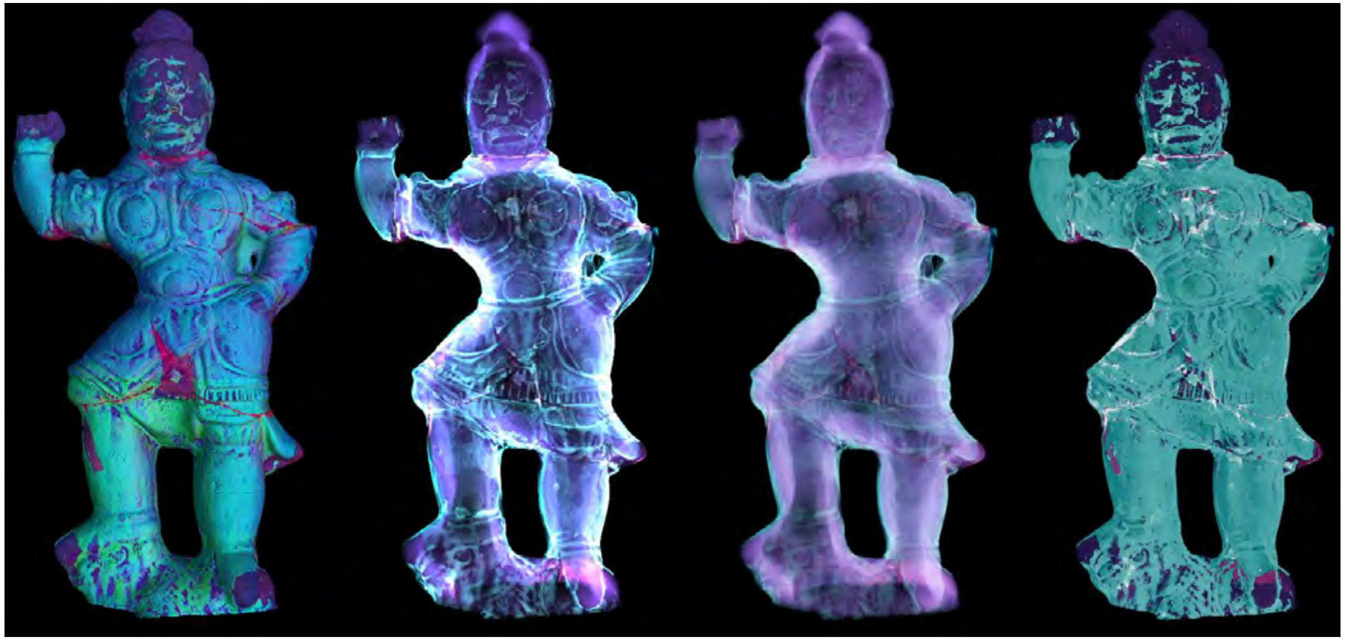

IMBL energy 2 –
assign as blue


Single merged RGB
dataset
Lubricating oil, PVC
Unidentified material 1
Aluminium
Stainless steel
Leather
High-density Gd glass lens
Paper



Merged RGB colourised dataset without data work up

Triple-scanning applied to statues



T’ang dynasty ‘Lokapala’ tomb guardian, China, c. 700-750.
MAAS Powerhouse Museum.

Merged Dingo thermal-neutron, IMBL monochromatic 70 keV and IMBL pink beam 220 keV peak CT.

Key
- adhesive
- glaze
- clay

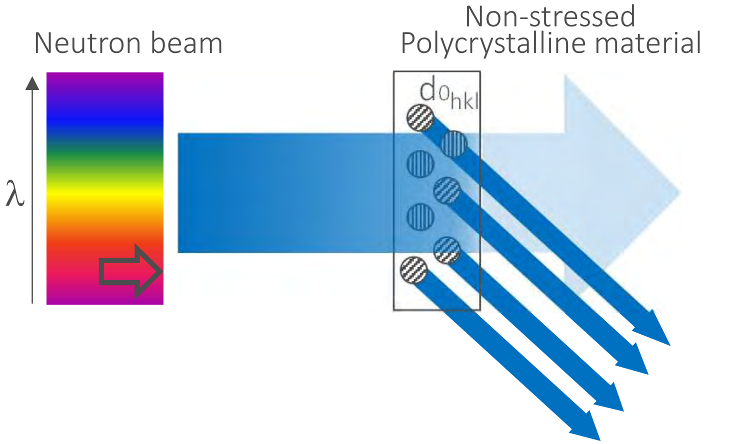
ANSTO

Neutron Diffraction: Residual Stress Analysis & Texture

ANSTO

Neutron diffraction

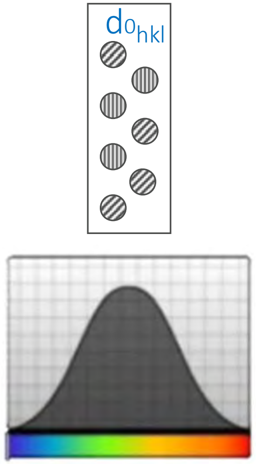
Phase Analysis

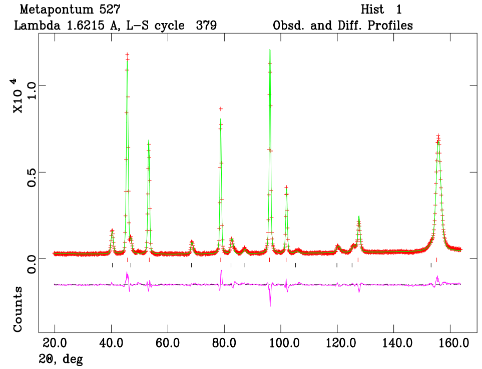


Bragg's law

$2d_{0hkl}\sin\theta=\lambda$

Non stressed metal

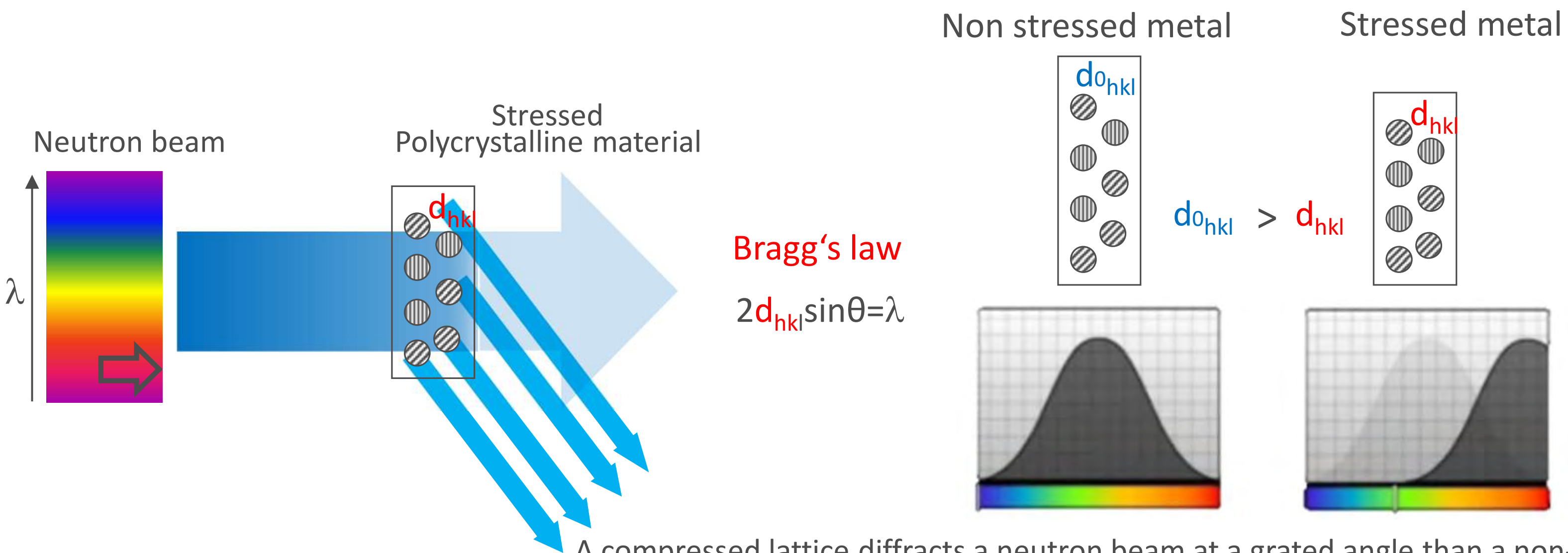




Neutron diffraction – residual stress

Kowari
Residual stress

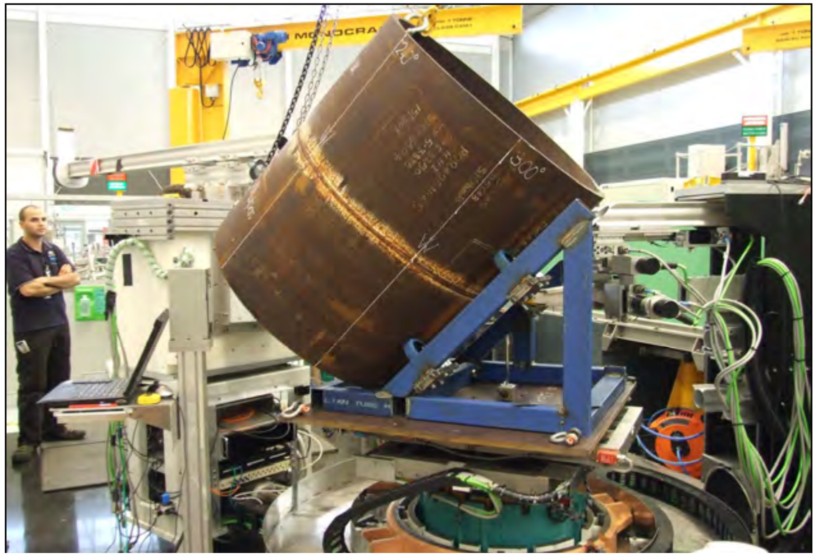
When a crystalline solid is subjected to heterogeneous plastic deformations, thermal contractions and phase transformations induced by thermo-mechanical treatments, permanent deformation can occur.



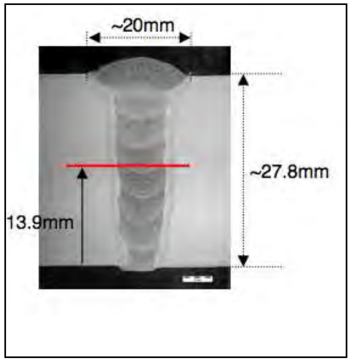
A compressed lattice diffracts a neutron beam at a grated angle than a non-stressed sample

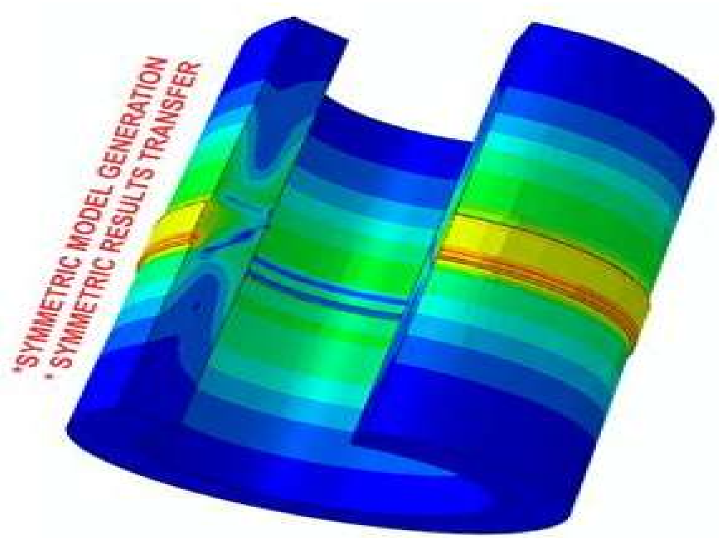
This results in the formation of residual internal elastic strains that are related to elongations and contractions of the crystal lattice. The tension or compression state remaining in the bulk without application of the external load is known as residual stress.

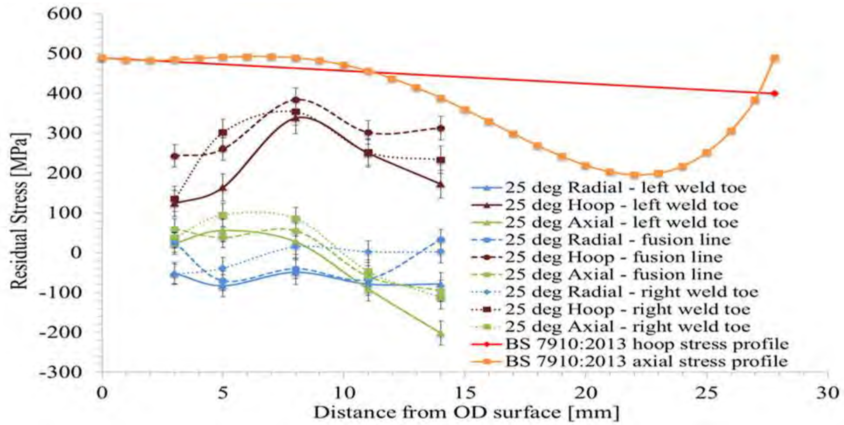
Residual Stress Measurement in a 630 kg Pipe

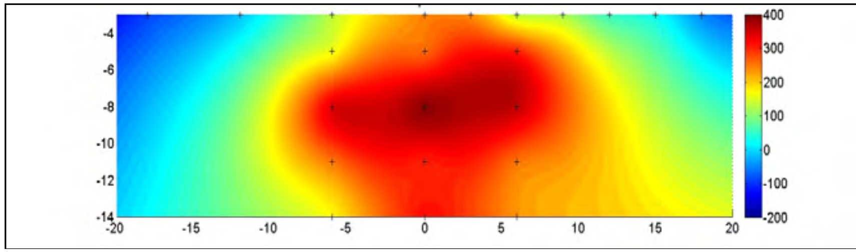


630kg pipe + supporting frame of ~200kg
1m diameter x 1m length x 28mm steel thickness





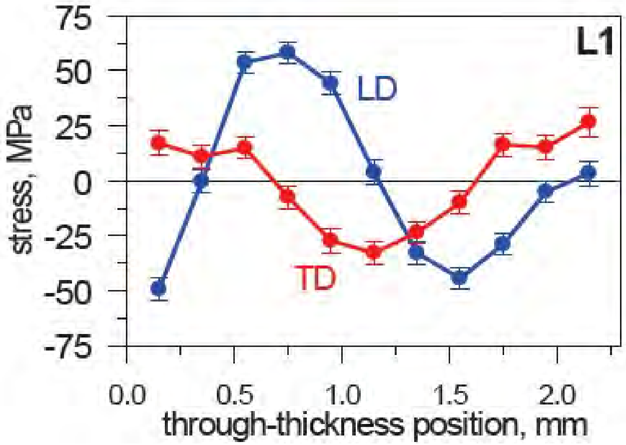




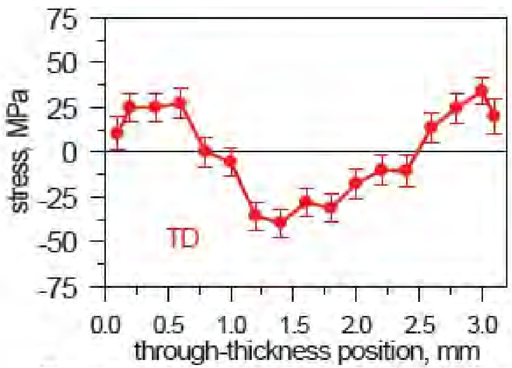
Stress Analysis - Manufacturing Techniques

Investigation of Cypriot Bronze Age knife blades and spear heads

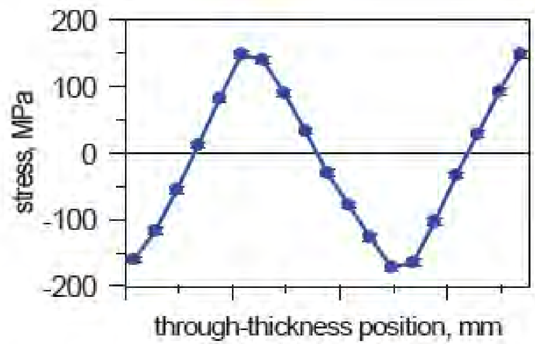
Approximate locations of the three positions used for residual stress measurements of IA 2.268.



