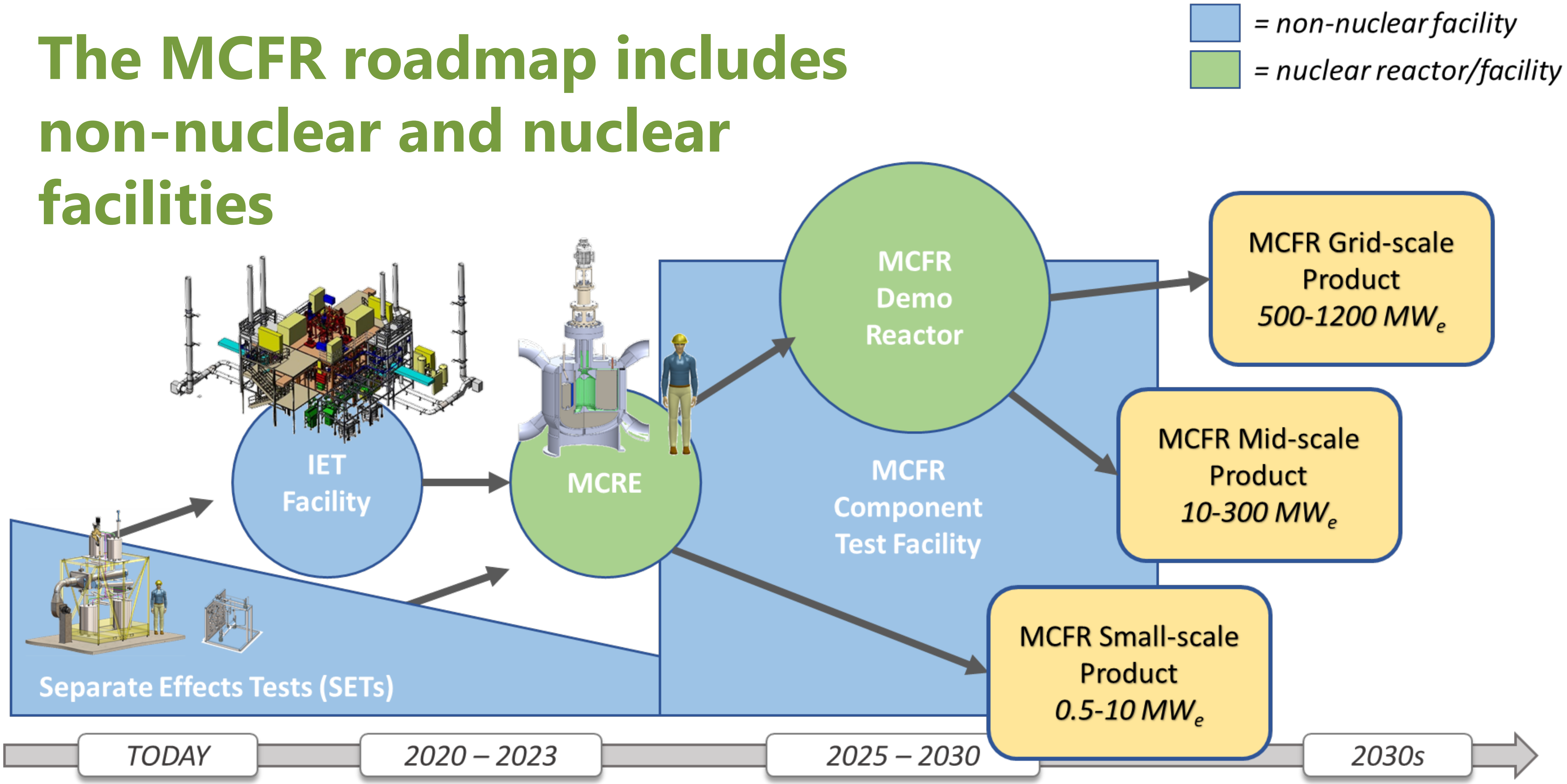
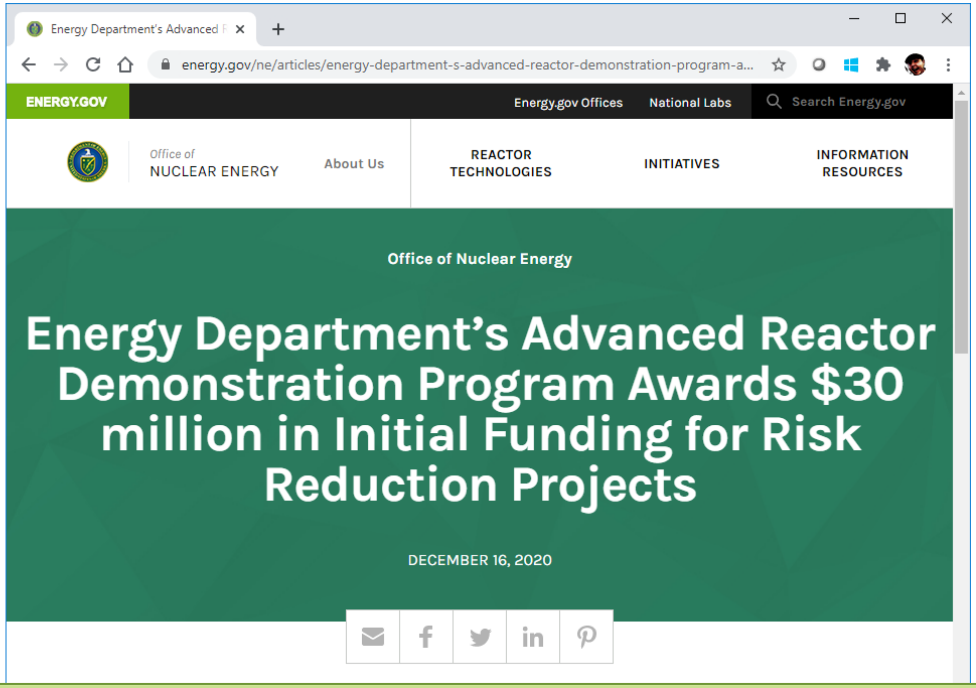
Molten Chloride Reactor Experiment Nuclear Data Uncertainty Analysis and Needs

