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The neutron facility at NCSR "Demokritos" and neutron activation research activities of NTUA

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The Neutron Facility – Available Beams

The 5.5 MV tandem T11/25 Accelerator at NCSR "Demokritos" in Athens is the only accelerator facility in Greece.
It is currently under major renovation through the program CALIBRA/EYIE.

The neutron facility can deliver quasi-monoenergetic neutron beams at energies :

- ~ 120 – 650 keV via the $^{7}Li(p,n)^{7}Be$ reaction - Flux: ~ 10^{4}n/cm^{2}s
- ~ 2- 5.3 MeV via the $^{3}H(p,n)^{3}He$ reaction – Flux : ~ 10^{5}n/cm^{2}s
- ~ 4.0 – 11.4 MeV via the $^{2}H(d,n)^{3}He$ reaction - Flux: ~ 10^{6}n/cm^{2}s
- ~ 16 – 20 MeV via the $^{3}H(d,n)^{4}He$ reaction - Flux: ~ 10^{5}n/cm^{2}s

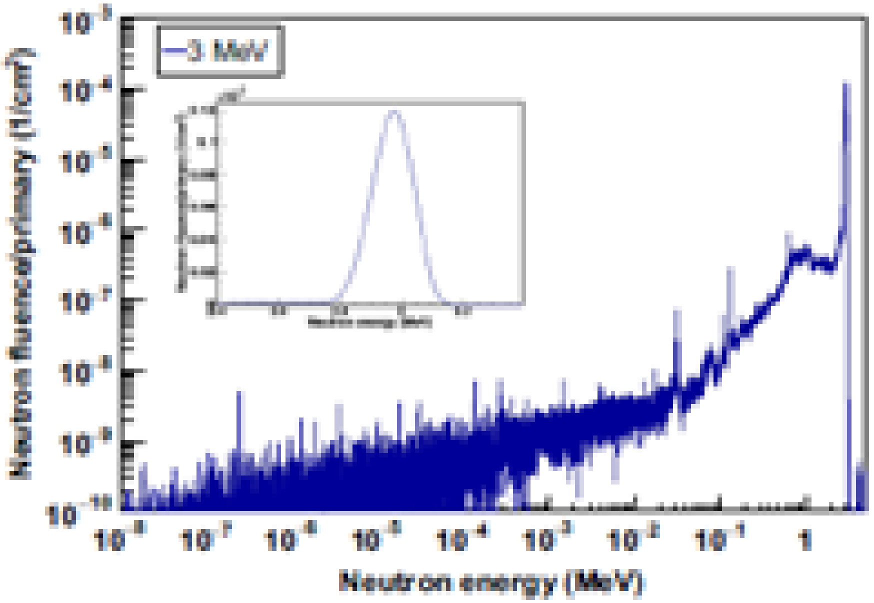
The flux variation of the neutron beam is monitored by using a BF3 detector with parafin moderator, whose spectra are stored at regular time intervals. The absolute flux of the beam can be obtained with respect to reference reactions, such as $^{56}Fe(n,p)$, $^{27}Al(n,\alpha)$, $^{197}Au(n,2n)$ and $^{93}Nb(n,2n)$ and is used for cross section measurements implementing the activation technique

The Neutron Facility – the $^{7}Li(p,n)^{7}Be$ reaction

^{7}LiF target on Al backing and proton beams in the energy range 1.9 – 2.4 MeV to produce purely mono-energetic neutrons at zero degrees between 120 keV and 650 keV, respectively. At proton energies above 2.4 MeV, neutron emission to the 1st excited state in ^{7}Be at 429 keV is possible and produces a second group of monoenergetic neutrons.

The Neutron Facility – the $^{3}H(p,n)^{3}He$ reaction

Ti tritiated target of 373 GBq activity on a Cu backing (with 10μm Mo foil in front) and proton beams in the energy range 3.4 – 6.5 MeV to produce neutrons between 2- 5.3 MeV . Purely mono-energetic neutrons in the range ~ 2-3 MeV, then (p,n) reactions Mo, Ti, Cu, C and ^{2}H implanted in the TiT target from previous irradiations, become important and lead to a long neutron tail down to the thermal region. NeuSDesc and MCNP simulations.



V.Michalopoulou, EPJ A57(2021)277

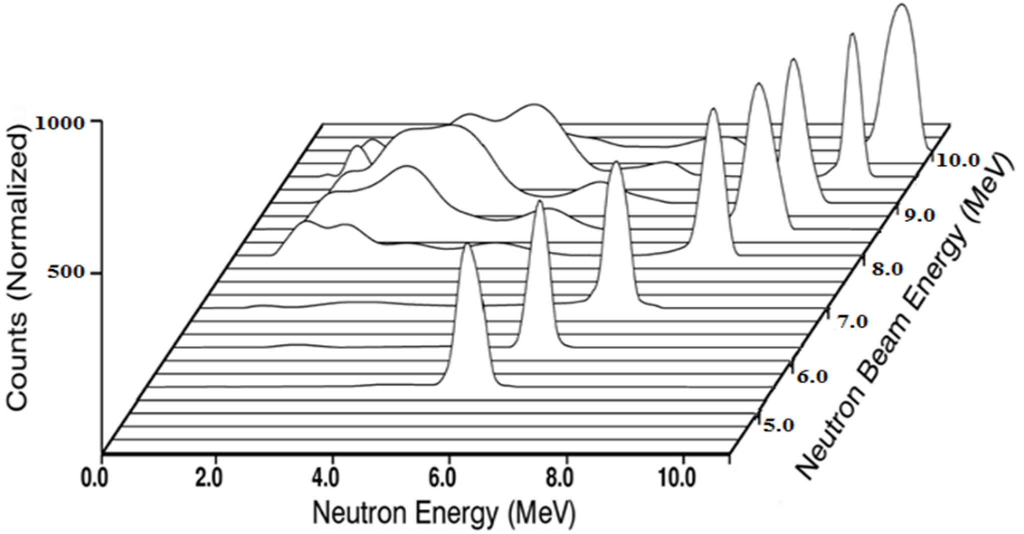
The Neutron Facility – the $^{2}H(d,n)^{3}He$ reaction

A 3.7 cm gas cell with a 5μm Mo entrance foil and deuteron beams in the energy range 0.8 – 9.6 MeV to produce neutrons between 4-11.4 MeV

Purely mono-energetic in ~ 4-7 MeV –above parasitic neutrons mainly due to deuteron break up reactions :

- $^{2}H(d,pn)^{2}H$ above Ed = 4.5 MeV
- $^{2}H(d,2n)^{2}He$ above Ed = 8.9 MeV
- reactions with the isotopes of Mo gas cell window, above the Coulomb barrier Ed = ~7 MeV and structural materials of the gas cell, collimators etc