Red = transverse,
Blue = longitudinal
residual stresses



Transverse component residual stress profile of a hot rolled Cu strip.



Longitudinal component residual stress profile of a cold bent Al plate.

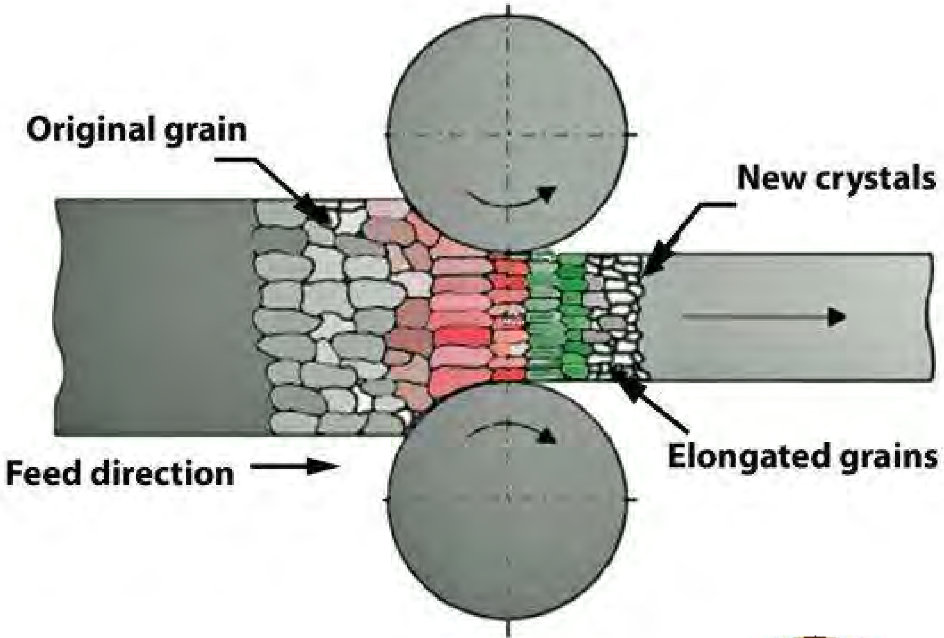
Materials Research Proceedings **2** (2016) 515-520

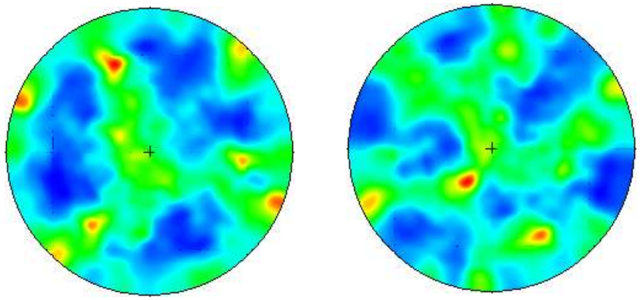
UNE

Australian institute of ARCHAEOLOGY

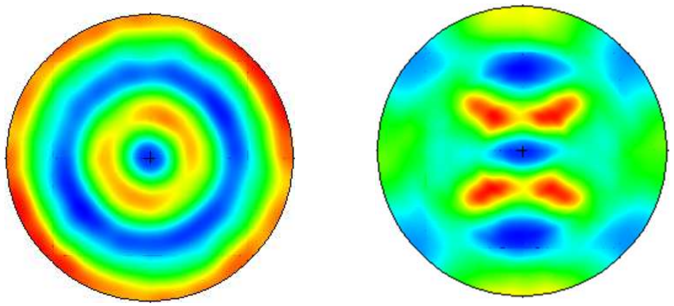
ANSTO

Identifying Metal Manufacturing Process with Neutron Diffraction





No preferred orientation



Preferred orientation

Kowari
Texture measurement

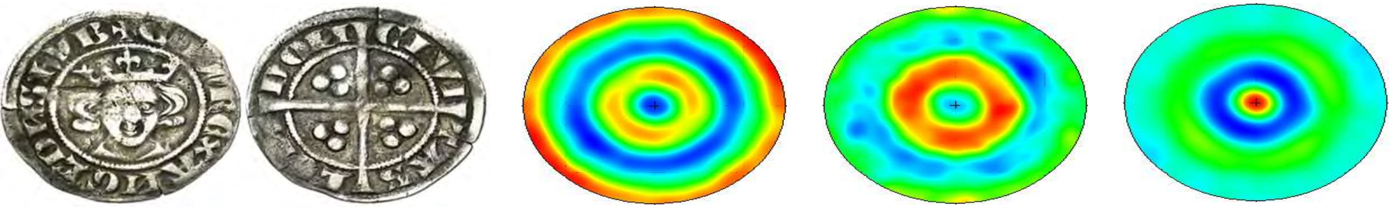
Wombat
Texture measurement

ANSTO

Texture analysis

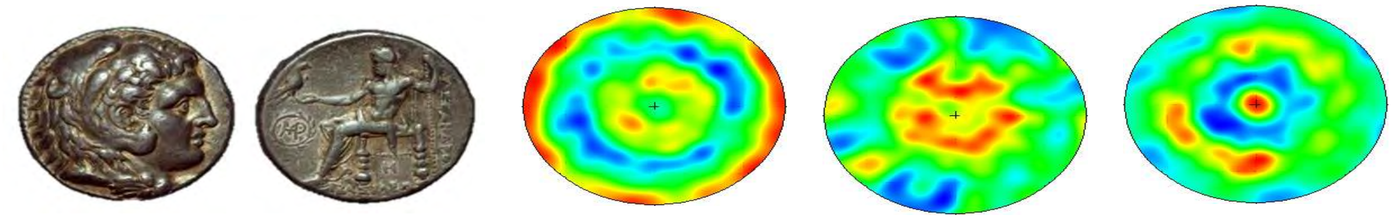
Non-incuse coins	Ag (111)	Ag (200)	Ag (220)

Edward I 1270 AD Silver penny Ø 18 mm th ~ 0.52 mm M = 1.37 g



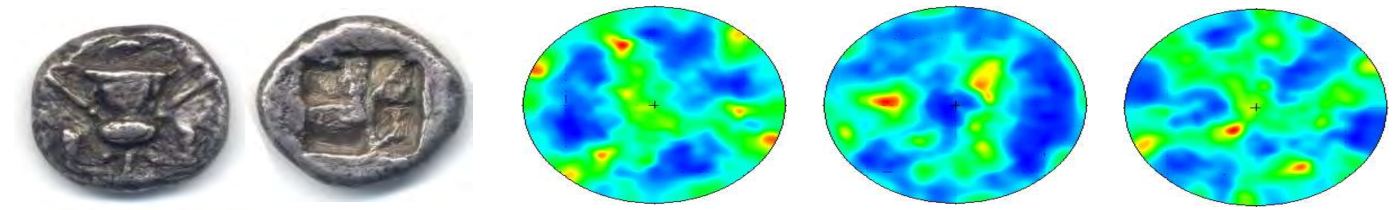
min: 0.60 max: 1.44 min: 0.73 max: 1.26 min: 0.65 max: 1.68

Alexander the Greatc.330-320 BC silver drachma Ø 18 mm th ~ 1.50 mm M = 4.04



min: 0.79 max: 1.20 min: 0.76 max: 1.19 min: 0.88 max: 1.17

Naxos c. 550-500 BC. Non-Incuse stater, Ø 19.5 mm; th ~ 3.27 mm; M = 10.25 g



min: 0.41 max: 2.27 min: 0.45 max: 2.57 min: 0.62 max: 1.83

Cold hammering is historically documented technique for the production of English medieval pennies by hammering silver sheets. This result in a strong texture pattern.

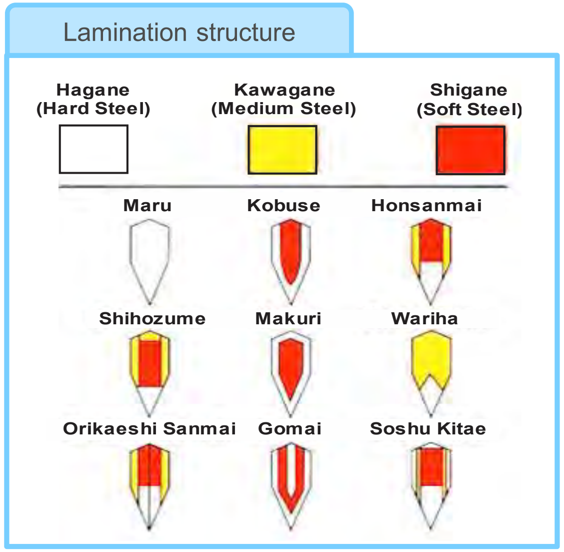
Hot forging involves heating up a piece of silver and tricking it when still hot. It produces much weaker texture.

Casting involves complete melting of silver material that is poured it into a mould to give shape to the coin. This produces more or less random texture.

Samurai Swords from the MAAS collection

Prior studies by Floriana Salvemini

Samples



Methods

- Neutron tomography
- Neutron diffraction
- Neutron residual stress

Aim

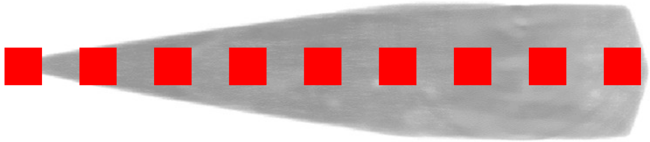
- Characterising bulk macro- and crystallographic structures as result of the manufacturing process
- Identification of lamination structure.
- Development of a non-invasive approach to scientifically attribute unknown artefacts
- Build up a database of references

Salvemini, F., et al. (2017). Structural characterization of ancient Japanese swords from MAAS using neutron strain scanning measurements. Materials Research Proceedings.

Tremsin, A., et al. (2019). "Energy-resolved neutron imaging options at a small angle neutron scattering instrument at the Australian Center for Neutron Scattering." **90**(3): 035114.

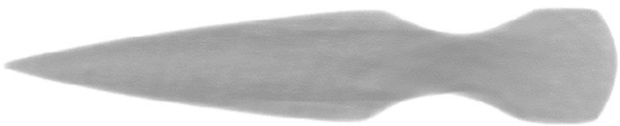
Neutron tomography
cross section

* H:0008



* H:0096

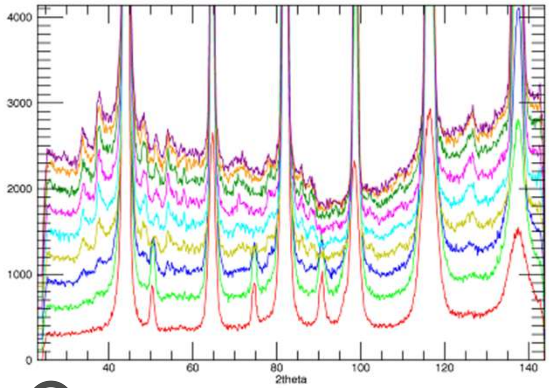
○ H:0006



○ H:0007

Diffraction pattern
tip-back 2mm increase

*



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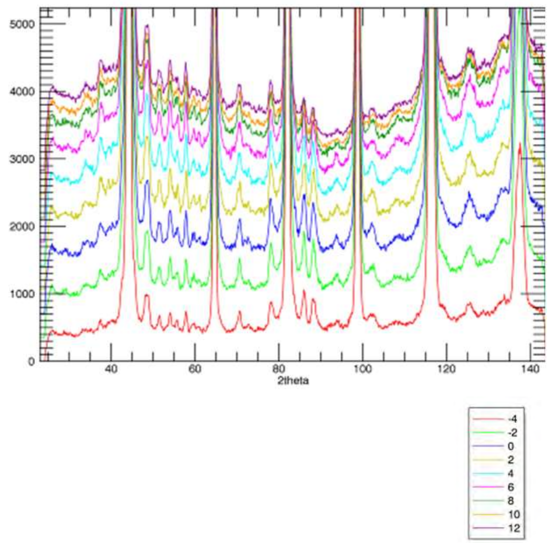
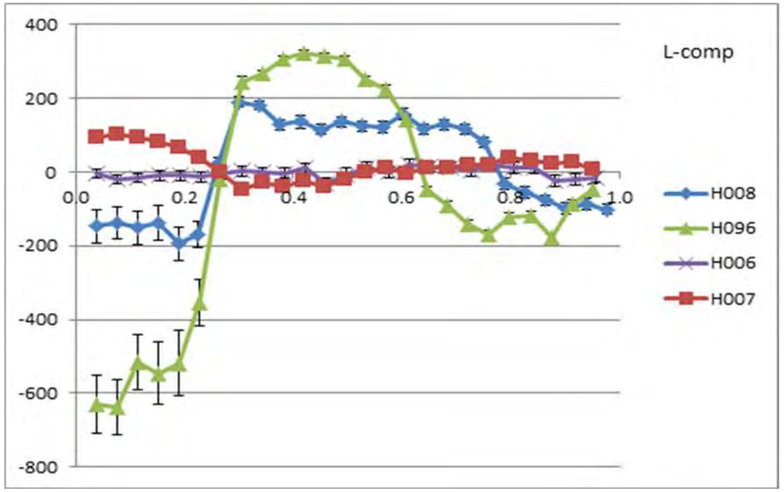


Residual stress
profile L-component



*

Layered structure
Diffraction peaks associated to the presence of different phase appear proceeding from the cutting edge (profile -4) to the back (profile 12) of the blades. Residual stress profile consistent with traditional production.