Tommy Cisneros

The MCFR roadmap includes non-nuclear and nuclear facilities

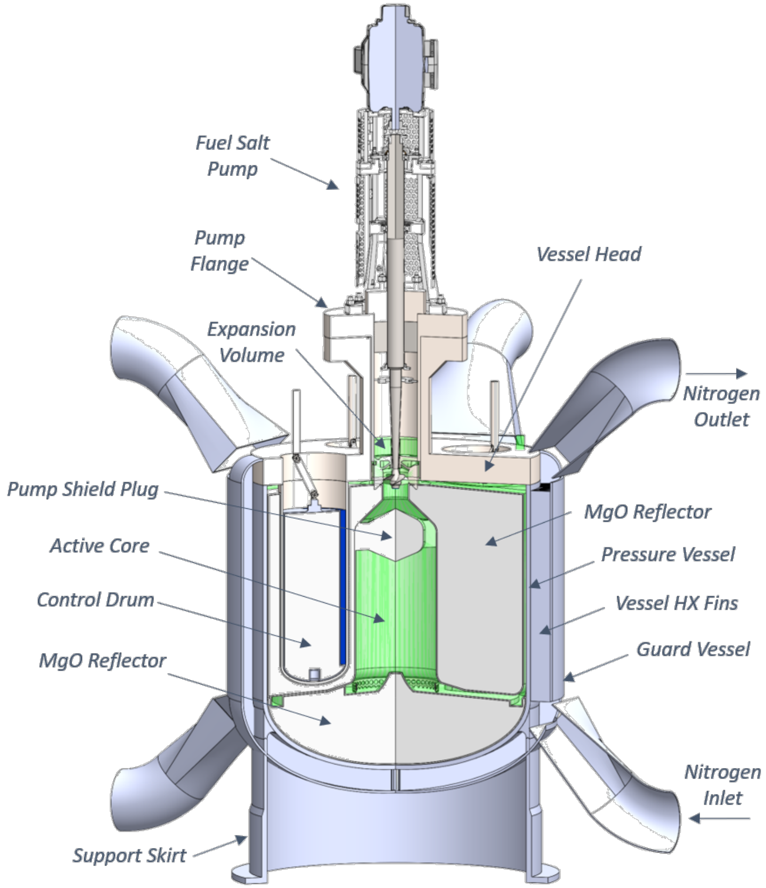


Molten Chloride Reactor Experiment (MCRE)



Molten Chloride Reactor Experiment – Southern Company Services, Inc (Birmingham, AL) will lead a project to design, construct and operate the Molten Chloride Reactor Experiment (MCRE) – the world's first critical fast-spectrum salt reactor relevant to TerraPower's Molten Chloride Fast Reactor.

[1] Energy Department (2020)



Nuclear Data Uncertainty is Important to MCRE Design

- Excess reactivity mitigates ND uncertainty
- Control worth mitigates ND uncertainty
- Uncertainty Covariance Data defines which benchmarks are representative to the MCRE

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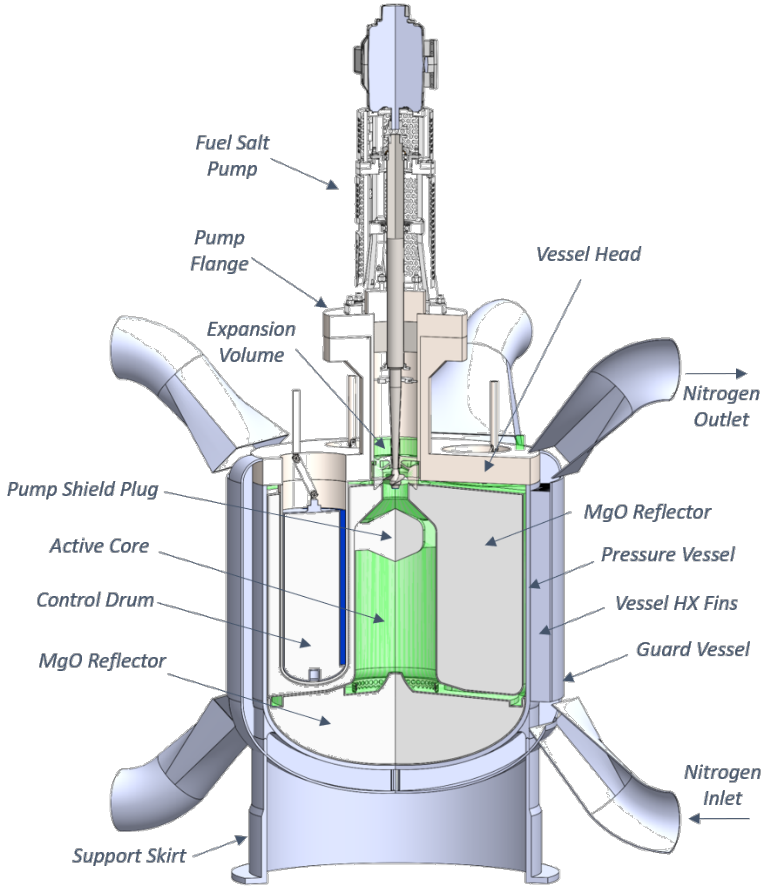
MCRE Will Demonstrate Novel Neutronic Features