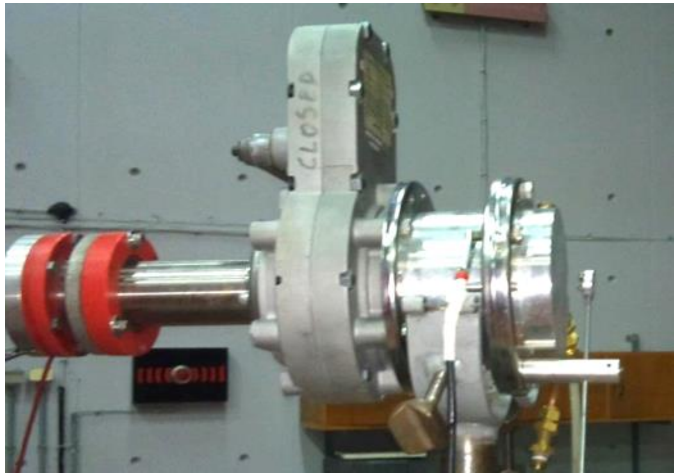
In absence of time-of-flight capabilities, the neutron beam has been characterized by means of a) MCNP5 Monte Carlo simulations, b) multiple foil activation technique in combination with the SULSA unfolding code and c) deconvolution of recoil energy spectra taken with the BC501A liquid scintillator detector at various neutron energies with the DIFBAS code e) Gas-in gas-out tests, irradiations with and without Cd foil in front of reference foils



R.Vlastou et al. Nucl.Instr.Meth. B269 (2011)3266

The Neutron Facility – the $^3H(d,n)^4He$ reaction

Ti tritiated target of 373 GBq activity on a Cu backing (with 10μm Mo foil in front) and deuteron beams in the energy range 0.8 – 3.7 MeV MeV to produce neutrons between 16 - 20 MeV



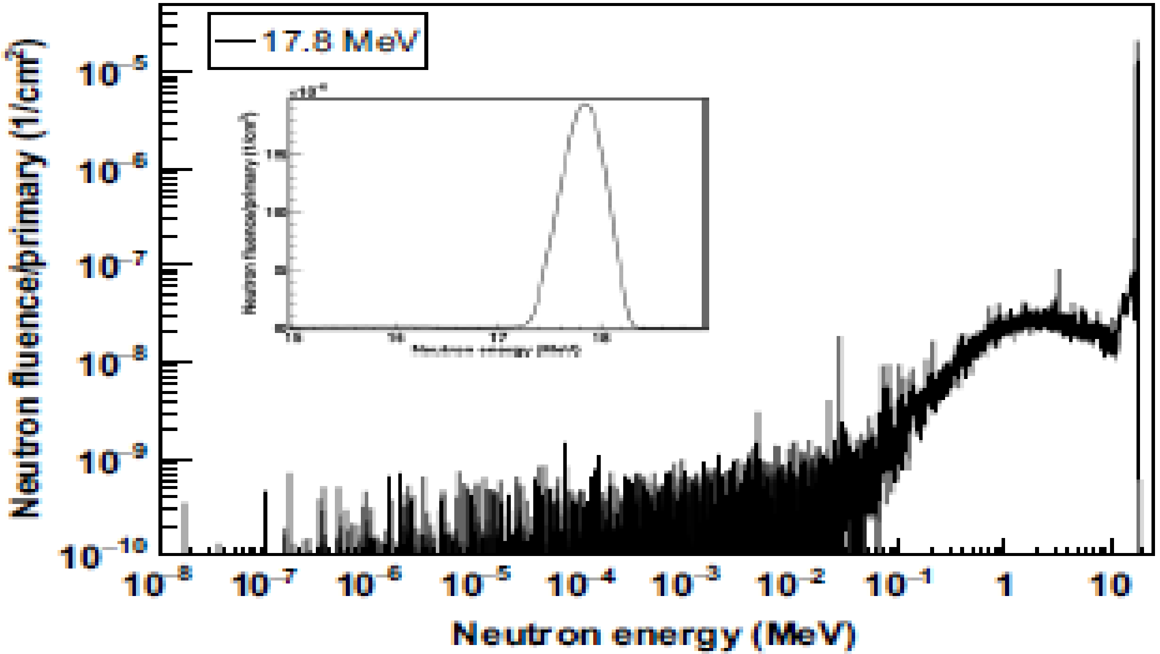
Neutron beam not purely monoenergetic due to parasitic neutrons from deuteron break up reactions and reactions with materials of beam line and target : $^3H(d,pn)^3H$, $^2H(d,n)^3He$, Ti(d,n), O(d,n) and C(d,n)

Characterization via:

NeuSDesc and MCNP5 Monte Carlo Simulations

Multiple foil activation technique and other experimental techniques

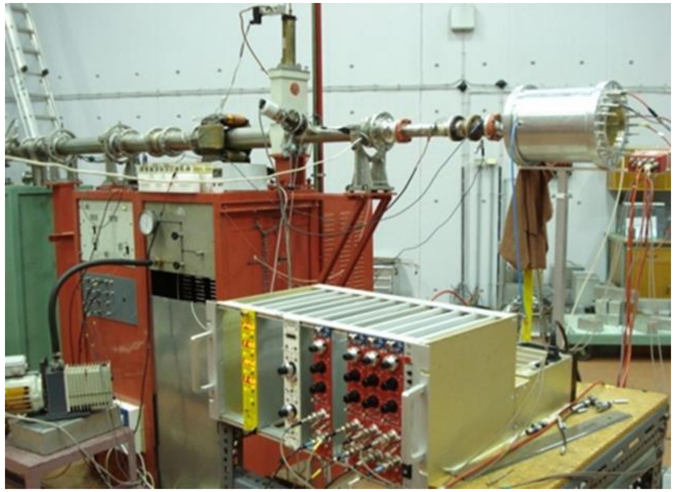
V.Michalopoulou, EPJ (2021) A57-277



The Neutron Facility – Research Activities

a) Irradiations for applications:

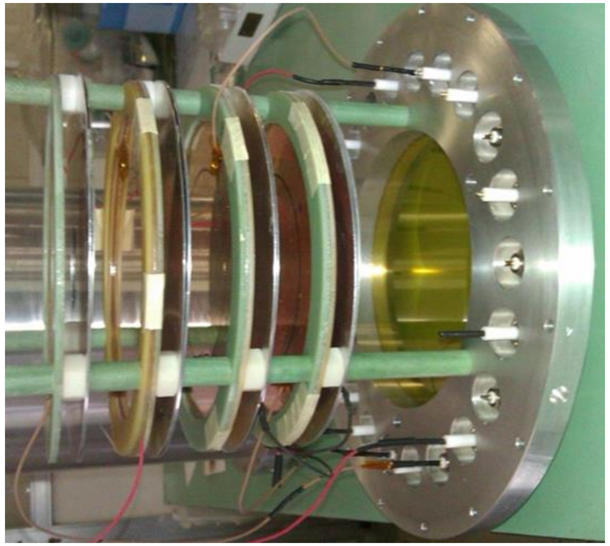
- detector physics (CERN ATLAS Muon Detector Tubes, …)
- space (ESA)



b) n-induced reactions relevant to nuclear energy applications:

Reactions on minor actinides with importance to fundamental research and applications like development of fast reactor systems, nuclear waste etc