○

Homogenous structure
Confirmed by tomography and diffraction analyses. Both blades were made of an uniform piece of steel that was fully annealed. Additionally in H007, after annealing, the cutting edge was formed by grinding, thus resulting in tensile stress

Resolvable Structural Detail

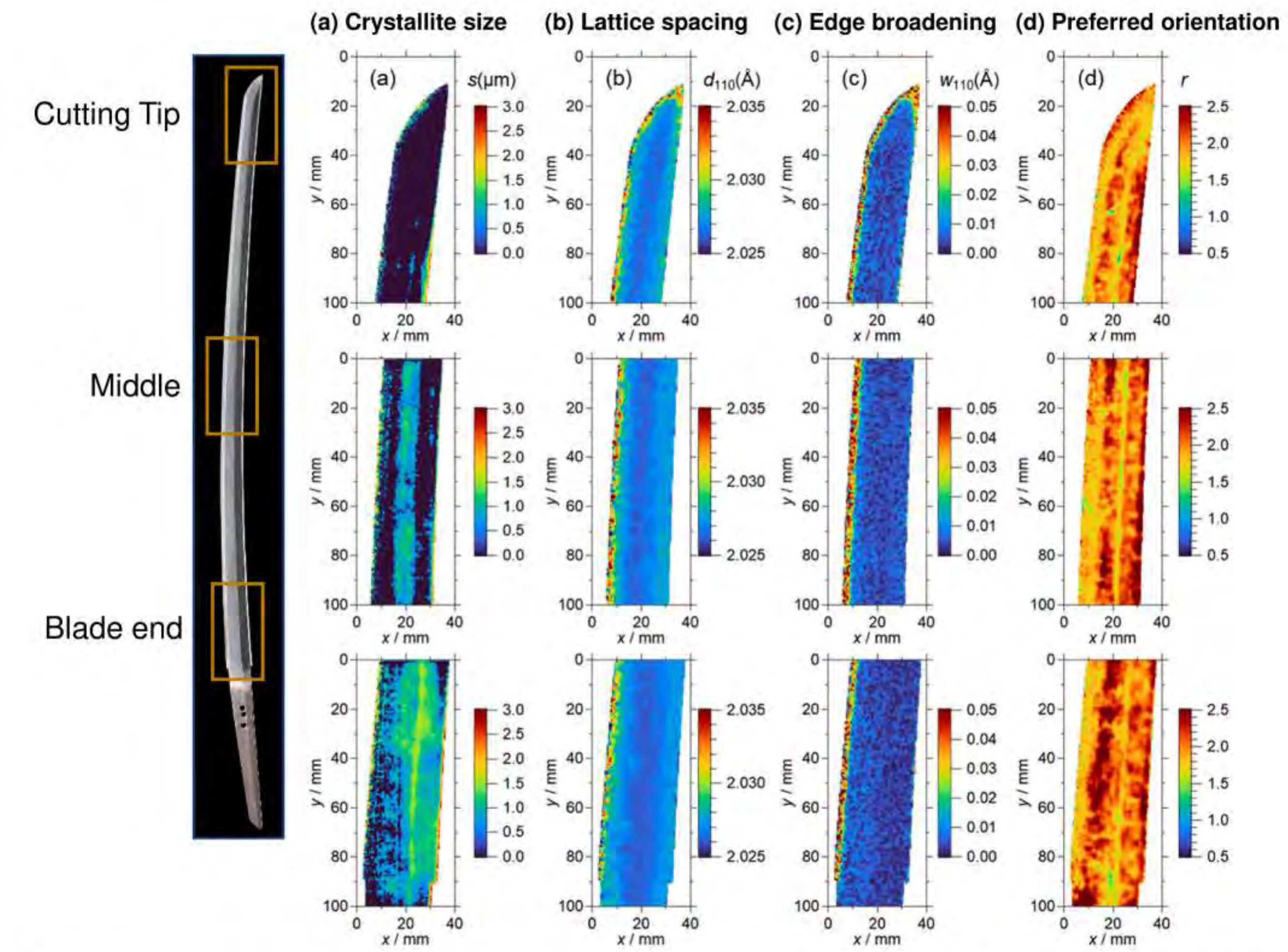


Fig. 3. Two-dimensional mapping of (a) crystallite size s (μm), (b) lattice spacing d_{110} (Å), (c) edge broadening w_{110} (Å) of the (110) plane, and (d) preferred orientation parameter r for Kashu Kiyomitsu.

Fake or Real?
Numismatic Case Studies

The Lydian Stater – the World's First Coin

- The Lydian Stater (~620-560 BC) was the first coin officially issued by a government and the model for virtually all subsequent coinage.

MAAS Powerhouse purchased in 1984
Object Number 94/106/1

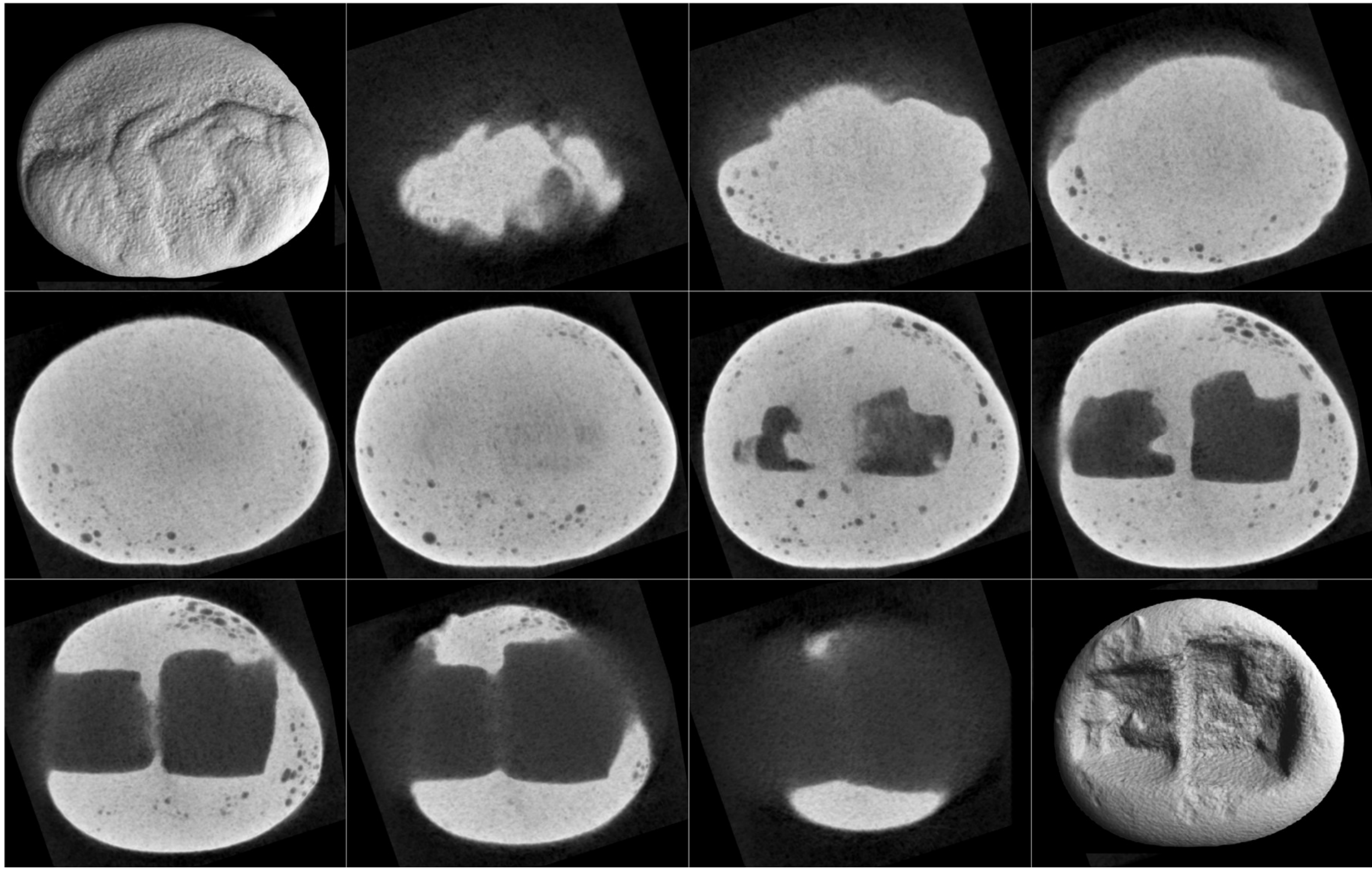
POTENTIAL FORGERY

Tungsten-filled gold forgeries

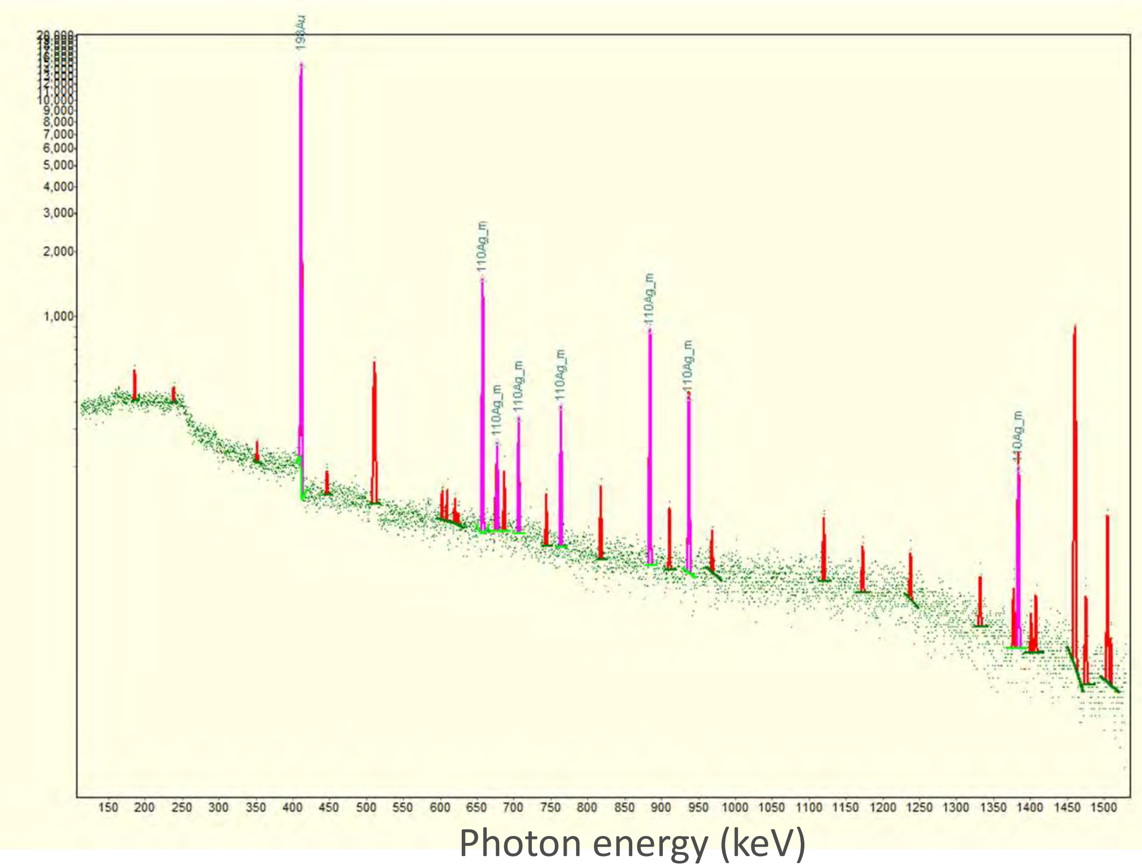
Density: Gold = 19.3 g/cm^3
Tungsten = 19.25 g/cm^3

The Lydian Stater – the World's First Coin

Object Number 94/106/1
Coin, Stater, gold, Sardis, Lydia
circa 505-500 BC



Neutron Activation Analysis



Isotope	Gamma Energy (keV)	Abundance (%mass)
^{198}Au:	411.80	94
^{110}Ag:	657.50	
^{110m}Ag:	657.76	5.9
	884.68	
	937.49	
	1384.29	
	763.94	
	706.67	
	1505.02	
	677.62	
^{64}Cu:	1345.77	0.00
^{60}Co:	1332.49	0.0765
	1173.23	

Is this an authentic Lydian Stater?

- Composition varies from typical Lydian Staters:
  55% gold, 45% silver, small % copper

- Associate Professor Kenneth Sheedy, 25 March 2022:

The coin can be catalogued as Kings of Lydia, time of Cyrus II and Darios I. Stater light series, Sardes circa 505-500, AV g. Foreparts of confronted lion and bull. Rev. Two incuse squares of unequal size. Traité I 401-403. Carradice pl. XI, 8. Boston 2077. SNG von Aulock 2875. Dewing 2431. SNG Oxford 761.

As we now know that it is AV and not El then it becomes a perfectly normal light weight stater struck by the Persians after the fall of the Lydian empire. There are very few, if any, studies of the composition of these coins.

- Research Continues…

Leilira knife
of unknown provenance

Radiocarbon dating = *Abrus Precatorius* plant seeds harvested 1877 – 1930

Powerhouse museum object A3396. Acquired 1941.

Cassowary

Abrus seeds

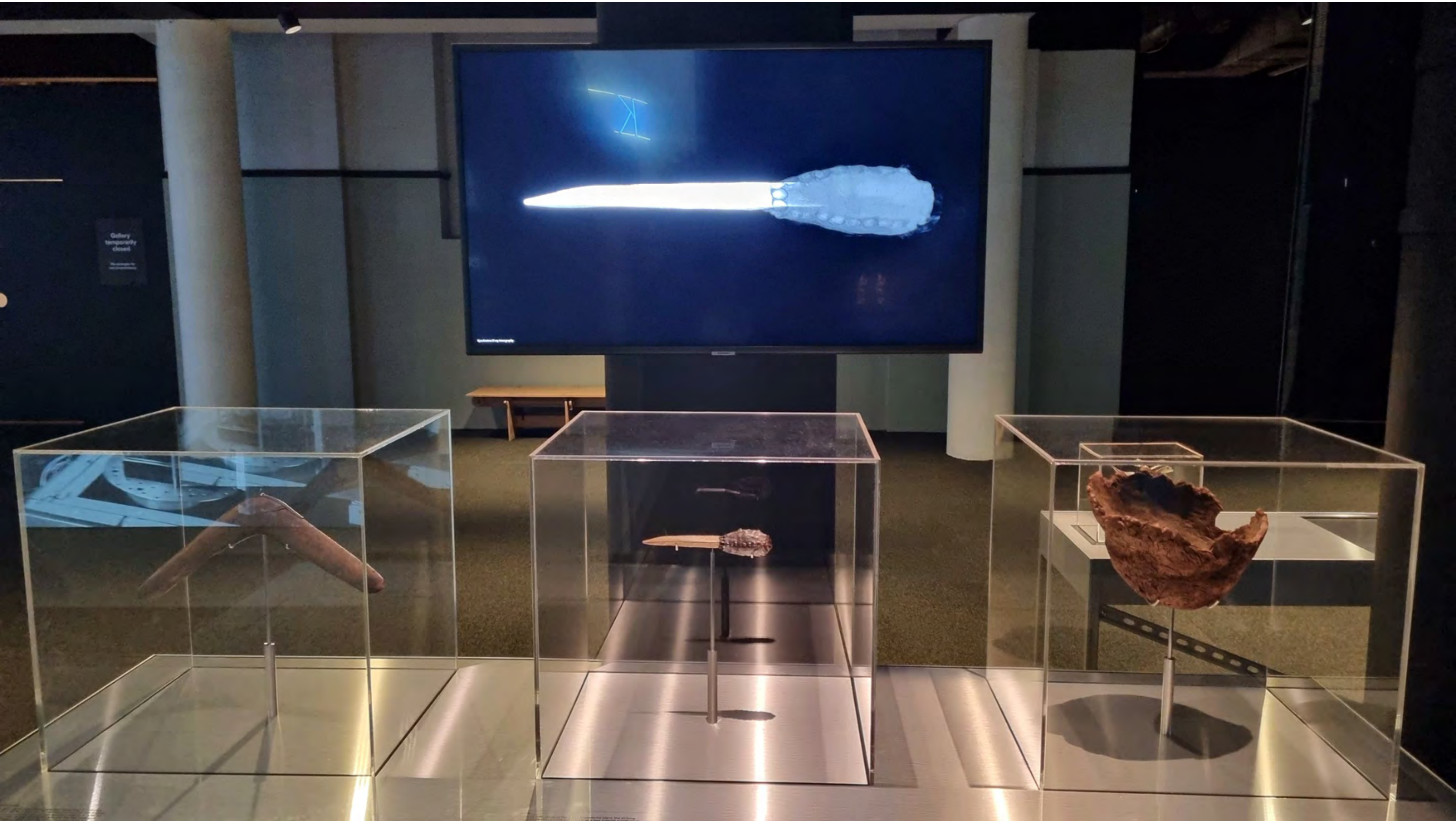
ANSTO

Australian Boomerang

Eora Nation (Sydney Basin)

Object 2013/23/15

ANSTO Radiocarbon analysis suggest the wood's age is 1520-1795 CE, making it one the oldest known Boomerangs from NSW


Gallery temporarily closed

POWERHOUSE

ULTIMO	PARRAMATTA
SYDNEY OBSERVATORY	MUSEUMS DISCOVERY CENTRE

Pocket watch, rose gold/glass, maker unknown, France, c.1810. Powerhouse Collection. Neutron tomography ANSTO 2021.