- Liquid Chloride Fuel Salt
  - Moving Fuel Salt
  - Chlorine in high importance region of the system
- Magnesium Oxide Reflector
  - Scattering on MgO reflects neutrons and moderates fast neutrons
- Plutonium Fuel
  - No Uranium in Fuel Salt Mix



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Nuclear Data Uncertainty

- To quantify nuclear data induced uncertainties of a design, covariance matrices may be convoluted with the sensitivity vectors via the "sandwich formula" to produce the desired uncertainty of integral parameters R.

$$\Delta R^2 = S_R^T D S_R$$

S_R Sensitivity of Integral Parameter R

D Covariance Matrix

[2] Salvatores (2008)

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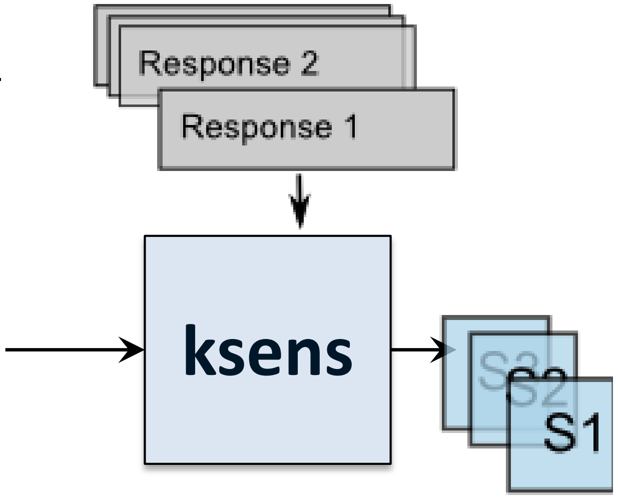
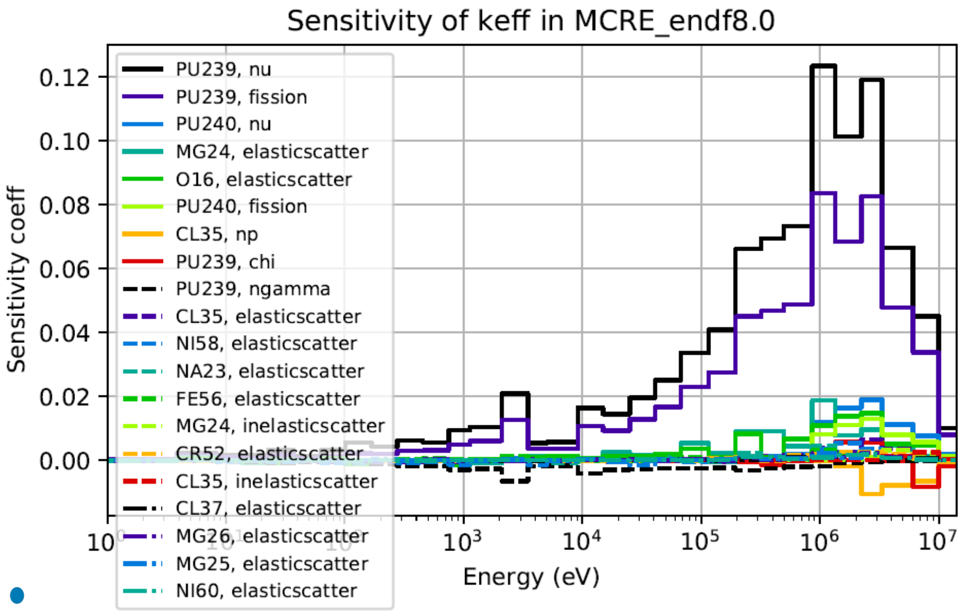
Sensitivity is Calculated with MCNP6 and ARMI® software





ADVANCED REACTOR MODELING INTERFACE

[3] Touran (2016)

[4] Kiedrowski (2013)

[5] Cheatham (2013)