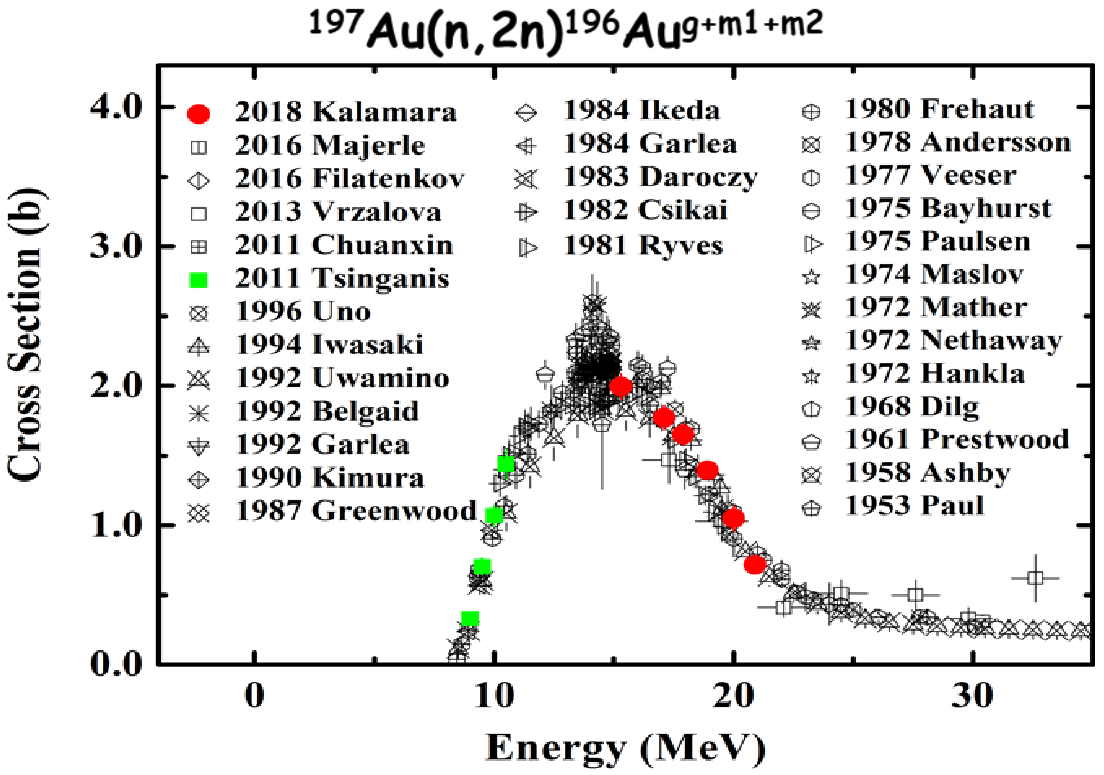
- (n,2n) reactions by the activation method (^{232}Th(n,2n), ^{241}Am(n,2n))
- Fission cross sections with MicroMegas detectors (^{232}Th, ^{234}U, ^{236}U, ^{237}Np) see Poster by V.Michalopoulou)

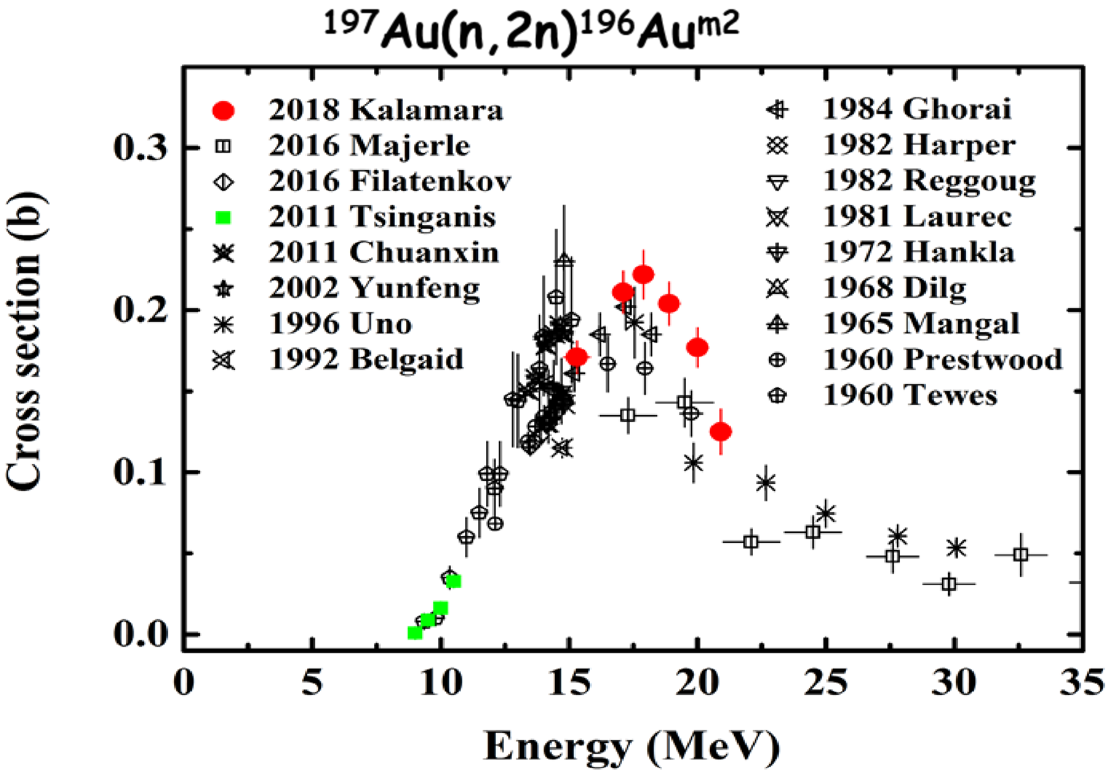


c) (n,2n), (n,p) and (n,α) cross section measurements by the activation method relevant to practical applications for nuclear technology, high energy neutron dosimetry, detector physics etc. and also important for investigation of the model parameters of statistical model calculations (Ge, Hf, Au, Ir isotopes)