The Invisible Revealed

Exhibition

26 November 2021–22 May 2022
Powerhouse Museum

26 objects | 3000+ years | 9 scientific processes

The Powerhouse collection of more than half a million objects tells us much about our material culture but it also inspires many questions. What are our objects made of? How old are they? Is anything hidden inside? Over time, new research and technologies can help us solve these mysteries – and reveal new ones. This exhibition is about work done through a partnership between the Museum and the Australian Nuclear Science and Technology Organisation (ANSTO). Using their state-of-the-art neutron beam and synchrotron X-ray facilities combined with digital visualisation techniques, this exhibition shows some of the discoveries we have made including how to identify different makers of our samurai swords and how a 200-year-old pocket watch can play a waltz.

The exhibition also features digital 3D models of some of the collection objects and a digital reconstruction of the missing portions of a fragmentary carpet done with Artificial Intelligence. These portions were completed by the EPICentre at UNSW.

The Invisible Revealed Augmented Reality content

Australian Government | ANSTO

ANSTO

Exhibition Showcase: The Invisible Revealed

Concept: "ANSTO's world-class nuclear reactor, synchrotron and particle accelerator facilities provide insights into how these artefacts were manufactured, their provenance, and how they be better conserved for future generations."

- November 2021 – September 2022
- 26 objects and 9 nuclear methods exhibited

https://www.maas.museum/event/the-invisible-revealed/

Science Communication: Glossary

Neutron activation analysis

Bombarding a sample/object with neutrons causes a tiny proportion of atoms within to form unstable radioactive isotopes. The radioactive atoms of each element decay, emitting gamma rays of well-defined energies. A gamma ray spectrum of an object is a unique fingerprint that is used to identify not just each element present but also the proportional amount of each element and its isotope.

Neutron activation analysis identified the composition of the coin in this exhibition.

Radiocarbon dating

Solar radiation generates a specific ratio of carbon-12 (carbon with 6 protons and 6 neutrons) to carbon-14 (6 protons and 8 neutrons) atoms in the atmosphere. Plants absorb this carbon through photosynthesis, which then makes its way through the food chain. When an organism dies, it stops absorbing carbon from the environment. The radioactive carbon-14 decays at a known rate. Measuring the proportion of carbon-14 to carbon-12 in a material tells you the age of that organic material, up to a maximum of 40,000 years.

Neutron diffraction

Diffraction patterns occur when any wave encounters an obstacle or an opening. Sub-atomic particles like neutrons can behave like waves. When a beam of neutrons strikes a sample being analysed, the neutrons are diffracted to form patterns that reveal the structural arrangement of atoms in crystalline materials. The principle of neutron diffraction is similar to X-ray diffraction but is more sensitive to crystalline structure and changes due to a difference in nuclear interaction.

We used neutron diffraction to learn how our katanas were made.

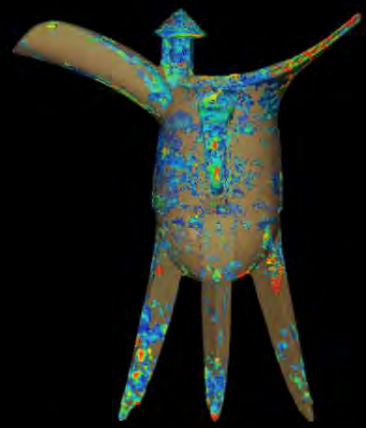
Residual stress analysis

When materials such as metals are bent, beaten, welded or subject to other localised forces, stresses are applied to the atomic structure of the material. These stresses can remain after the forces are no longer applied. Mapping the residual stress using neutron diffraction can provide insights into the way an object, such as a sword, has been manufactured. It can also indicate how manufactured components may fail

We used residual stress analysis to learn how our katanas were made.

PIXE (proton induced X-ray emission)

When a sample is bombarded with high-energy particles such as protons, the atomic collisions cause X-rays to be emitted that are distinctive of the atoms that have been hit. This means the elements in a material can be identified, and their concentrations measured, with very high accuracy.



We used PIXE on our ancient Chinese wine vessel, or *jue*, to find out about the metal it is made from.

X-ray fluorescence microscopy

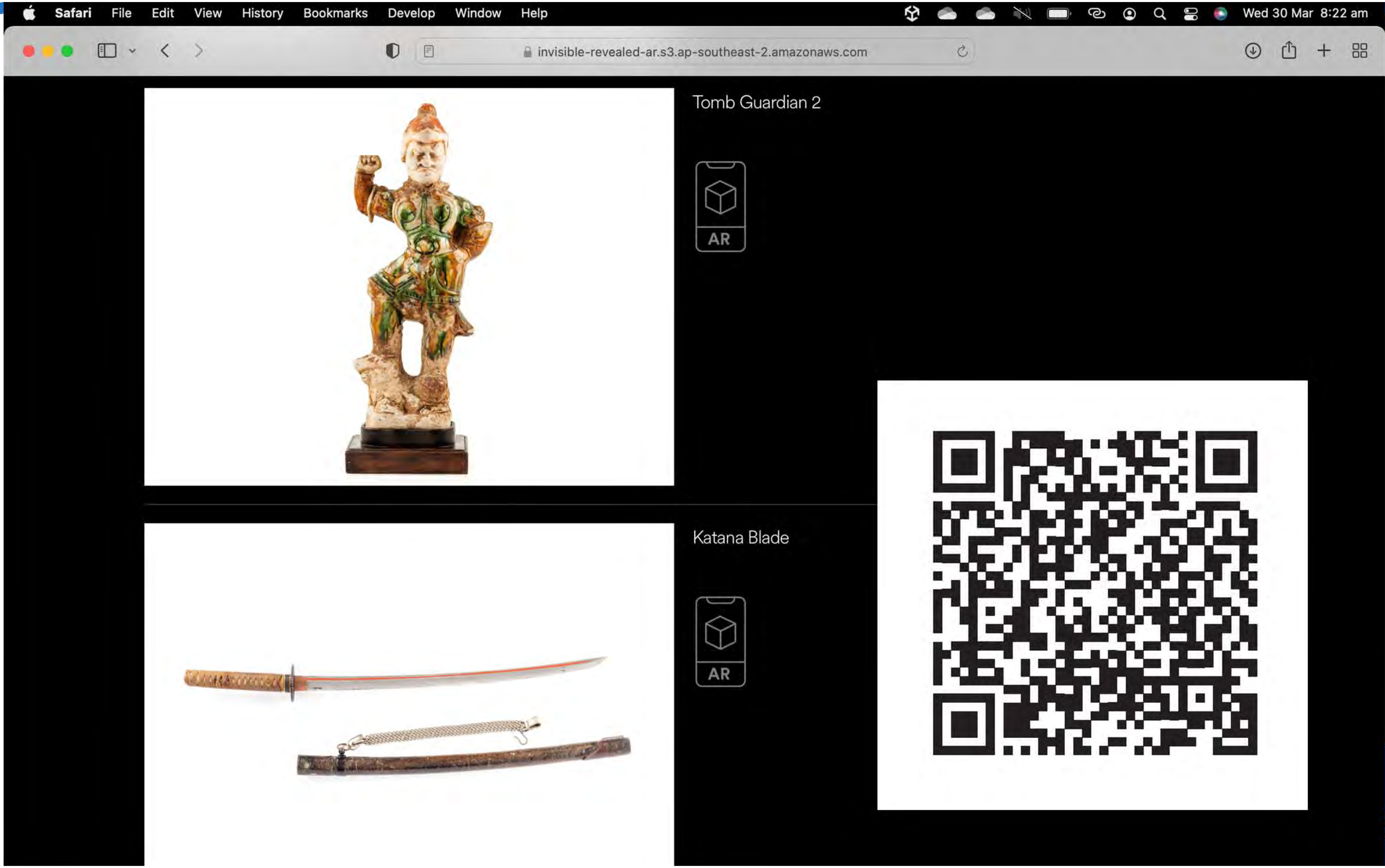
Like PIXE, high energy X-rays cause secondary X-rays to be emitted from a target sample. Those secondary X-rays are distinctive of the atomics present and therefore provide a compositional analysis. X-ray fluorescence is very effective for metal, glass and ceramics.

https://invisible-revealed-ar.s3.ap-southeast-2.amazonaws.com/pages/glossary.html

ANSTO

Events: Powerhouse Late 5PM Thursdays

- First Nations discussions
- First Nations Interpretive dance
- Public lectures
- Tours
- Large format displays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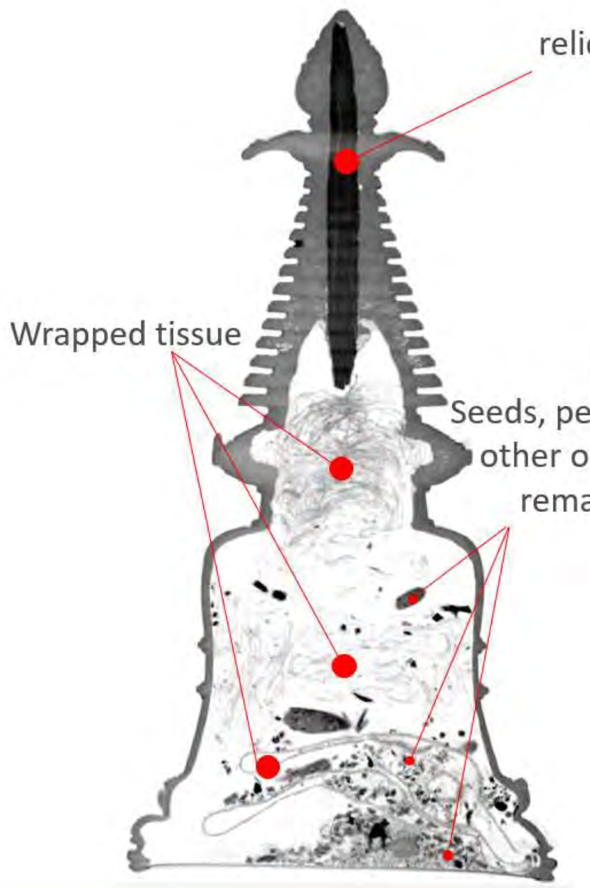
invisible-revealed-ar.s3.ap-southeast-2.amazonaws.com
Tomb Guardian 2
AR
Katana Blade
AR



Kadampa chorten
Tibet, 1200s

Provenance Research Project

Items with incomplete provenance

Consistent with the practice of other institutions, the Museum's provenance research results are published on our website to ensure accessibility by the public and other researchers including those who may be able to add to the provenance information. This information can assist the Museum complete its documentation and, in the event that it identifies an illicitly traded object, to restitute that object to its rightful owner.

Asian objects with incomplete provenance

Claims inquiries

No claims have been made on the objects listed here. In the event of such

Kadampa chorten (stupa) sculpture from Tibet

Accession number

2014/132/26

Object statement

Sculpture of kadampa chorten (stupa), bronze, Tibet, 1200s
Credit line: Donated through the Australian Government's Cultural Gifts Program by Alastair Morrison

Date	Notes
2005	Acquired into the Powerhouse collection through the Cultural Gifts Program.
Unknown date – 2005	Owned by Alastair Morrison, ACT, Australia.
June 2002	Sold through Parkham Place Gallery, Surry Hills, Australia.
Prior to 2002	Alex Biancardi.

Exhibition recognised with prestigious MAGNA 2022 Research award

Advice to Facilities: Identify and Prepare for Risks Associated with Cultural Heritage

OFFICIAL

Australian Government

ANSTO

Management of Proposals having materials of cultural significance or other value

AP-8422

Purpose

This procedure describes how to manage Cultural or otherwise Valuable Objects to ensure that adequate oversight is in place and that risk to ANSTO is minimised.

Scope

This procedure covers the management of all Cultural or otherwise Valuable Objects that are at ANSTO sites for testing or analysis. A 'Cultural or otherwise Valuable Object' (**Valuable Object**) includes any museum catalogued item, objects destined for museum deposits, valuable items from private collections, valuable artworks, objects requiring special permits for ownership, loan, export or import. A Valuable Object may also be from mineralogical, palaeontological and biological collections as well as cultural heritage items.

Valuable Objects that are tested or analysed as part of internal ANSTO projects, merit access projects, commercial projects or at ANSTO's request are covered by this process.