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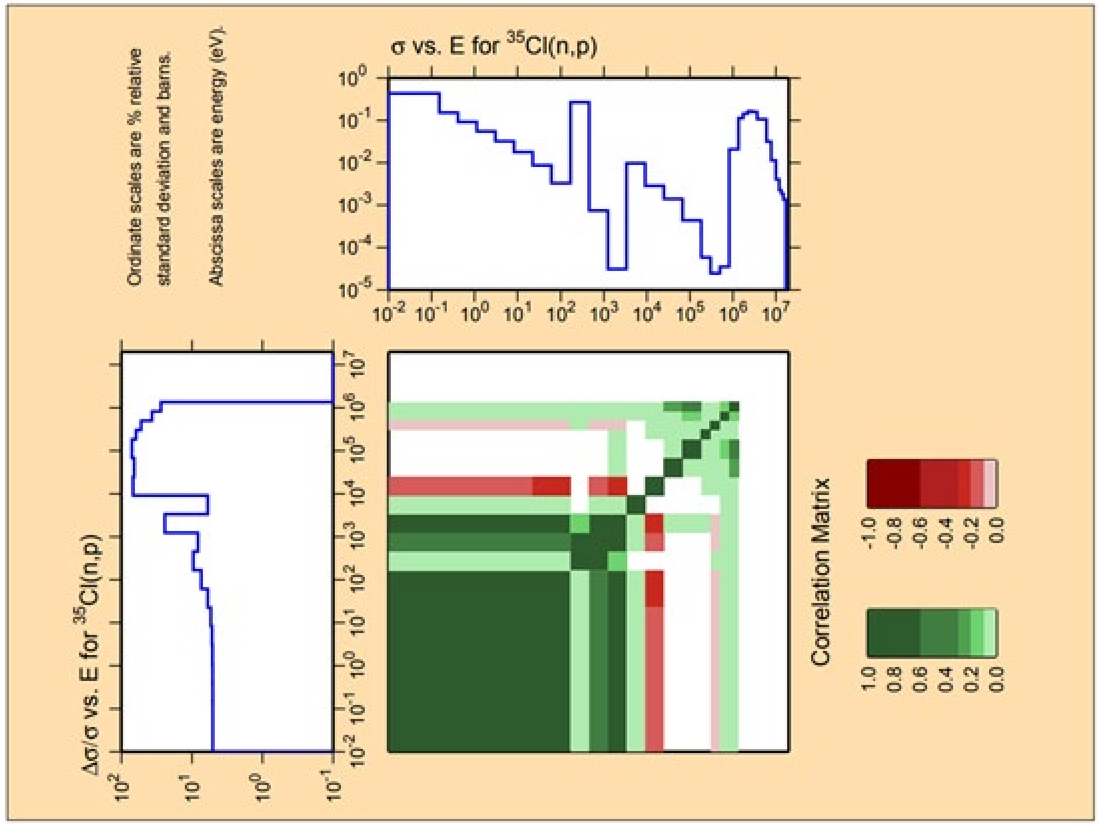
ENDF/B VIII.0 Covariance Data Processed with NJOY

Fissionable Isotopes: nu, (n, fission), (n, gamma), (n, 2n), elastic scattering, inelastic scattering, chi

Non Fissionable Isotopes: (n,gamma), elastic scattering, inelastic scattering, (n,proton)*



*35Cl (n,p) reaction is an important neutron loss mechanism in chloride salt systems

njoy

[6] Macfarlane (2017)

[7] Brown (2018)

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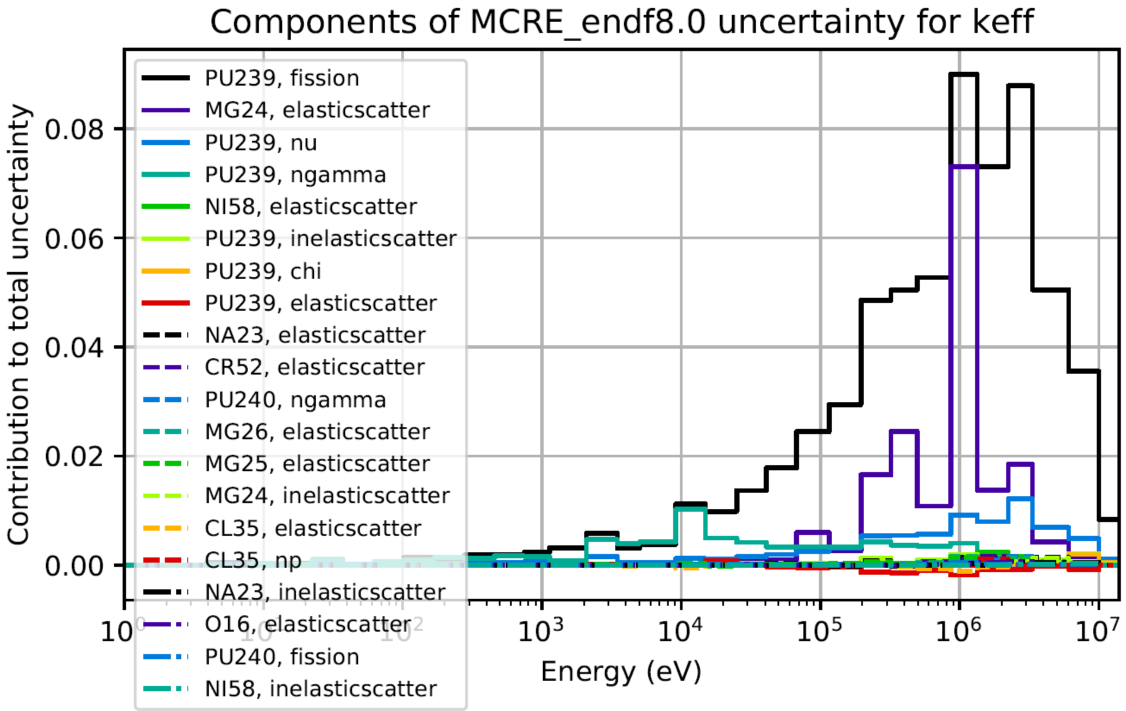
^{239}Pu Drives the known ND Uncertainty: ~900 pcm