The $^{197}Au(n,2n)^{196}Au^{g+m1+m2}$ and $^{197}Au(n,2n)^{196}Au^{m2}$ case

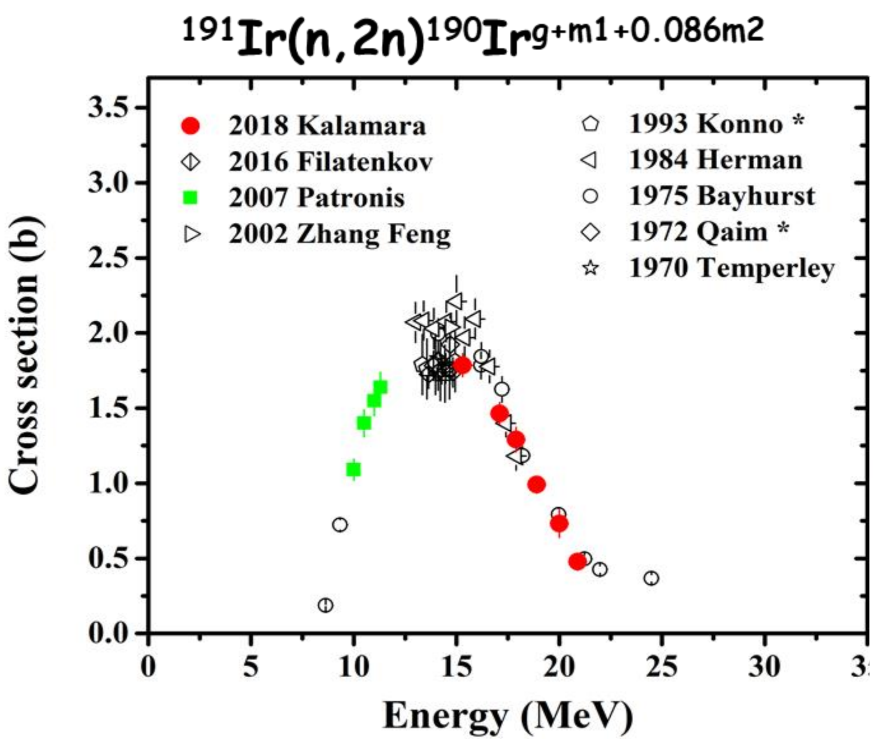
Neutron induced reactions on Au and Ir : Important as reference reactions - high energy neutron dosimetry - medical and industrial applications. Important reactions for the investigation of model parameters in the frame of statistical model calculations - population of both ground and metastable states - sensitivity to spin distribution of level densities

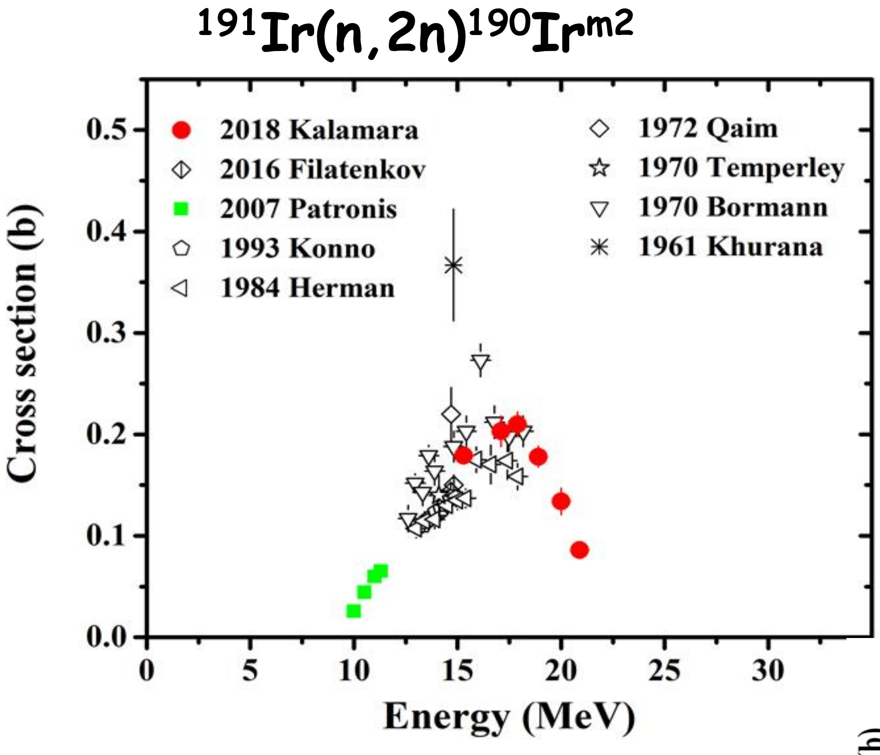


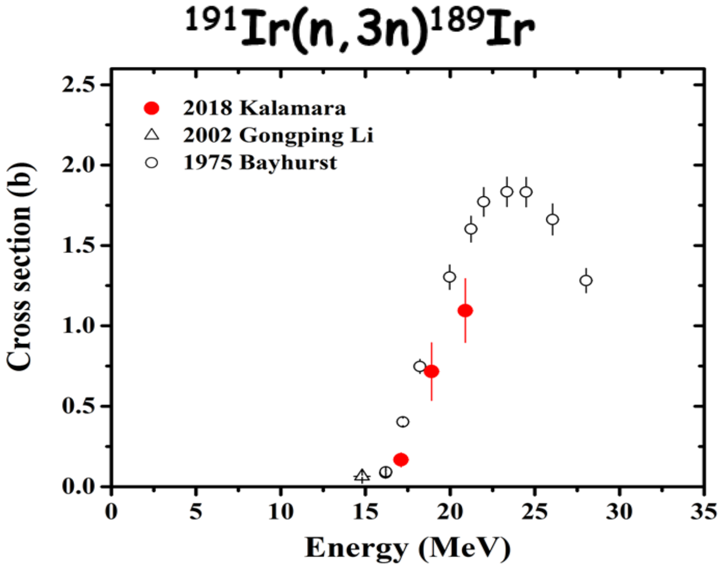


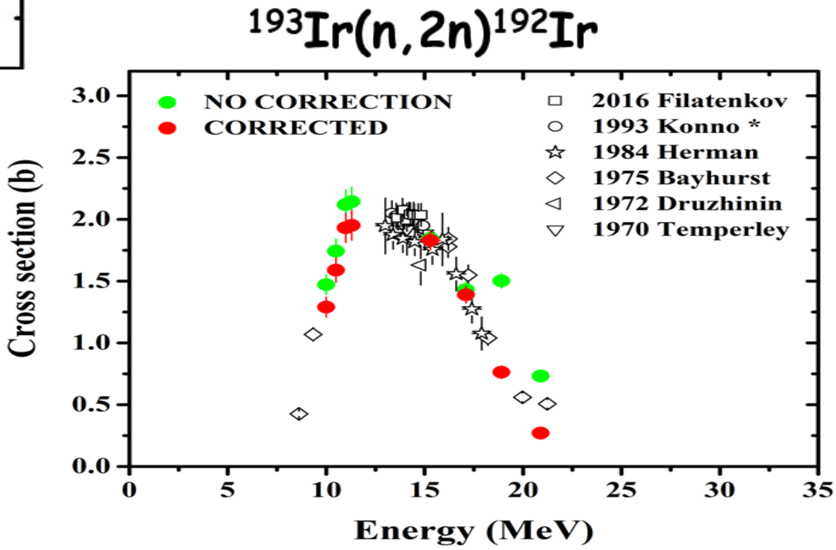
A.Tsinganis et al., Phys.Rev.C83 (2010)024609, R.Vlastou et al., Phys. Procedia 66(2015)425
A.Kalamara et al., EPJ Web of Conf. 146(2017)11013, A.Kalamara et al., Phys.Rev.C97(2018)034615

The $^{191}Ir(n,2n)^{190}Ir^{g+m1}$, $^{190}Ir^{m2}$, $^{191}Ir(n,3n)^{189}Ir$ and $^{193}Ir(n,2n)^{192}Ir$ case