Table of Contents

- Identify the inherent risks of dealing with Cultural Heritage and other 'high-value' or significant objects
- Work with your Legal teams to develop a policy for the analyses of Cultural Heritage items

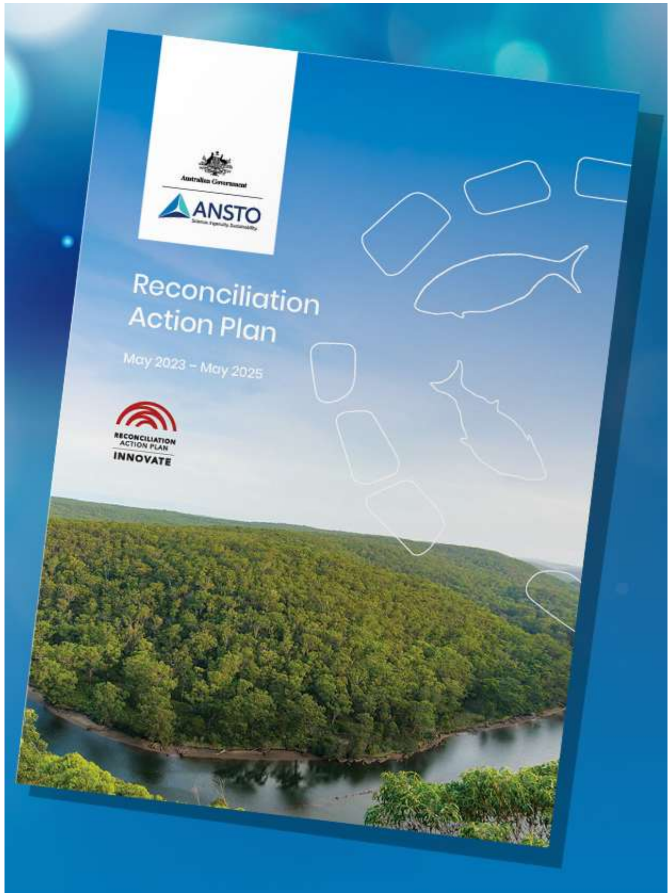
ANSTO

Respectful collaboration

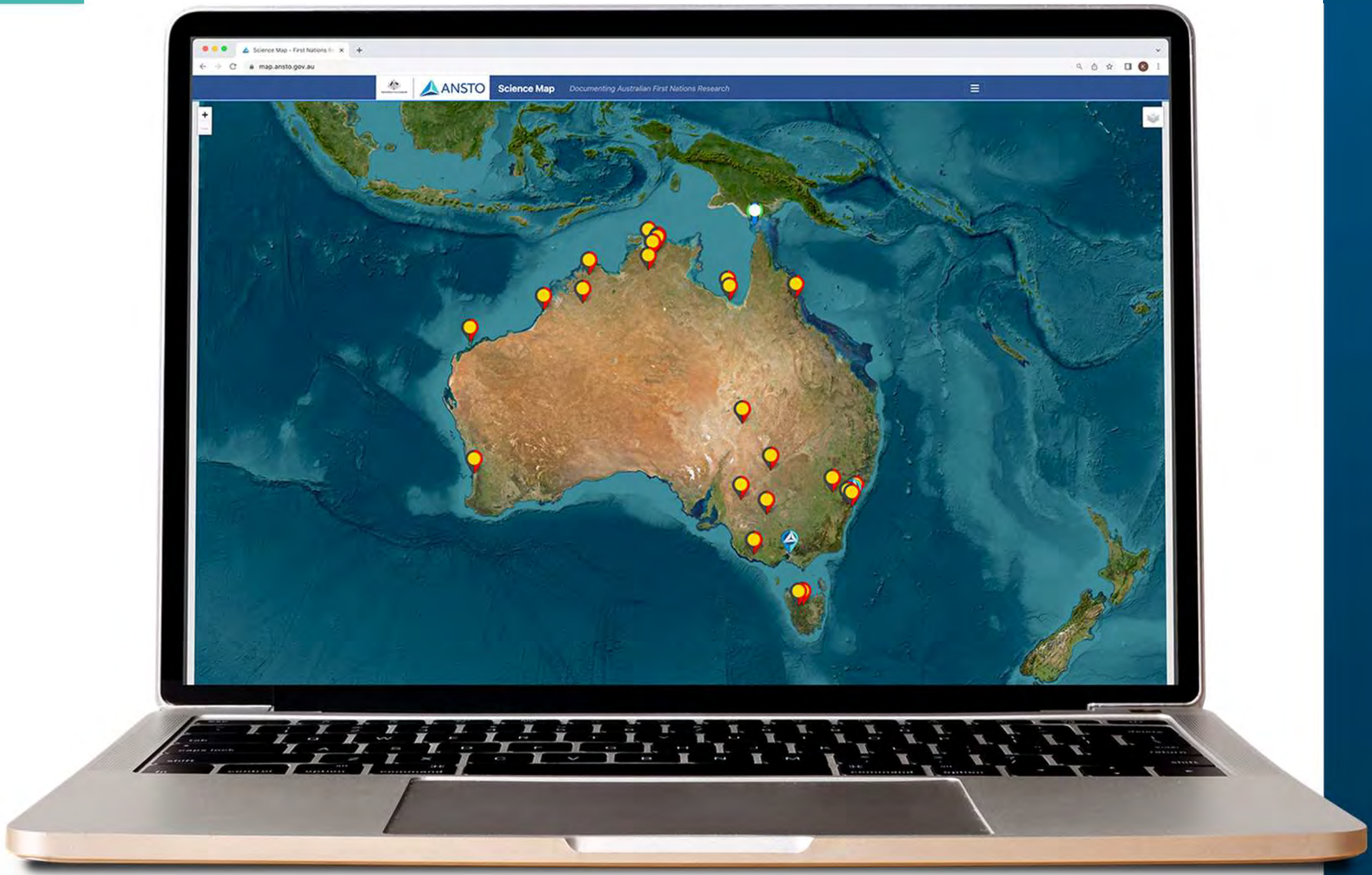
Tristen Jones from the Australian National University and Njanjma Ranger Hilton Garnarrdj undertaking investigations on rock art known as Red Lily

ANSTO

Reconciliation Action Plan



Indigenous project map



This interactive map on the ANSTO website highlights cultural heritage research projects from the last decade where ANSTO has made a contribution

ANSTO

Ethics & Law: Fossils are Cultural Property

“Fossils are considered cultural property and fall under the special protection of the UNESCO Convention of 1970 on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property”

Shamila Nair-Bedouelle
Assistant Director-General for Natural Sciences, UNESCO

French customs return 998 stolen fossils to UNESCO Global Geopark in Brazil

On 24 May, French customs officers returned a palaeontological treasure trove to the Brazilian authorities: 998 fossils dating from the Cretaceous period (145–65 million years ago). These fossils had been stolen from a geopark in the basin of Araripe in north Brazil that has been part of a UNESCO global network since 2006. The fossils were

Brazil donated a replica of one of the seized fossils to UNESCO

Documentation for Specimens

NATURAL HISTORY MUSEUM OF DENMARK
UNIVERSITY OF COPENHAGEN

Fossil specimens for scientific studies

27 FEBRUARY 2019

COLLECTIONS DEPARTMENT

To whom it may concern,

This document follows 1 (one) fossil specimen in 5 (five) pieces, which I have loaned to Dr. Joseph Bevitt to be received by Dr. Ulf Garbe.

The specimen is on loan from the research collections of the Natural History Museum of Denmark (NHMD), Copenhagen.

It is intended for scientific studies by Dr. Bevitt and will be returned to Denmark within a year.

This fossil is in the category of geological samples, having been collected from a quarry in Jameson Land, East Greenland in 1991.

The specimen is clean and free of any biosecurity risk material.

Specimens

NHMD 74799 A–E (*ex*-MGUH.VP 3393 *ex*-MCZ f.no. 13/91/G)	*Arcticodactylus (Eudimorphodon) cromptonellus* HOLOTYPE: Main block (A), counterpart (B), phalange in block (C); metacarpal (D) & element in matrix (E) (Triassic: Norian-Rhaetian; Fleming Fjord Formation: Ørsted Dal Member; MacKnight Dal Quarry, Jameson Land, East Greenland)

Biosecurity Letter

"The specimen is clean and free of any biosecurity material"

Object Loan Agreement

Preferably with the PI's name. Negotiable.

NOTE: ANSTO DOES NOT insure specimens

NATURAL HISTORY MUSEUM OF DENMARK
UNIVERSITY OF COPENHAGEN

Loan Number: NHMD 2019-VP-004

28 FEBRUAR 2019

Loan issued to: Dr. Joseph Bevitt

COLLECTIONS

under the conditions detailed on page 3

Return of the material is expected no later than 01/07/2019

See page 2 for an itemized list of the loan contents:

Please sign the form and indicate any damage to the material that you notice upon receipt on page 2

Loan of material authorised

REF: Loan of material
LOAN: NHMD 2019-VP-004
Please specify on inquiry

ANSTO

IAEA
International Atomic Energy Agency

unicri
United Nations
Interregional Crime and Justice
Research Institute

Objective:
To establish and operate an **IAEA-UNICRI Technology-driven Integrated Platform** to fight illicit trafficking in Cultural Property

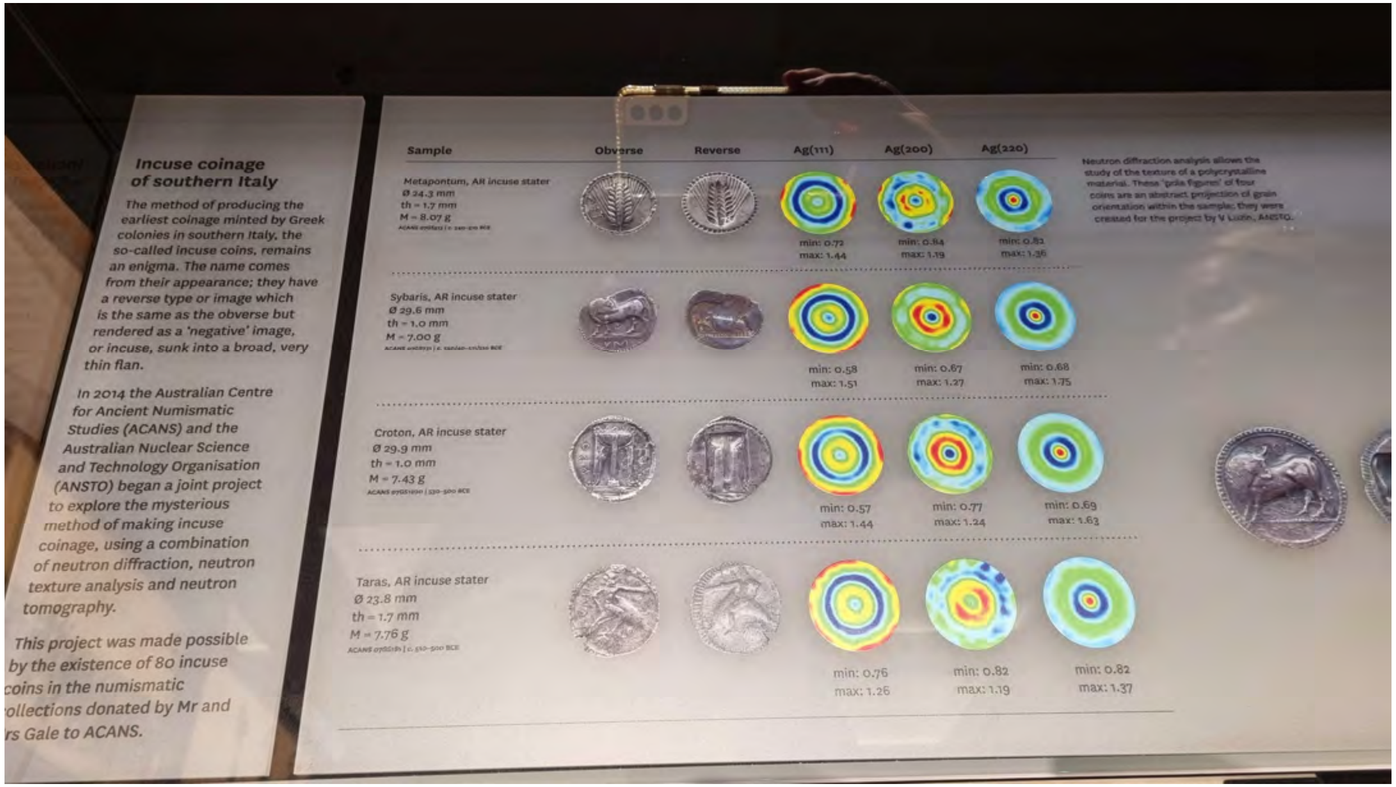
ANSTO

Museum Installations: Danish Natural History Museum

- *Arcticodactylus*, an extinct genus of pterosaur that lived in Greenland during the Late Triassic

Life reconstruction art by Gabriel Ugueto

Museum Installations: Macquarie University



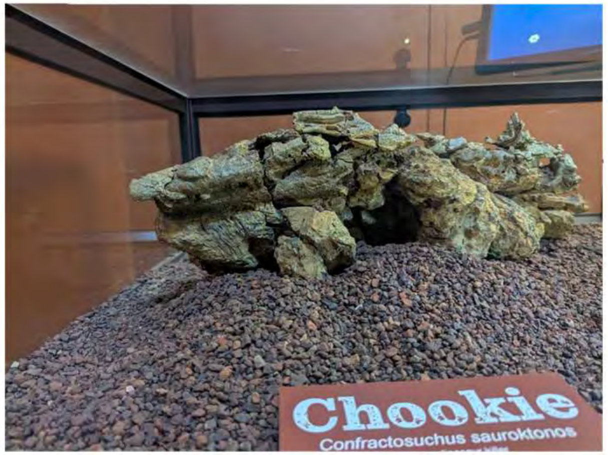
MACQUARIE University SYDNEY·AUSTRALIA

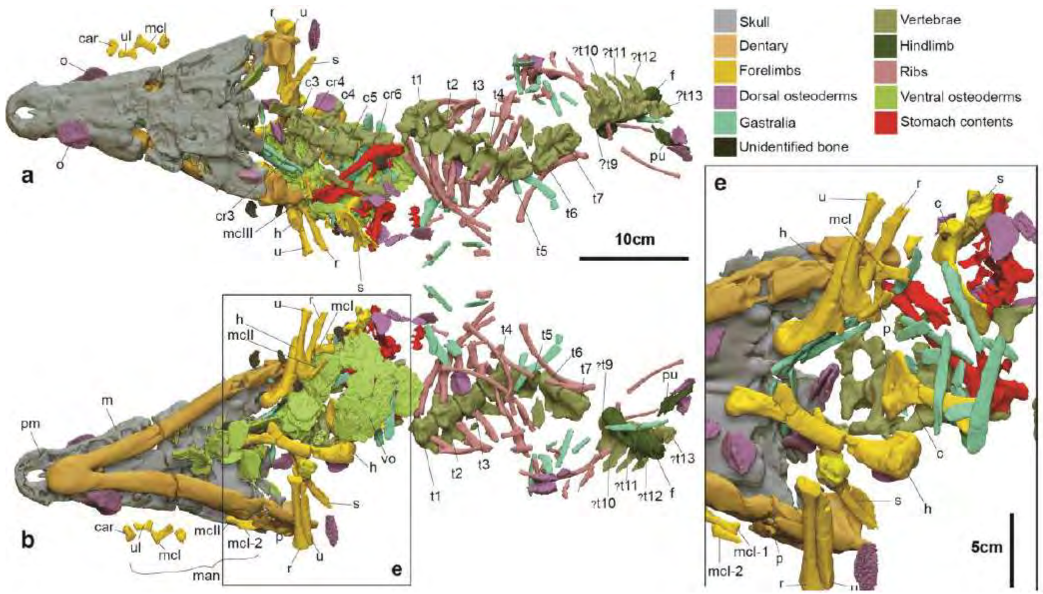
The Gale History Museum
at Macquarie University

ANSTO

Museum Installations: AAOD NHM

AUSTRALIAN
AGE OF DINOSAURS
WINTON Q.
www.australianageofdinosaurs.com



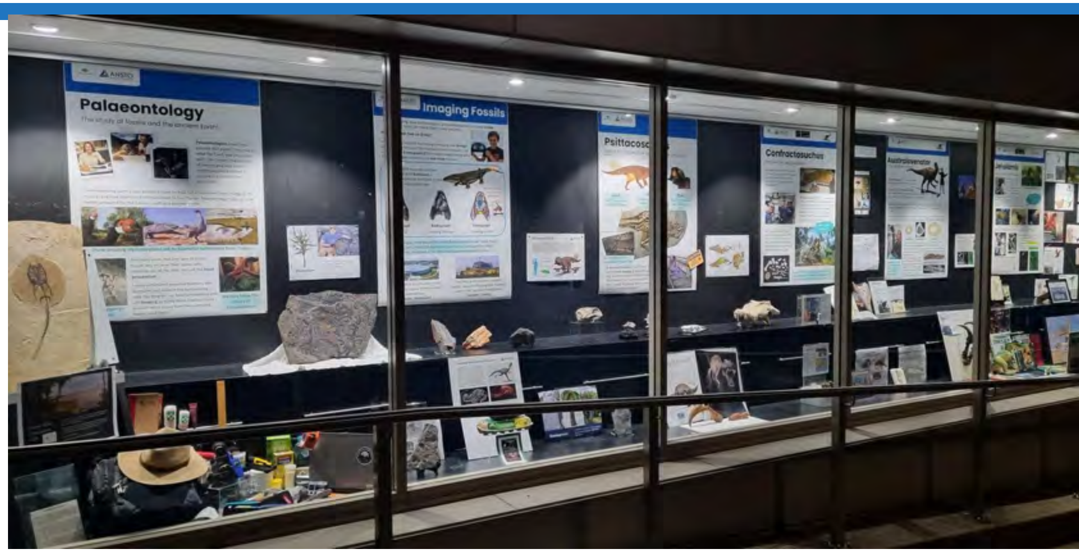


Confractosuchus sauroktonos: A New Cretaceous Australian Crocodilian
Combined Neutron AND Synchrotron X-ray CT on display