Nuclide	Reaction	Uncertainty (pcm)
^{239}Pu	Fission	721
^{24}Mg	Elastic Scat	378
^{239}Pu	Nu	251
^{239}Pu	(n,γ)	241
^{239}Pu	Inelastic Scat	85
^{23}Na	Elastic Scat	75
^{58}Ni	Elastic Scat	68
…	…	…
Total		**908**



ADVANCED REACTOR MODELING INTERFACE

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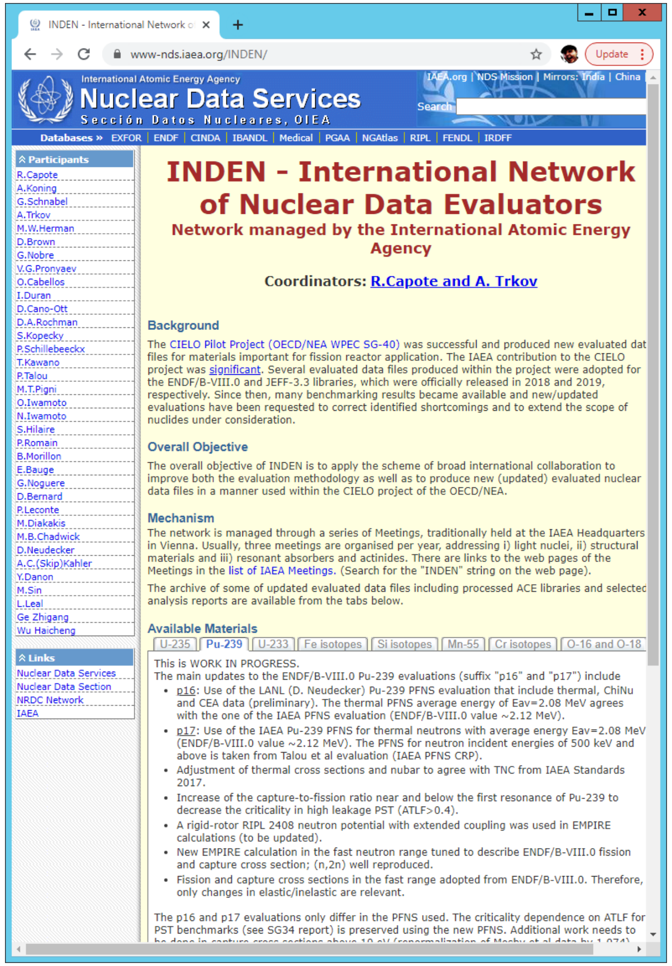
INDEN Project is Advancing Nuclear Data of Many Uncertainty Drivers for the MCRE

INDEN is the follow up to the CIELO Pilot Project that produced several evaluated data files adopted by ENDF/B-VIII.0 and

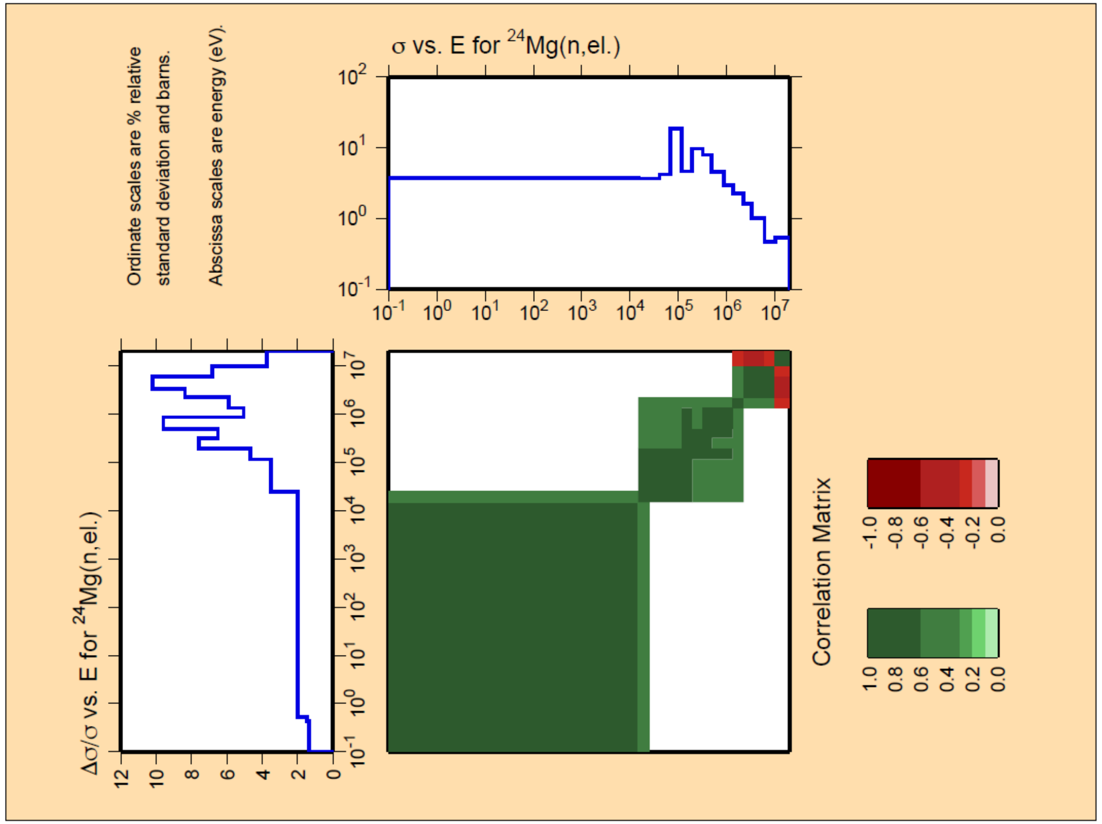
- **INDEN (actinides): ^{239}Pu**
- INDEN (structural materials): ^{58}Ni
- INDEN (light elements): ^{16}O