After corrections due to contribution from $^{191}Ir(n,\gamma)^{192}Ir$

N. Patronis et al., Phys. Rev. C75 (2007), 034607

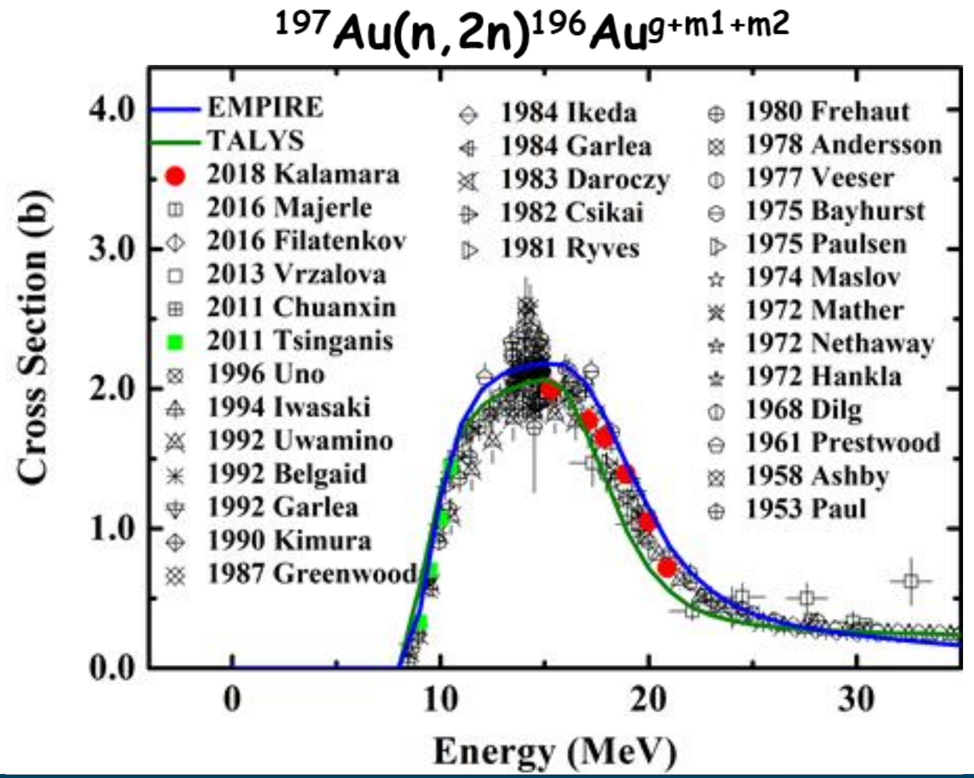
R. Vlastou et al., EPJ Web of Conf. 146(2017)11013

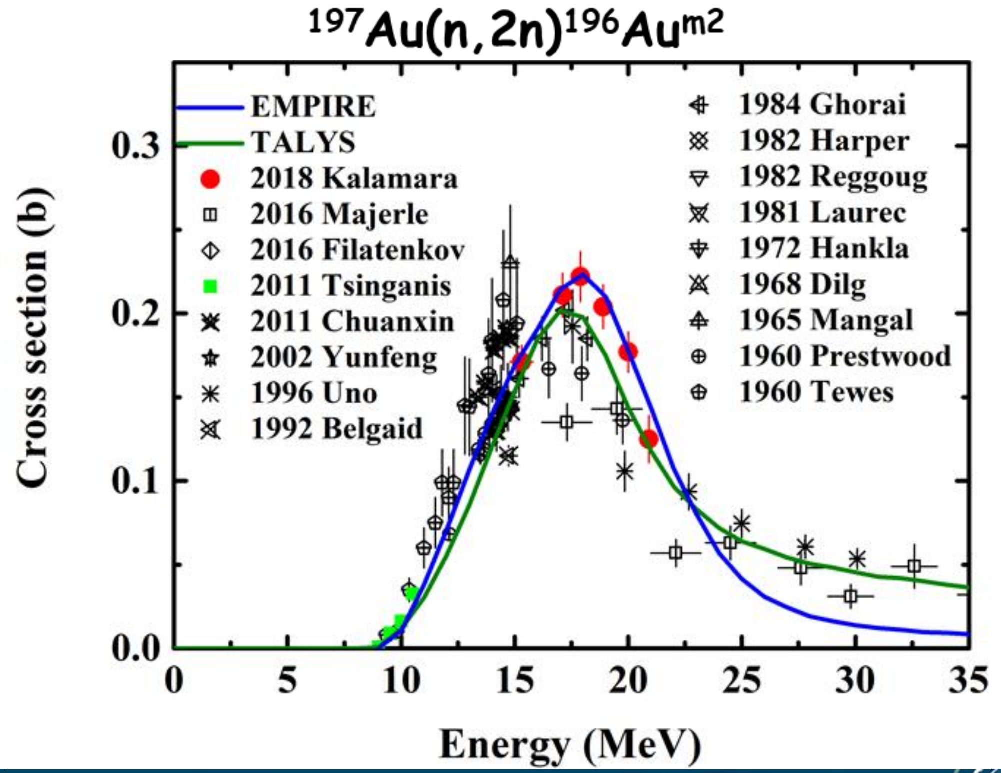
A. Kalamara et al., Phys. Rev. C 98, 034607 (2018)

A. Kalamara et al., Eur. Phys. J. A, 55: 187 (2019)

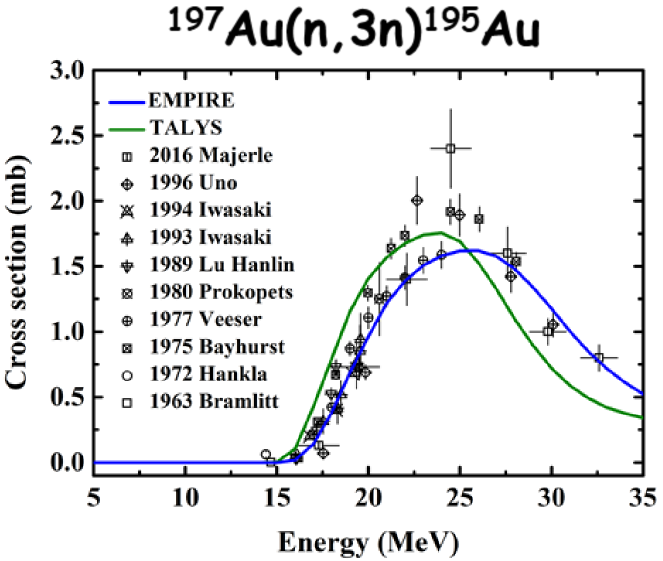
Theoretical Calculations

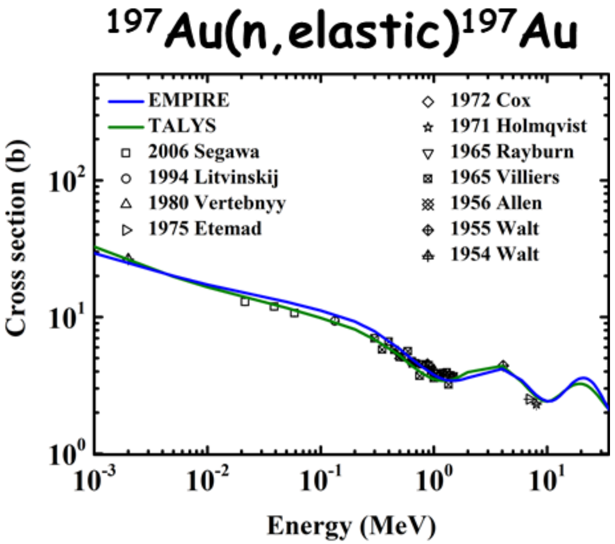
The simultaneous reproduction of the isomeric cross section along with other channels sets a significant constraint, rendering theoretical calculations quite sensitive to the choice of specific nuclear model parameters. Theoretical calculations using EMPIRE 3.2.2 and TALYS 1.8 codes revealed that **same sets of parameters** were able to reproduce very well all measured cross sections populating both ground and metastable states of Au and Ir as well as all other reactions available in literature