ANSTO

Public Outreach

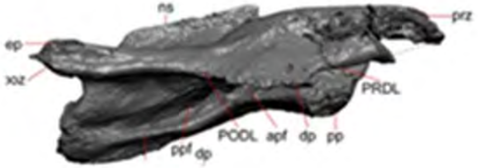
Public School and Scout group visits



Stanhope Gardens Library

Max Webber Library, Blacktown

ANSTO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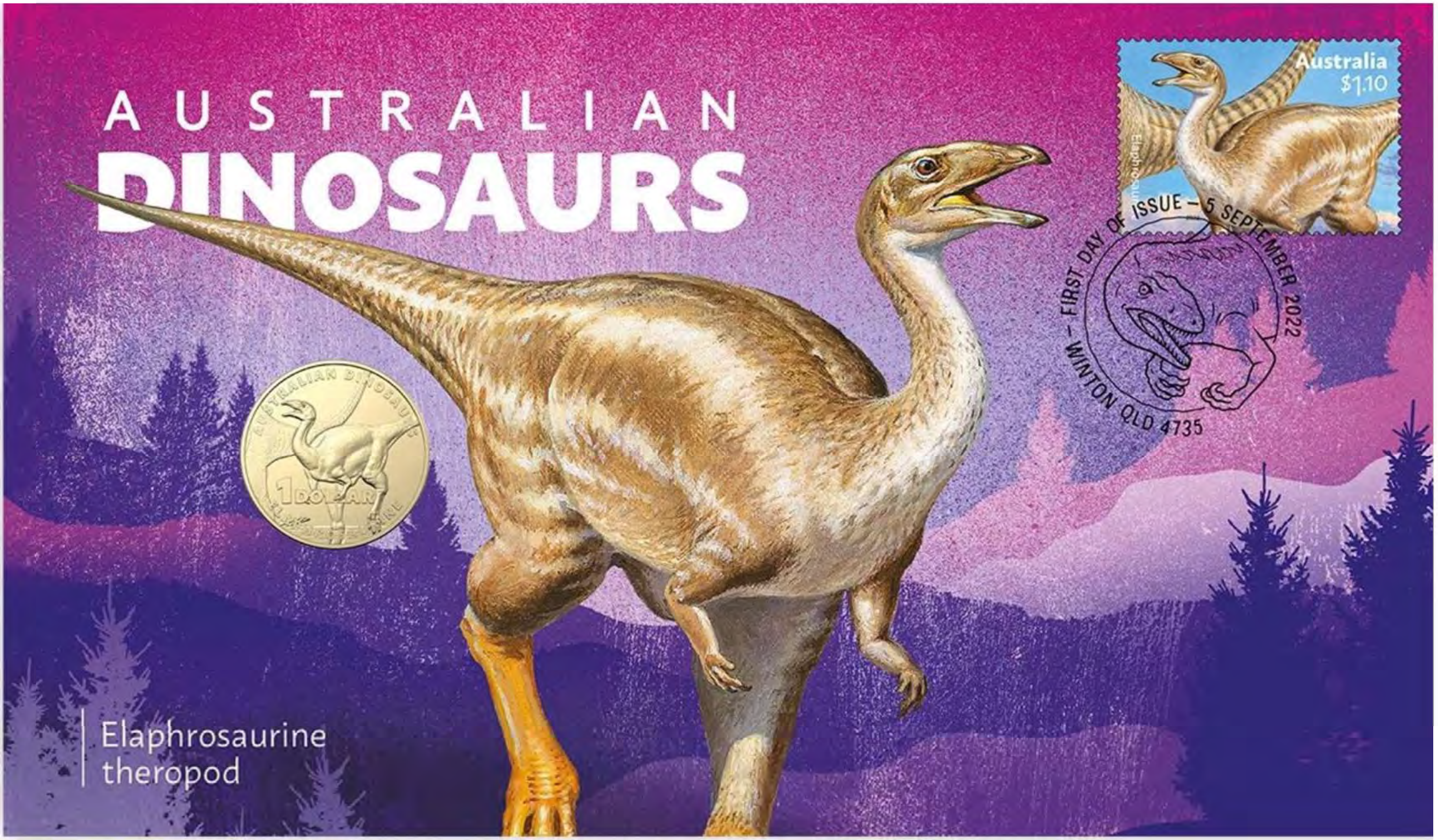
Elaphrosaurine
2022


AUSTRALIAN
DINOSAURS
Australia
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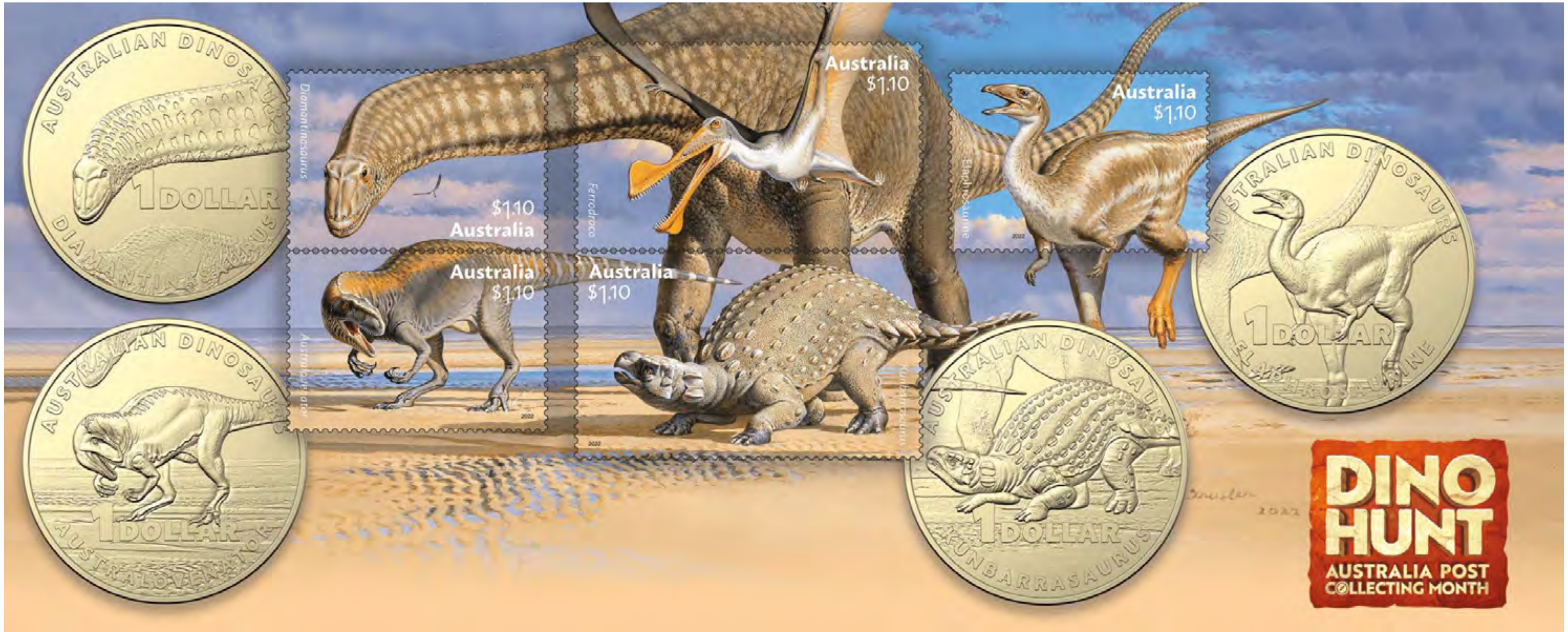
FIRST DAY OF ISSUE – 5 SEPTEMBER 2022
WINTON QLD 4735
Elaphrosaurine
theropod


AUSTRALIAN DINOSAURS
1 DOLLAR
ELAPHROSAURINE

ANSTO

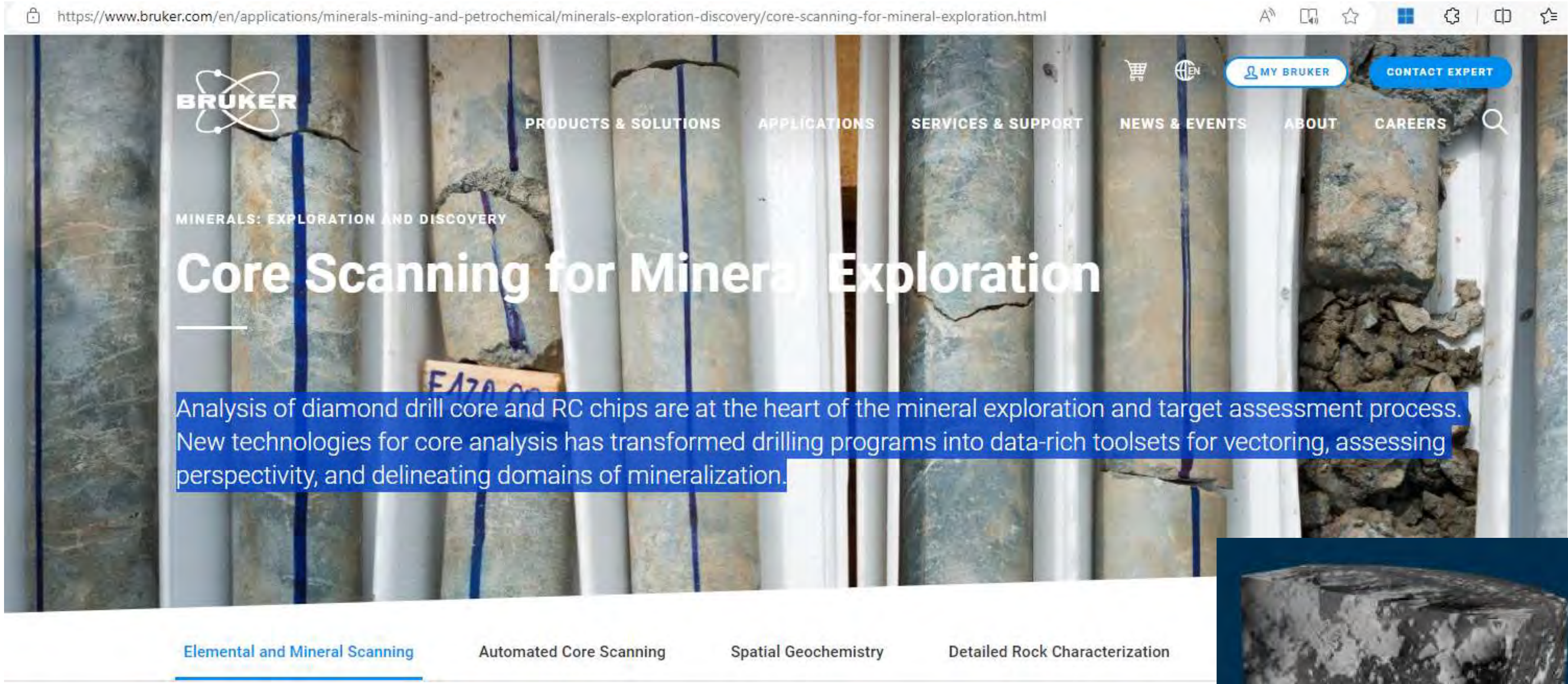
ANSTO Discoveries Featured on Stamps and Coins

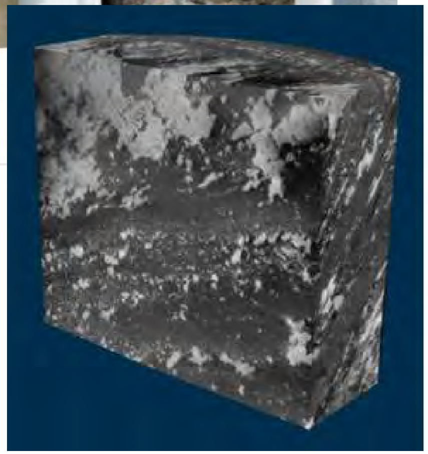


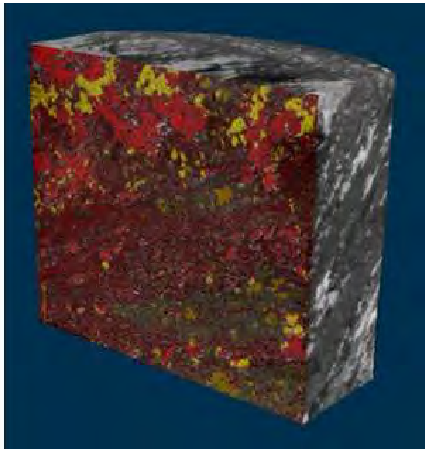
ANSTO

Where to from here?