[8] Capote (2020)

^{24}Mg (mt=2) May be an Opportunity to Reduce Uncertainty in the MCRE

- Given the limited attention, significant uncertainty and novel application – this analysis has highlighted ^{24}Mg as an opportunity for updates
  - ^{24}Mg data was ported from JENDL-3.2 (1995)
  - Covariance data was added from the lo-fidelity covariance project (2011)



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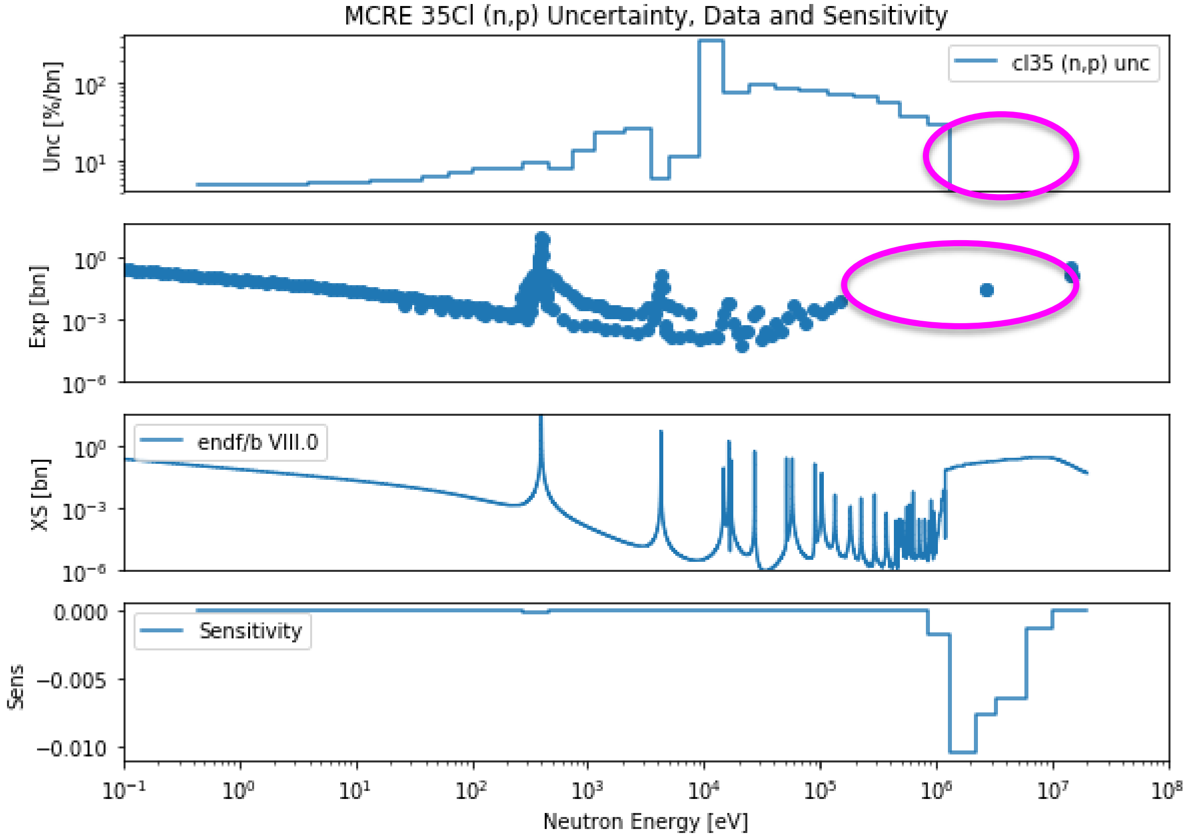
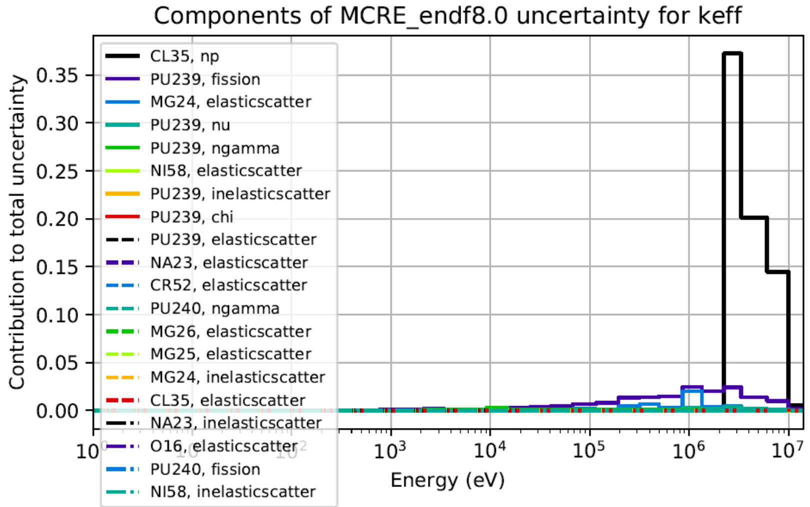
^{35}Cl (n,p) Gaps May Result in Uncertainty Biased Low