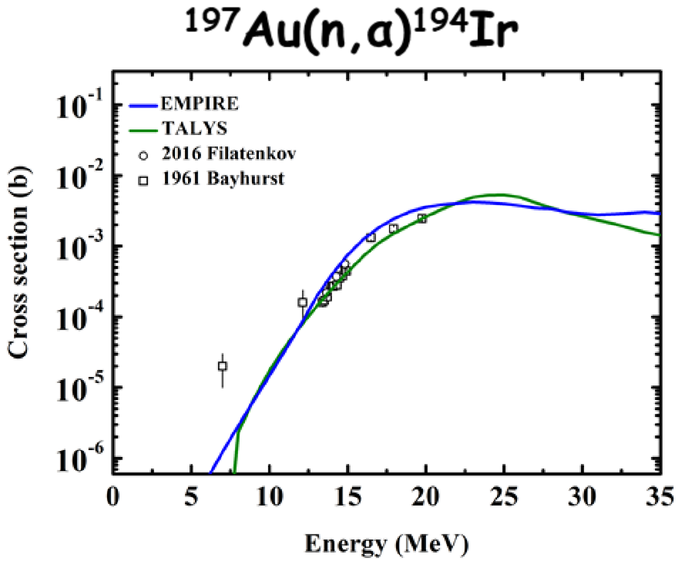


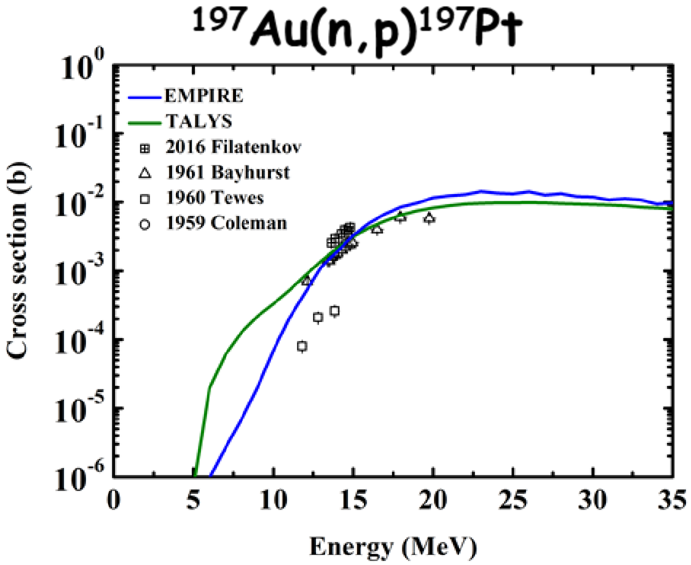
Theoretical Calculations

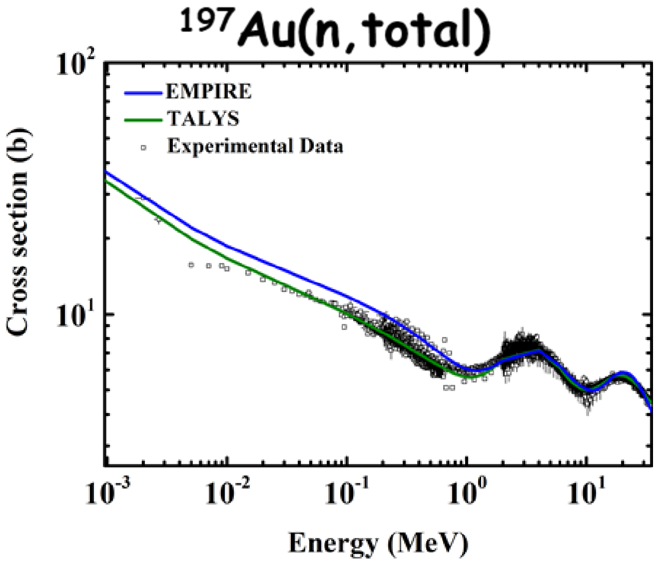




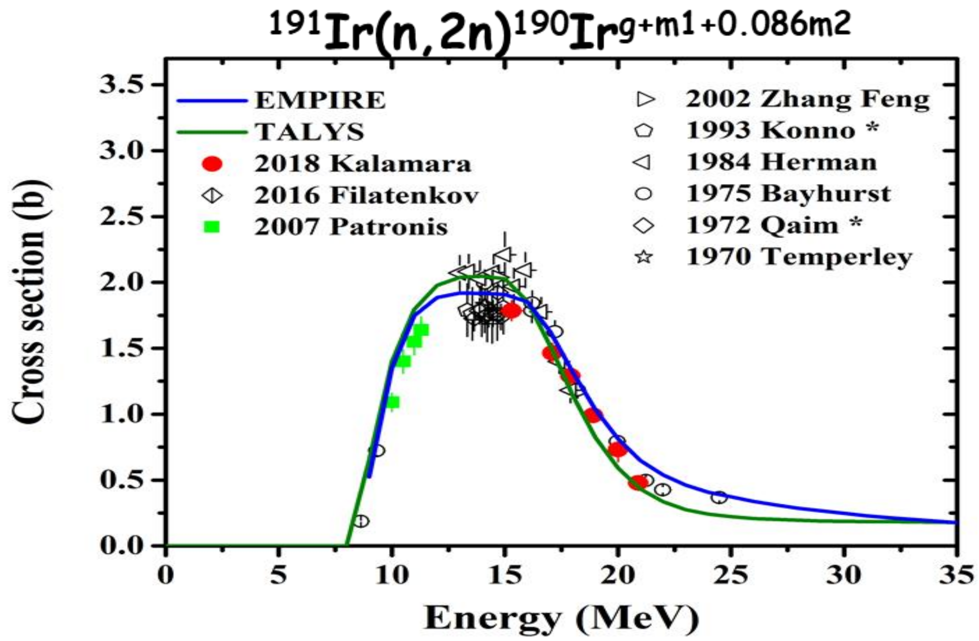
EMPIRE : EGSM for Level Density model
O.M. by Wilmore et al.
TALYS : GSM for Level Density model
O.M. by A. Koning and J. Delaroche
Encouraging confirmation of how successfully the theoretical models can reproduce the experimental results in this mass region.