High-throughput Drillcore Characterisation







Base technology = X-ray tomography (3D imaging)
When X-rays can't penetrate dense rock – 2D surface scanning (XRF) is used. **There is potential here for commercial neutron tomography**

A new capability: High-throughput mining drillcore NCT

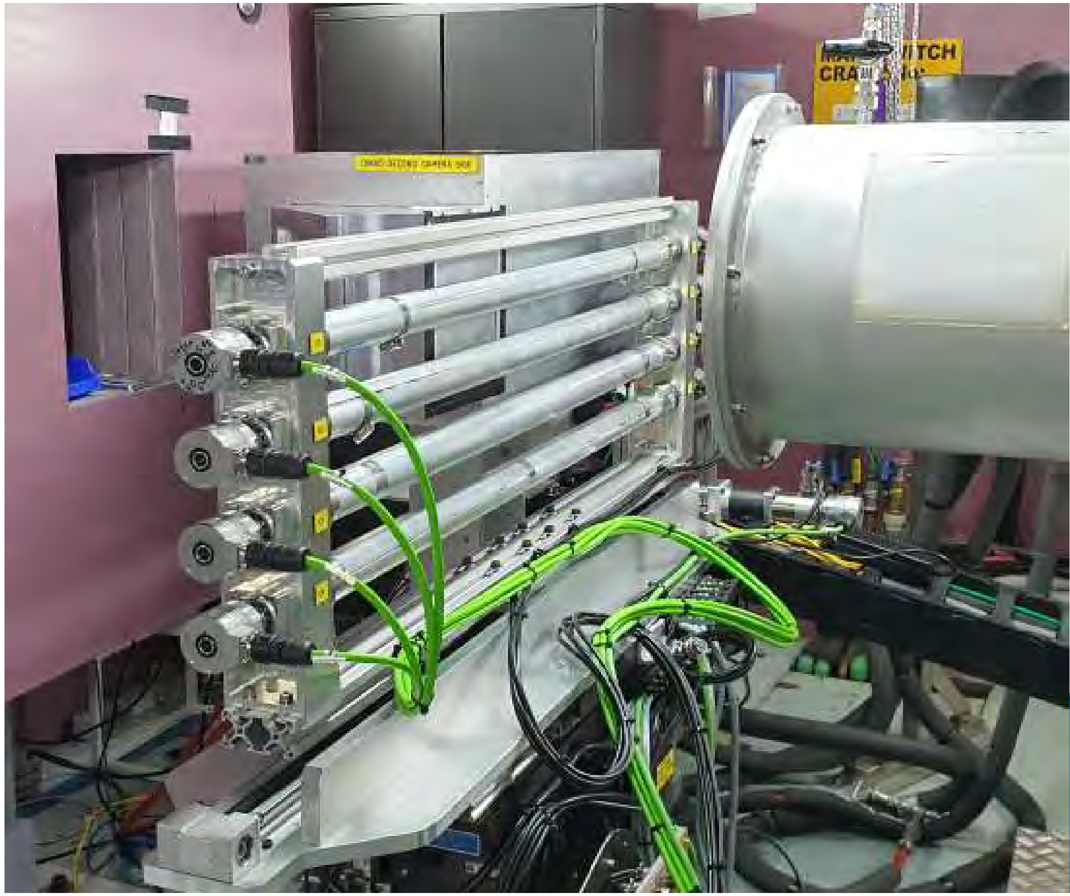
Prototype 1 (implemented 2020)

- Up to 1.4m of drillcores held **horizontally**
- 2 x 20cm core sections scanned simultaneously
- 55 min scan
- 15 min delay between scans
- Significant downtime (manual handling)

Prototype 2 (implemented 2025)

- Up to 1.0m drillcores held **vertically**
- 3 x 20cm core sections per scan
- Optimised scans = 30 min
- 10 - 20 scans per rig = reduced manual handling
- Potential for simultaneous X-ray CT

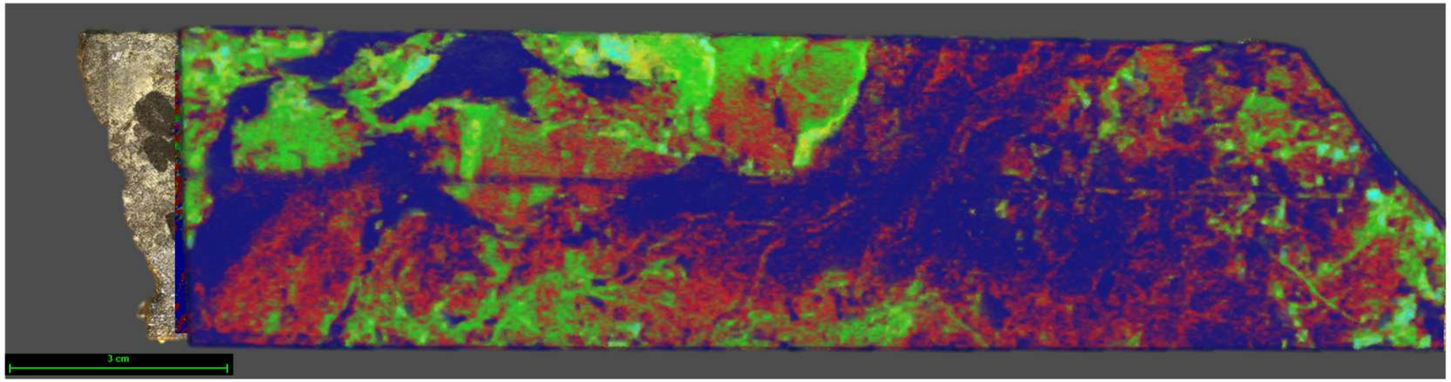
Mining drillcore rig, prototype 1



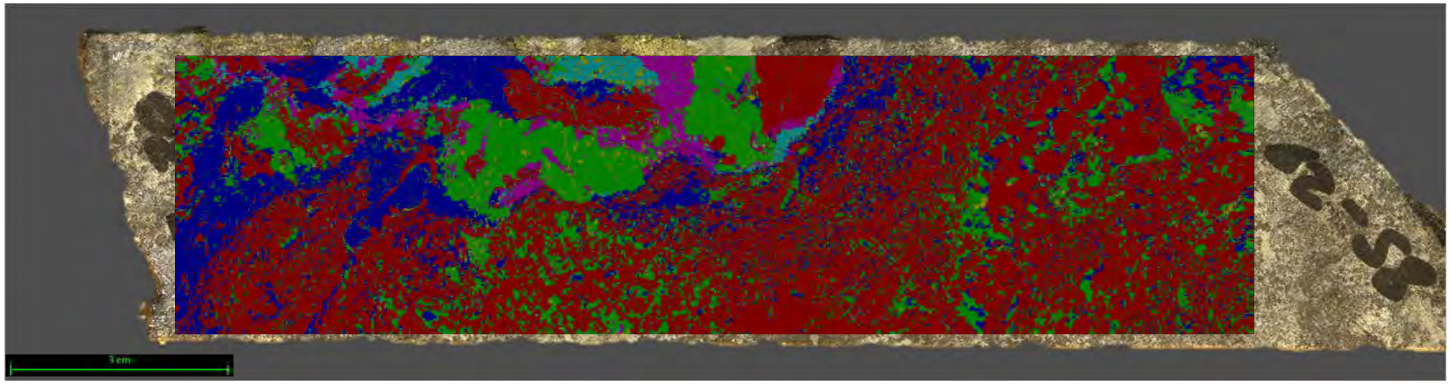
3D NCT data compared to 2D XRF. Good agreement

- Neutrons offer the ability to 3D map some mineral concentrations that are currently only reported from 2D cross-cuts.
- Increase accuracy of reported mine value, and life.

NCT



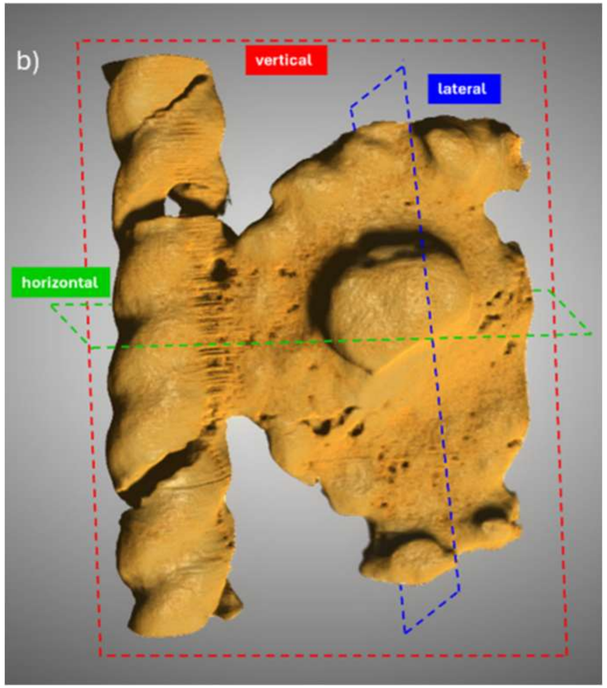
XRF

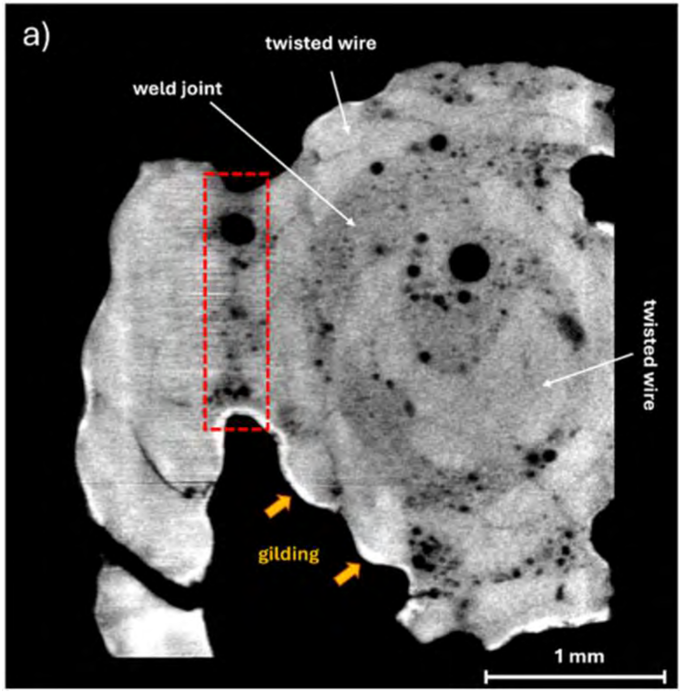


This data courtesy of Dr Tim Murphy, Macquarie University

Former PSI Neutron Microscope: First Application

The Chiaravalle Cross: a 13th century masterpiece of medieval goldsmithery from Chiaravalle Abbey near Milan, Italy.





Vigorelli, L., Salvemini, F., Marcucci, G. *et al.* High resolution neutron tomography as non-invasive tool for the study of a filigree from the Medieval Chiaravalle Cross. *Archaeol Anthropol Sci* **17**, 138 (2025). https://doi.org/10.1007/s12520-025-02254-y

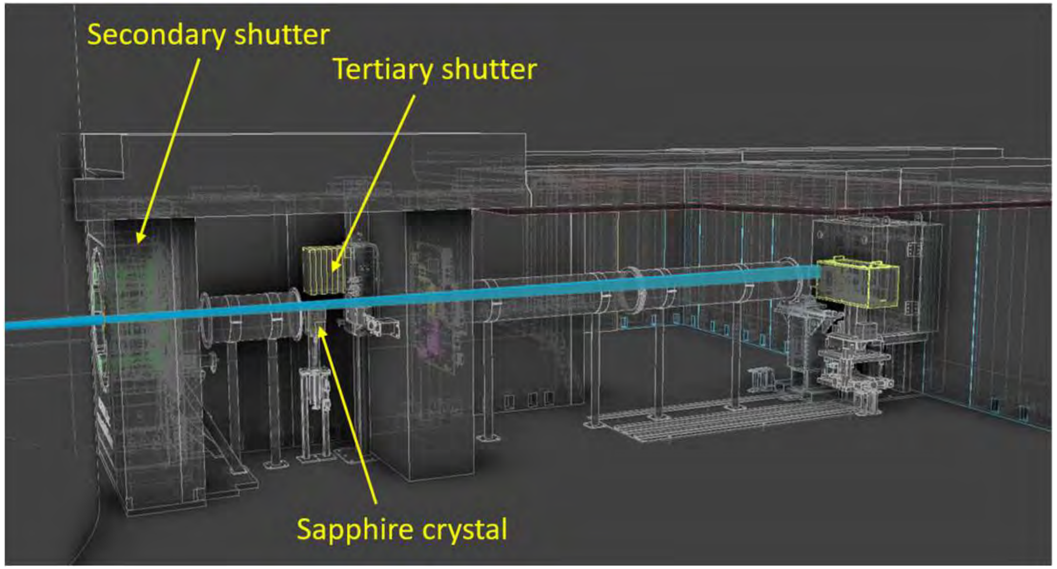
UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

ANSTO

Digital Twin of the Dingo Thermal Neutron Imaging Instrument

Aims

- Characterisation of the mixed gamma/neutron field
- Prediction of the in-beam neutron spectrum
- Maximise research quality
- Extension of the instrument's capabilities to radiobiological research



Article | Open access | Published: 02 April 2025

A functional digital model of the Dingo thermal neutron imaging beamline

Klaudiusz Jakubowski, Joseph J. Bevitt, Nicholas Howell, Chris Dobie, Frederic Sierro, Ulf Garbe, Scott Olsen, Attila Stopic, Daniel R. Franklin, Linh T. Tran, Anatoly Rosenfeld, Susanna Guatelli & Mitra Safavi-Naeini

Scientific Reports **15**, Article number: 11233 (2025) | Cite this article

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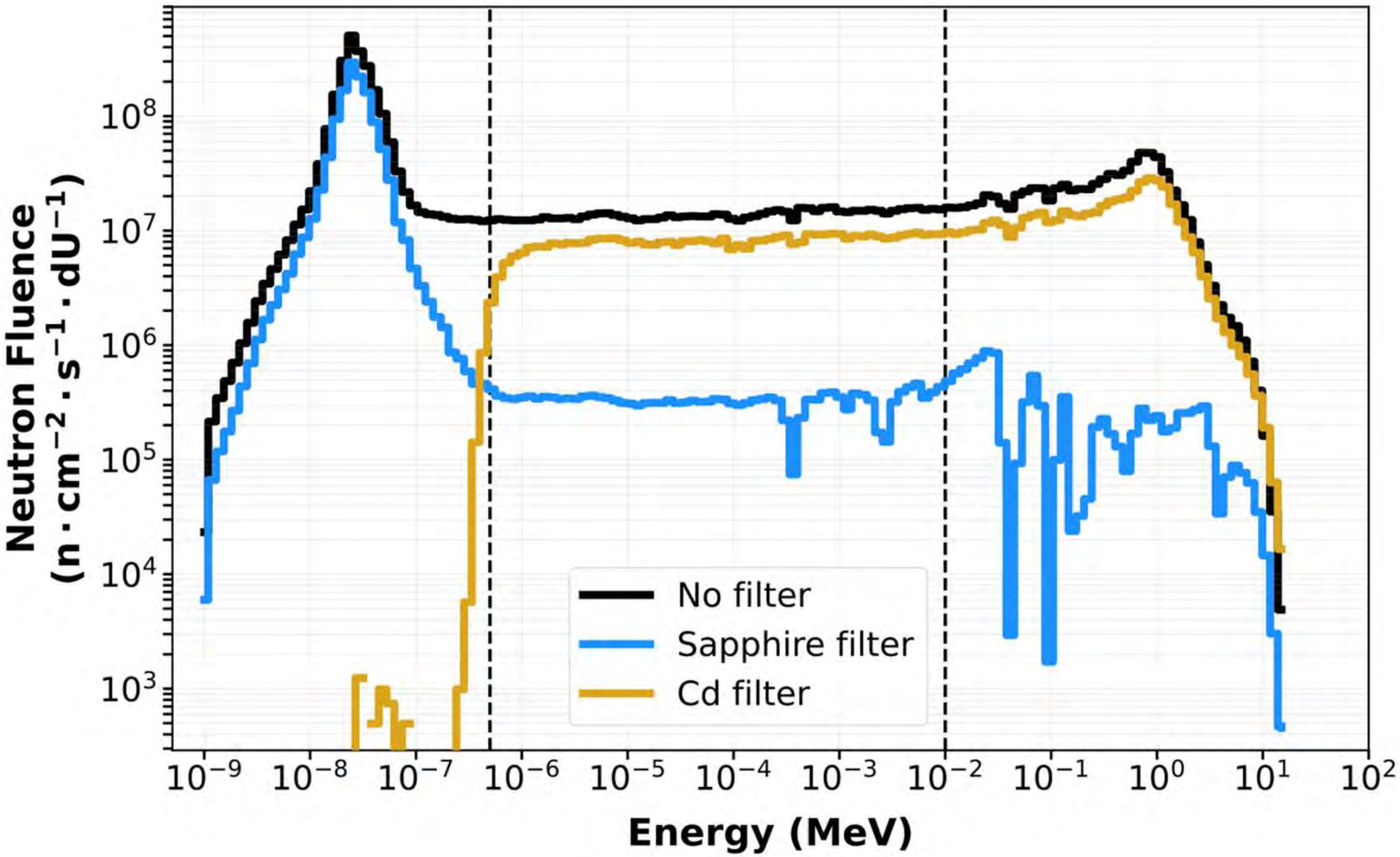
Dingo's Neutron Energy Spectrum