If you assume 100% cov >1.2MeV:

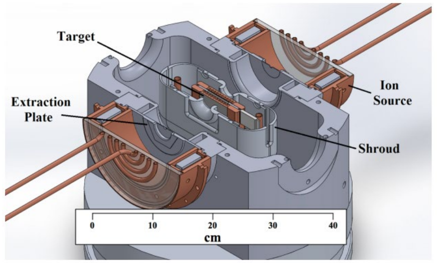
^{35}Cl (n,p) σ: 30 -> 1472 pcm

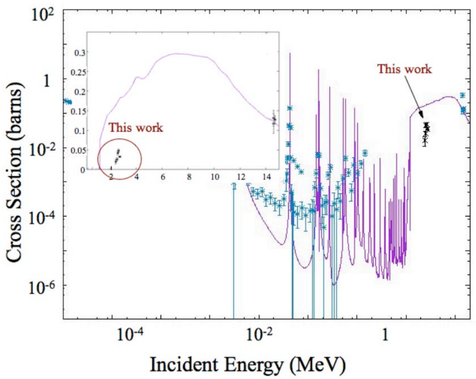
Total σ : 900 -> 1729 pcm

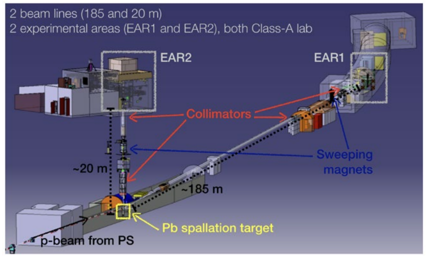


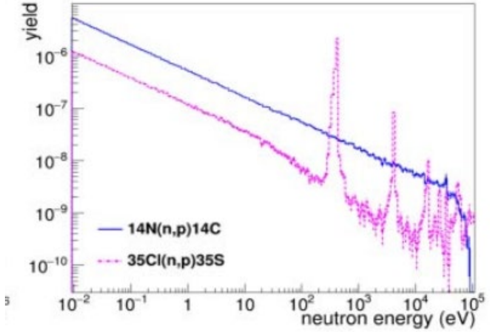
[9] Zerkin

Recent Nuclear Data Experiments for ^{35}Cl (n,p)









[10] Batchelder (2019)

[11] Praena (2017)

[12] Ogállar (2019)

Conclusions

- The MCRE Nuclear Data Uncertainty is 900 -1700 pcm
- The known MCRE Nuclear Data Uncertainty is driven by ^{239}Pu
- ^{35}Cl (n,p) reaction has been identified as a need for chloride MSRs
  - Total ND Uncertainty increases from 900-1700 if covariance is assumed above 1.2 MeV
  - The research community is collecting new experimental data
  - New data should be integrated into new evaluations for cross sections and uncertainty
- MCRE S/U highlighted ^{24}Mg scattering as an opportunity for advancement.
- Focus of INDEN aligns well with ^{239}Pu uncertainty in MCRE