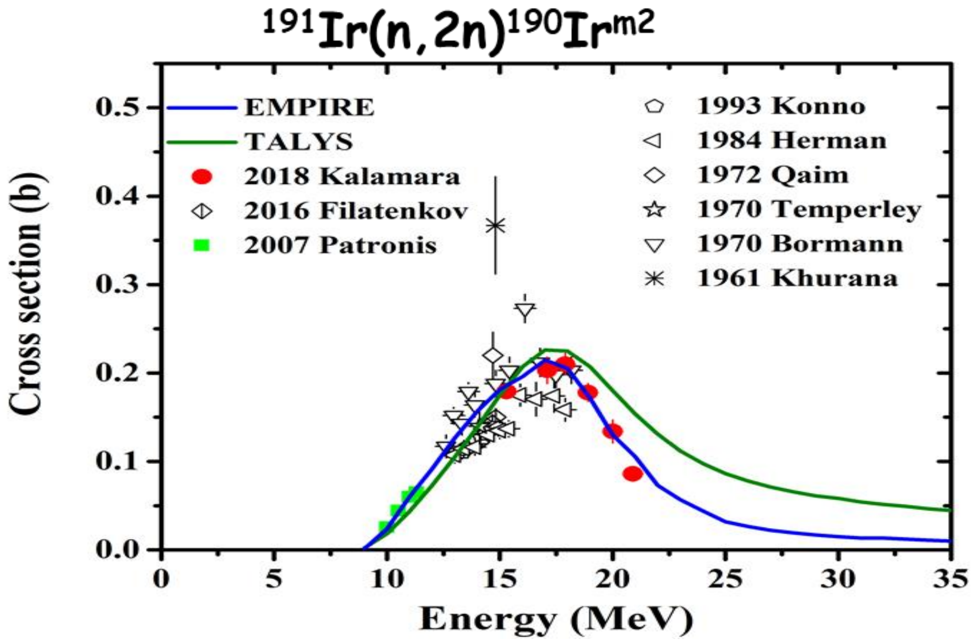


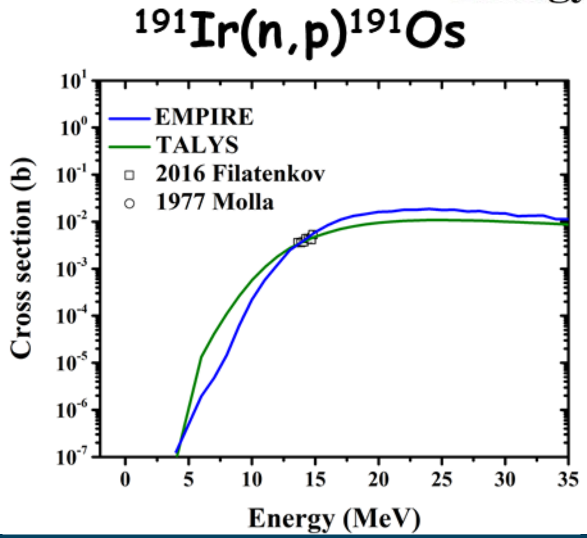


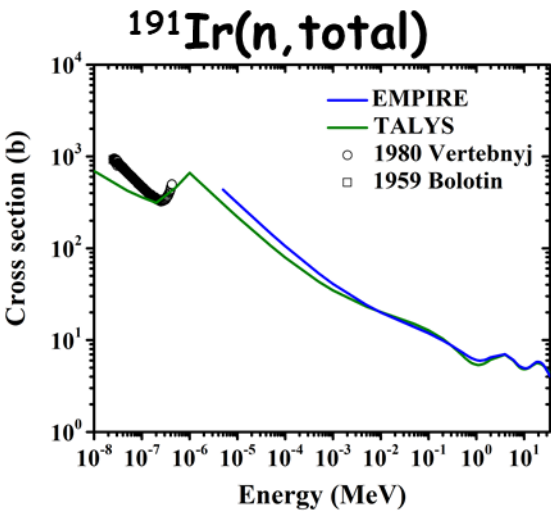


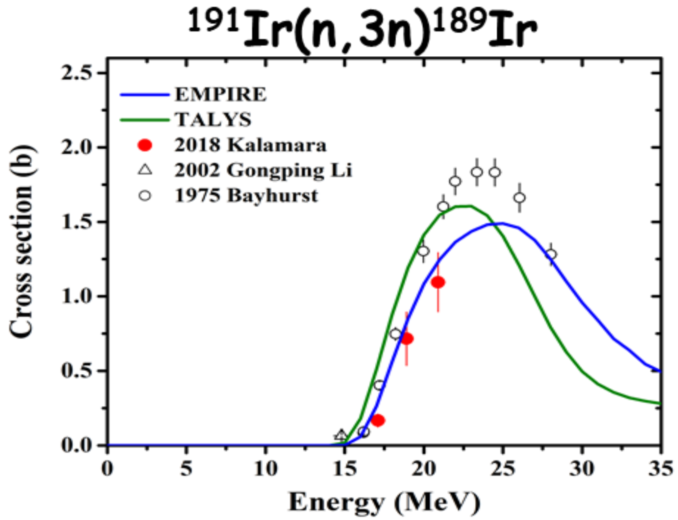
Theoretical Calculations



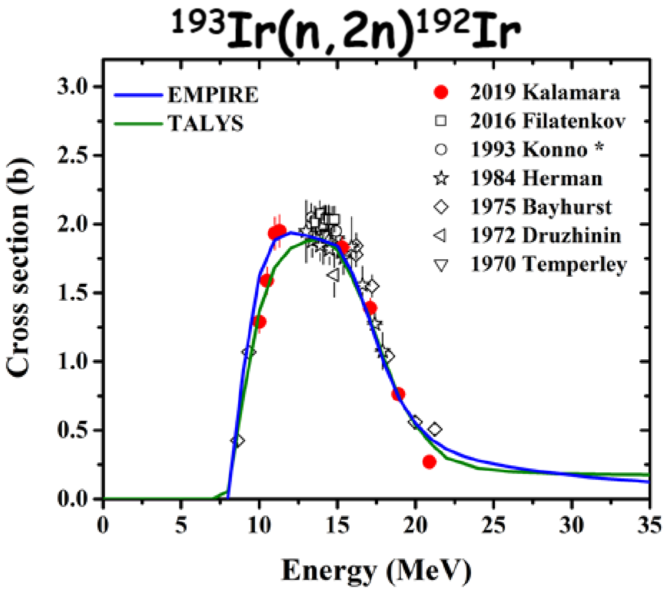


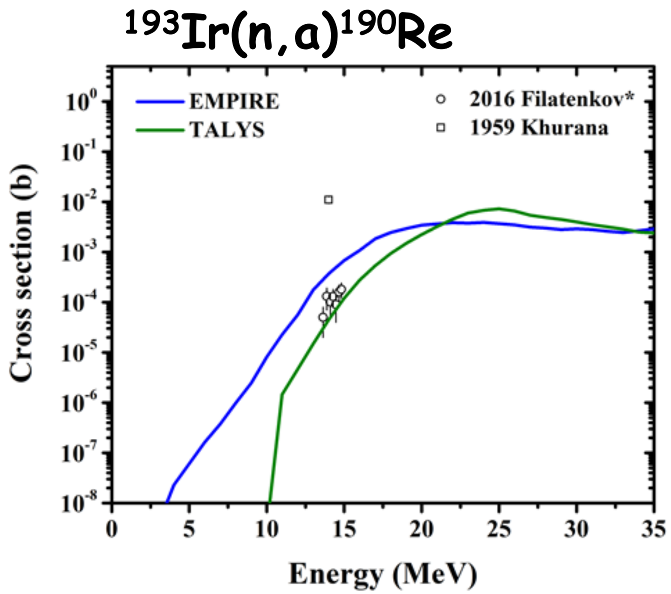


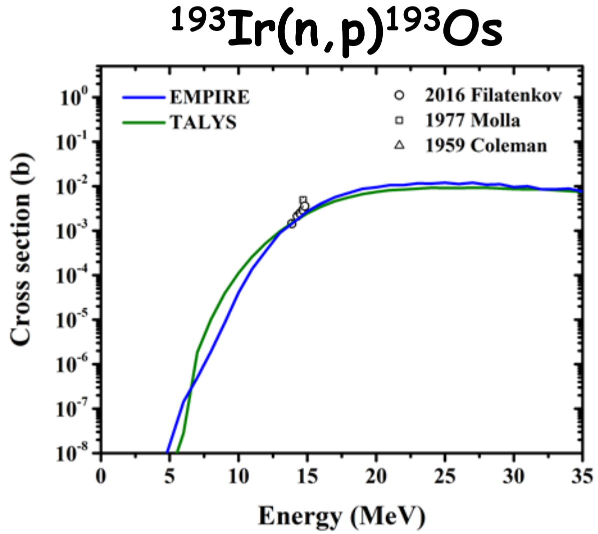


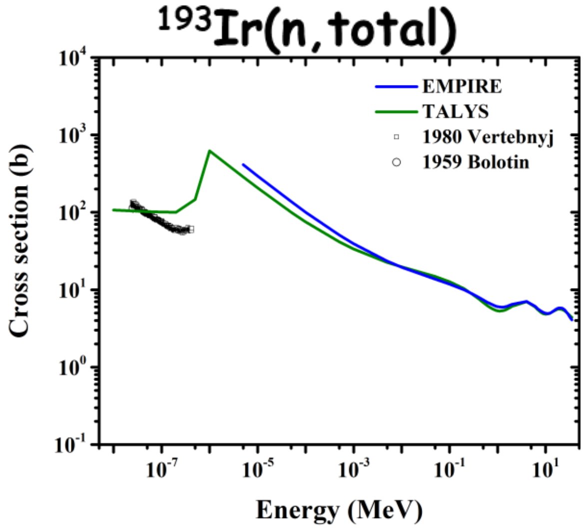


Theoretical Calculations









These similarities in the theoretical parametrization are not that surprising since both Au and Ir nuclei belong in the transitional region from well deformed to spherical nuclei near the Z = 82 shell closure (Os–Pb