neutrons < 0.5 eV
Thermal neutrons

neutrons > 0.5 eV
epithermal & fast neutrons

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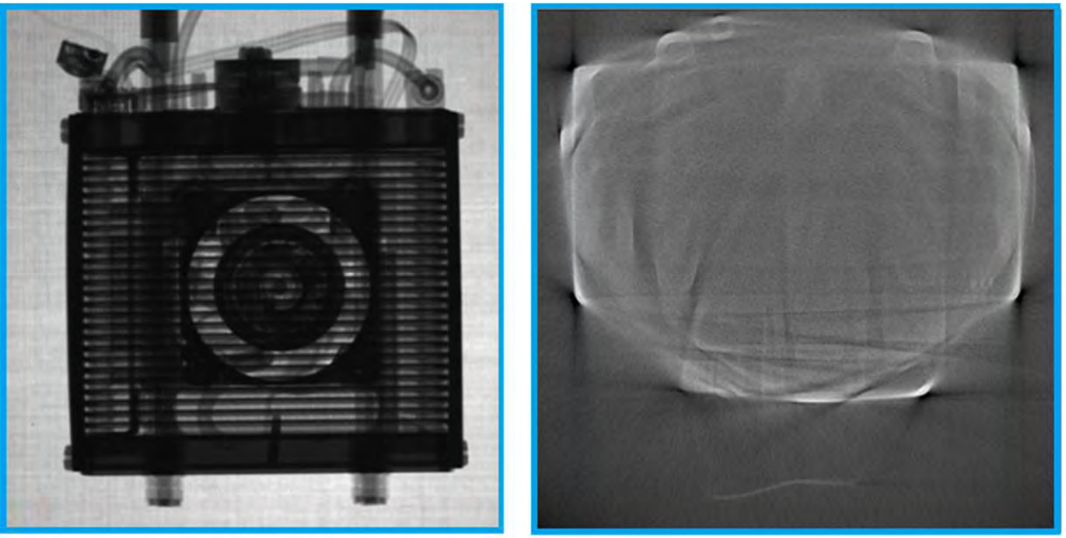
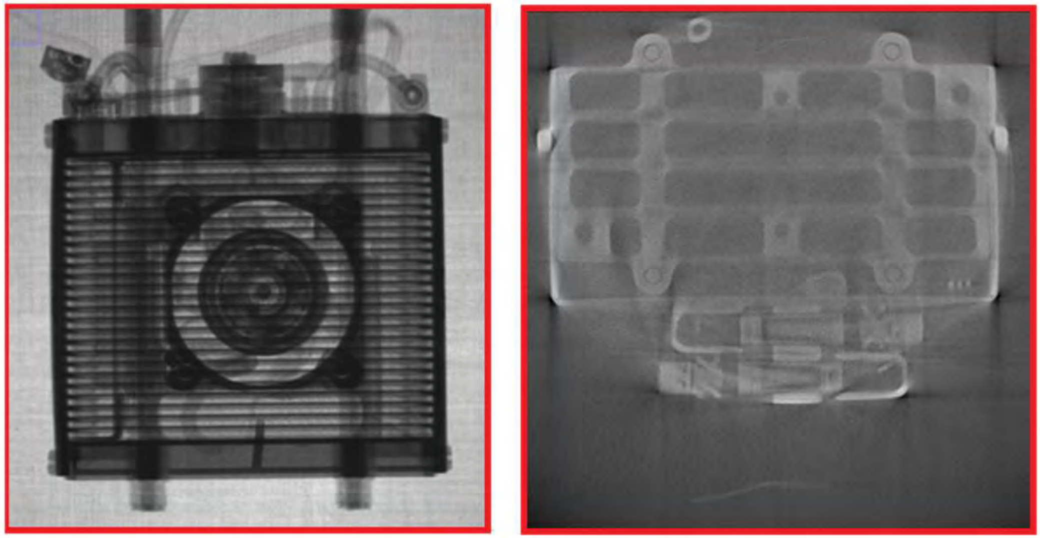
Cd-filtered (>0.5eV) Neutron Imaging



Left: thermal-neutron radiograph of drone fuel cell
Right: CT cross-section showing poorly resolved internal details

Less penetration, better contrast.



Left: epithermal-neutron radiograph of drone fuel cell
Right: CT cross-section showing improved internal features

Better penetration, lower contrast.

An Exciting Time for Collaboration!

World class museum set for Parramatta

Powerhouse Museum Discovery Centre, Castle Hill

Powerhouse Parramatta Inaugural Exhibition

ANSTO

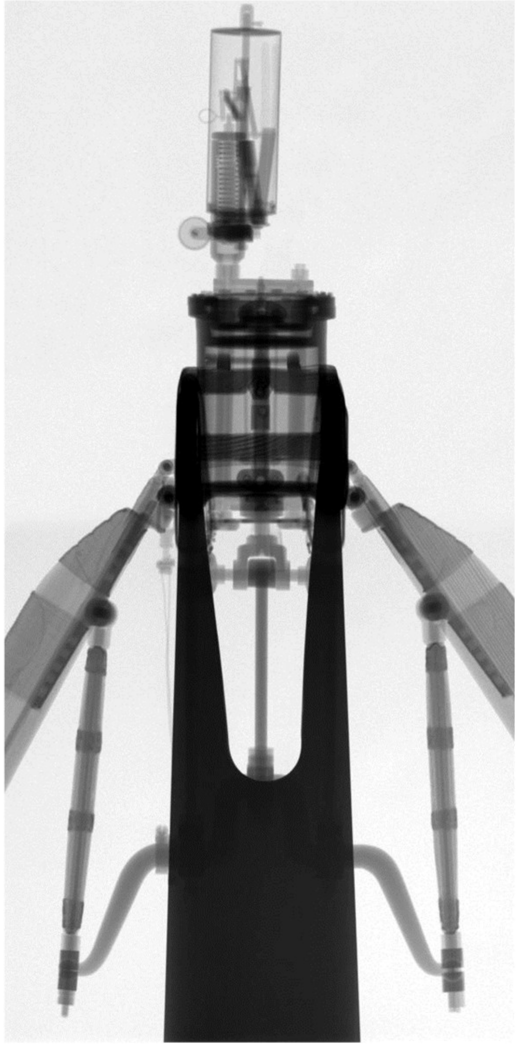
Lawrence Hargrave – Aviation Pioneer

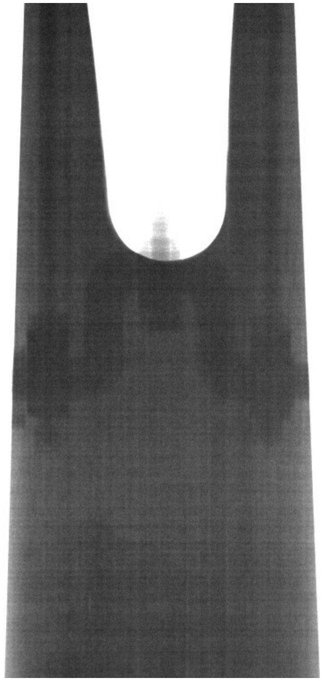
- Lawrence Hargrave invented a pioneering 3-cylinder rotary engine in 1889 and the box kite in 1893, influencing early flight.
- The Wright Brothers' 1903 Flyer and engine designs were strongly influenced by Hargrave’s box kite, rotary engine, and aerofoils.
- His research was shared globally rather than patented

Lawrence Hargrave working on a box kite at Point Piper, Sydney, about 1910

ANSTO

Lawrence Hargrave Engine No.1 (1888)





First application of epithermal-neutron imaging for cultural heritage on Dingo. Better visuals through wood.

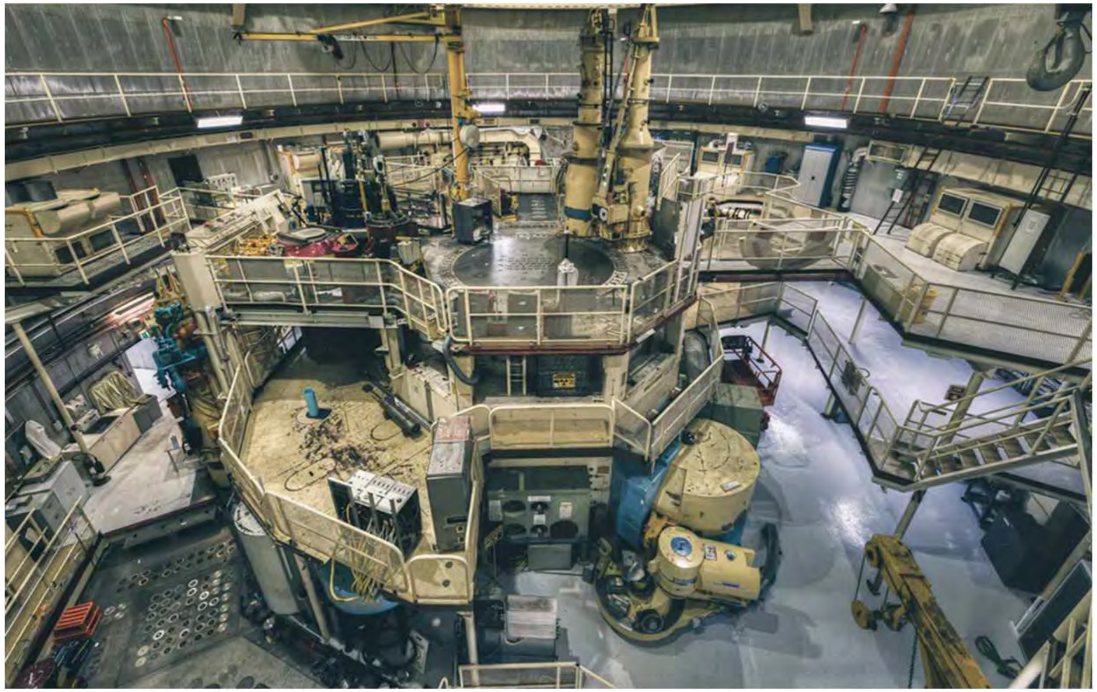
ANSTO

14 Nov 2023: Research Grant Success!

- ARC Linkage Project "Nuclear Nation: a contemporary archaeology of Australia's atomic heritage" has been funded $419k over 3 years!

- Aim: to generate new understandings of the significance of Australia's atomic heritage in a global context.
- Expected outcomes: improved heritage management and methods for understanding and interpreting Australia's role in the Atomic Age.

Nuclear Nation: A Contemporary archaeology of Australia's Atomic Heritage



The High Flux Australian Reactor (HIFAR) c. 1958
Photos by Brett Patman, Lost Collective
https://lostcollective.com/collections/ansto-hifar

ANSTO

ANSTO's collaborating scientists

Dr Joseph Bevitt
Australian Centre for Neutron Scattering

Dr Vladimir Luzin
Australian Centre for Neutron Scattering

Dr Floriana Salvemini
Australian Centre for Neutron Scattering

Dr Geraldine Jacobsen
Centre for Accelerator Science

Dr Vladimir Levchenko
Centre for Accelerator Science

Dr Zeljko Pastuovic
Centre for Accelerator Science

A/Prof Ulf Garbe
Australian Centre for Neutron Scattering

Attila Stopic
Neutron Activation

Dr David Patterson
Australian Synchrotron

Dr Daryl Howard
Australian Synchrotron

Dr Anton Maksimenko
Australian Synchrotron

Dr Pimm Vovingsvut
Australian Synchrotron

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The Invisible Revealed is the result of an ongoing multidisciplinary partnership between ANSTO and the Powerhouse Museum.
This exhibition team was led by: Scientist Joseph Bevitt, Curator Deborah Lawler-Dormer and Lead Engineer Tomasz Bednarz.

ANSTO

Maxim Avdeev, Fiona Bertuch, Rodd Dowler, Patricia Gadd, Ulf Garbe, Daniel Hausermann, Quan Hua, Vladimir Levchenko, Vladimir Luzin, Anton Maksimenko, Mark New, Scott Olsen, Zeljko Pastuovic, David Roach, Filomena Floriana Salvemini, Attila Stopic.

Powerhouse

Matthew Connell, Callum Cooper, Christina Fedrigo, Julie Floyd, Rebecca Georgiades, Megan Hall, Jason Jaram, Alina Kozlovski, Dawn Leyland, Katrina O'Brien, Hugh O'Connor, Stella Palmer, Vanessa Pitt, Brooke Randall, Cara Stewart, Workshop, Media Technologies team.

ANSTO

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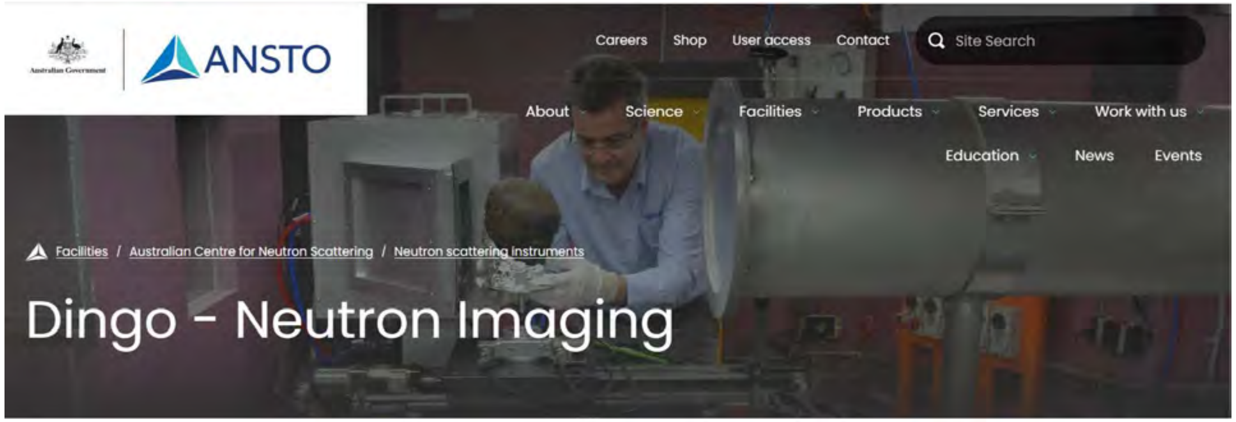
MACQUARIE University
AUSTRALIAN MUSEUM
MMI MACQUARIE MEDICAL IMAGING
cradle of humankind world heritage site
LA TROBE UNIVERSITY AUSTRALIA
AUSTRALIAN AGE OF DINOSAURS WINTON Q. www.australianageofdinosaurs.com
Flinders UNIVERSITY
THE UNIVERSITY of ADELAIDE
UNSW AUSTRALIA
MONASH University
한국지질자원연구원 KIGAM Korea Institute of Geoscience and Mineral Resources
서울대학교 SEOUL NATIONAL UNIVERSITY
吉林大学 恐龙演化研究中心 THE DINOSAUR EVOLUTION RESEARCH CENTER OF JILIN UNIVERSITY JLU
國立中央大學 National Central University
MAAS Museum of Applied Arts & Sciences
DENVER MUSEUM OF NATURE & SCIENCE
國立中興大學 National Chung Hsing University
UNIVERSITY OF TORONTO
THE UNIVERSITY OF SYDNEY
AMERICAN MUSEUM OF NATURAL HISTORY
AINSE

More Details

International Society for Neutron Radiography
Established 1996

http://isnr.de/index.php/ni-facilities



- Joseph Bevitt (ANSTO)
- dingo@ansto.gov.au
- kowari@ansto.gov.au
- https://www.ansto.gov.au/
- Next proposal deadline: 15 March 2026

Thank you

Australian Government

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