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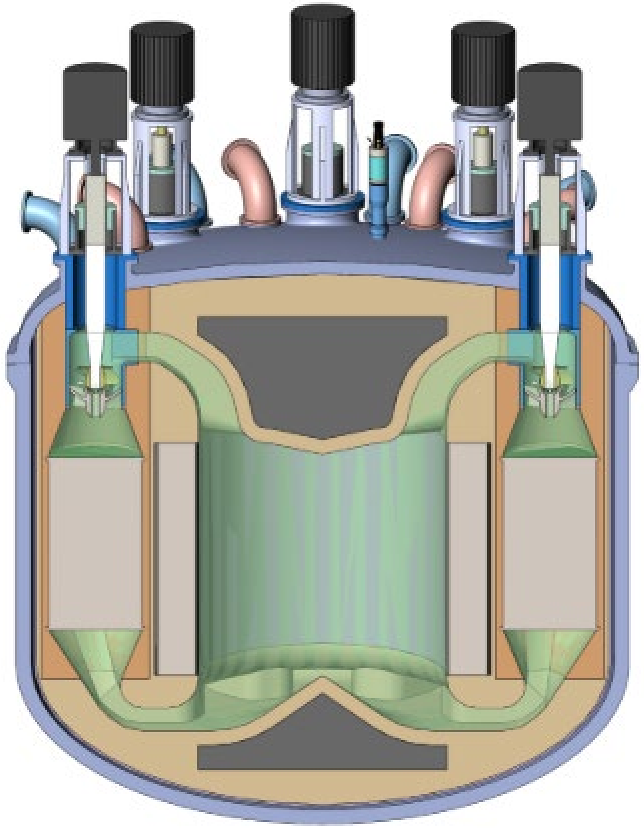
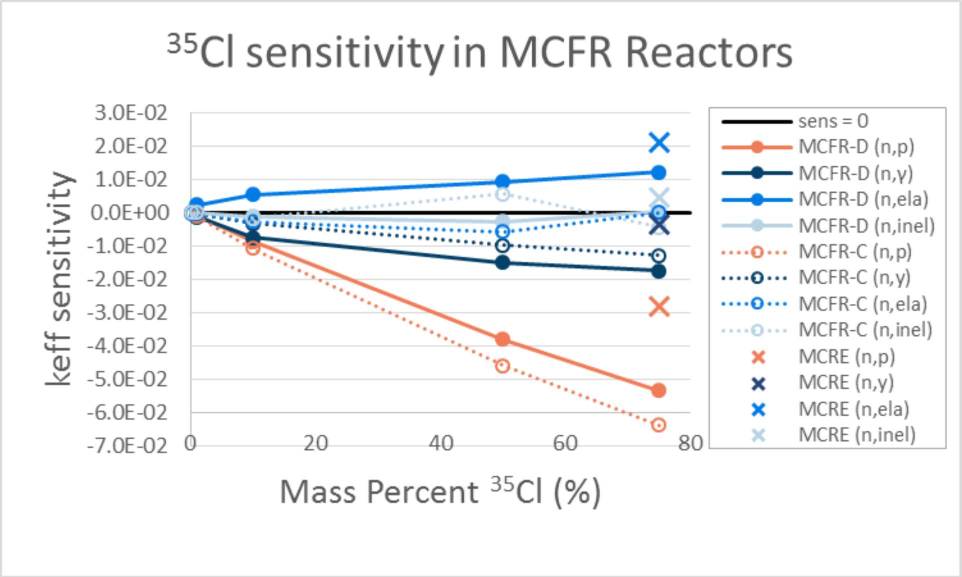
BACKUP

Commercial Power MCFR reactors are much more sensitive to ^{35}Cl



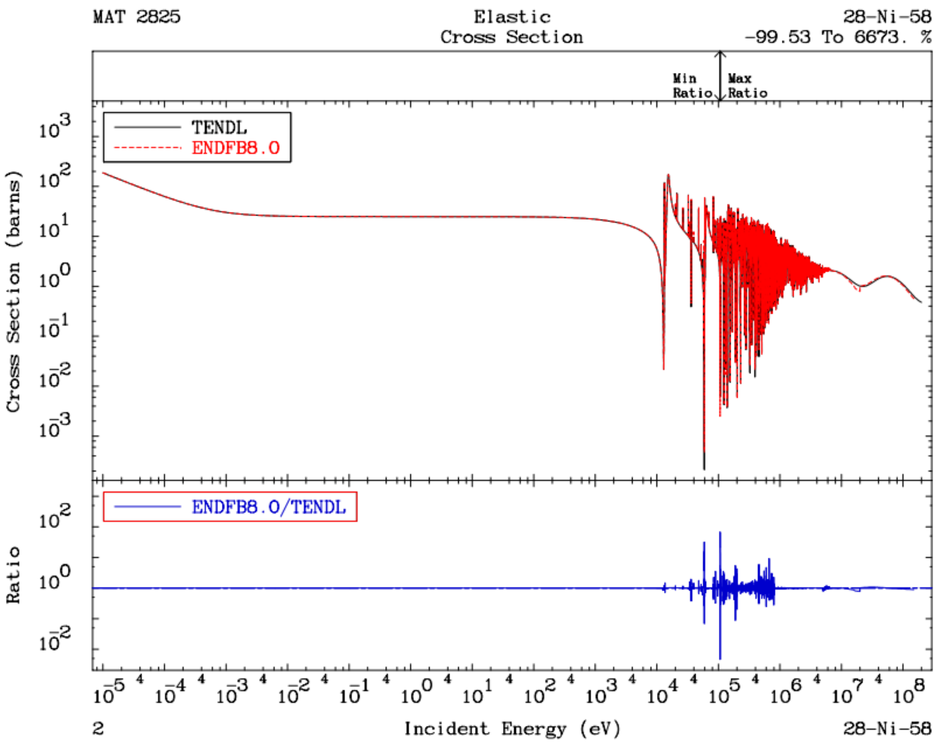
MCFR-C 500-1200 MWe



Negative reactivity of ^{35}Cl can be mitigated by chlorine enrichment or reducing leakage

PSI is updating Ni Evaluations in new releases of TENDL

Paul Scherrer Institute (PSI) is updating an evaluation of Ni as part of the INDEN (Structural Materials) effort.



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