region), where high spin intruder configurations result in high spin isomeric states unable to communicate with neighboring states

Collaborators : M.Kokkoris, M.Diakaki, N.Patronis, A.Tsinganis, S.Harissopulos, A.Lagoyannis, M.Axiotis, P.Demetriou, M.Serris

PhD Students: V.Michalopoulou, A.Kalamara, A.Stamatopoulos, S.Chasapoglou, Z.Eleme, E.Georgali

Many MSc and Diploma Students

Importance of Accelerator based neutron sources in

Education and training of young scientists !!!

Thank you

Acknowledgements

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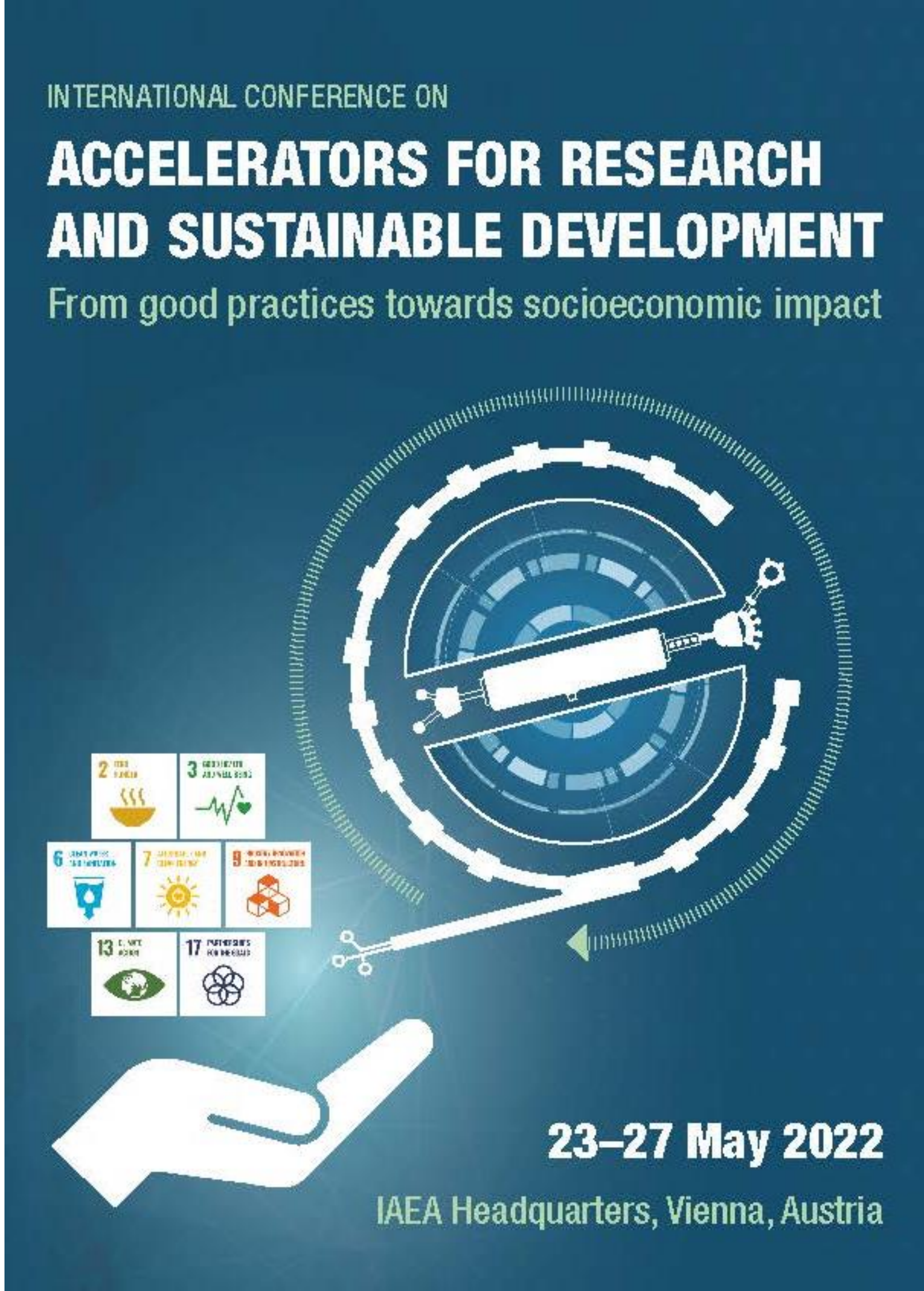

Back-up slides