Sensitivity to Chlorine Nuclear Data in Molten Chloride Fast Reactors

2nd Technical Meeting on Nuclear Databases for Nuclear Reactor Applications
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Outline

1. Company introduction
2. SSR-W reactor / WATSS recycling process
3. Current status of chlorine nuclear data
4. Sensitivity to chlorine nuclear data and resulting uncertainty
5. Discussion

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1. Company introduction

2014

- Company founded and master patent granted

2018

- Established office in Saint John, New Brunswick
  - Opportunity to build first reactor with NB Power at Point Lepreau
  - Supportive environment: regulations, federal and provincial policies
  - Other potential customers

1. Company introduction

2014	• Company founded and master patent granted
2018	• Established office in Saint John, New Brunswick
2019-2022	• Expanded team to focus on design, R&D, supply chain and stakeholder engagement • Major investments from established nuclear companies; first nuclear crowdfunding • Received ~U$40M from Canadian gov't; ~U$800K from Ontario Power Generation • Completed Canadian Nuclear Safety Commission Vendor Design Review Phase 1 • Formed strategic partnership with SNC-Lavalin and IDOM

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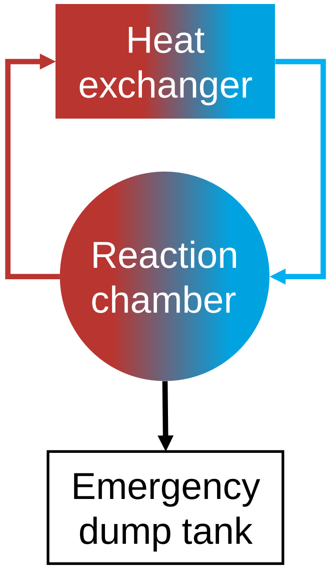
WATSS
(WAste To Stable Salt)
A facility in which nuclear waste is recycled to produce fuel suitable for a fast reactor.
GridReserve
A series of tanks used to store thermal energy from the reactor and dispatch it to the grid when needed.
SSR-W
(Stable Salt Reactor - Wasteburner)
A fast reactor that uses recycled nuclear waste as fuel.

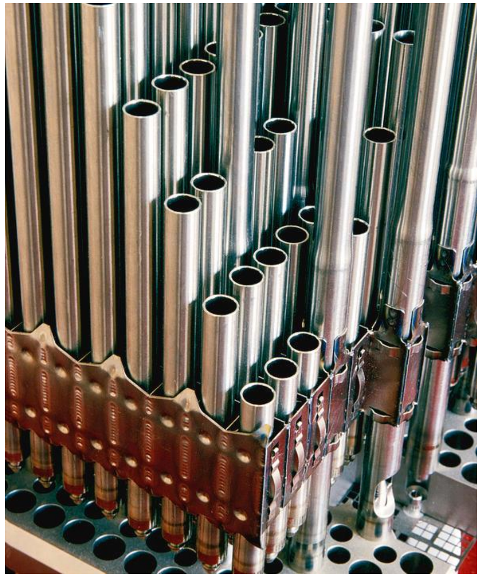
2. SSR-W reactor / WATSS recycling process

Conventional MSRs



- **Intensely radioactive fuel salt pumped at pressure round an engineered system which can never be approached by a human being**

Stable Salt Reactor platform

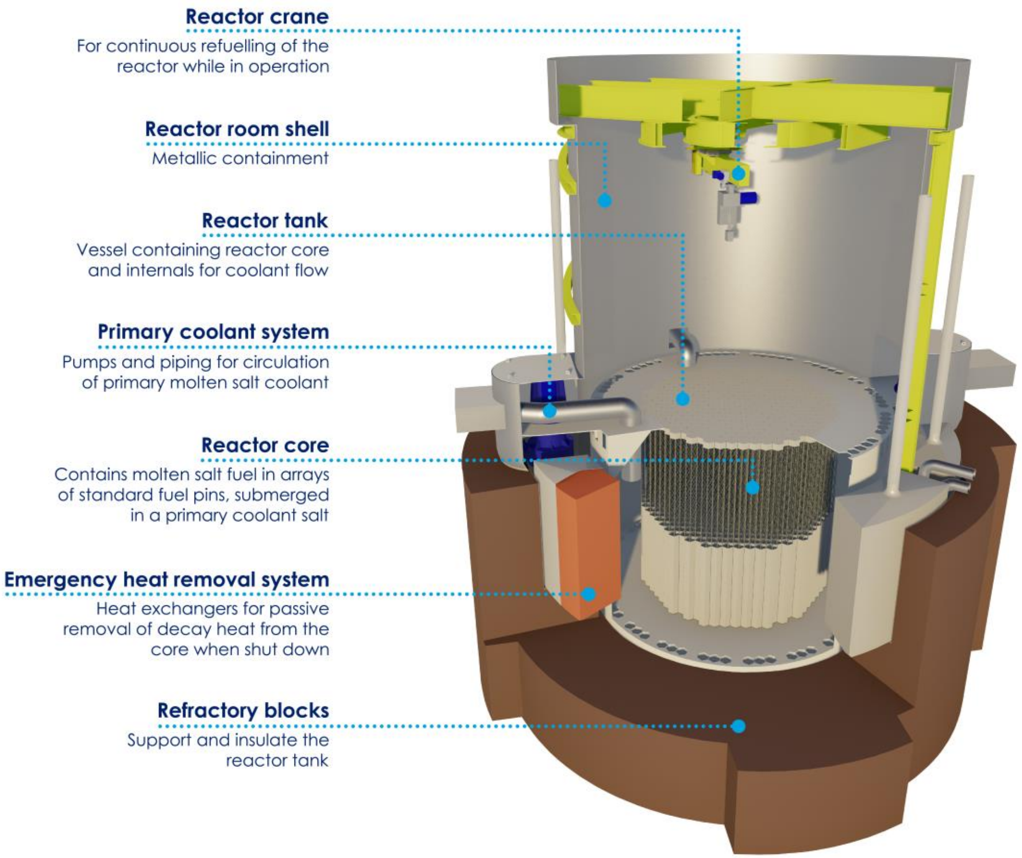


- **Fuel salt placed in fuel assemblies**
- **New concept, patent now granted worldwide**

2. SSR-W reactor / WATSS recycling process

Reactor overview – SSR-W

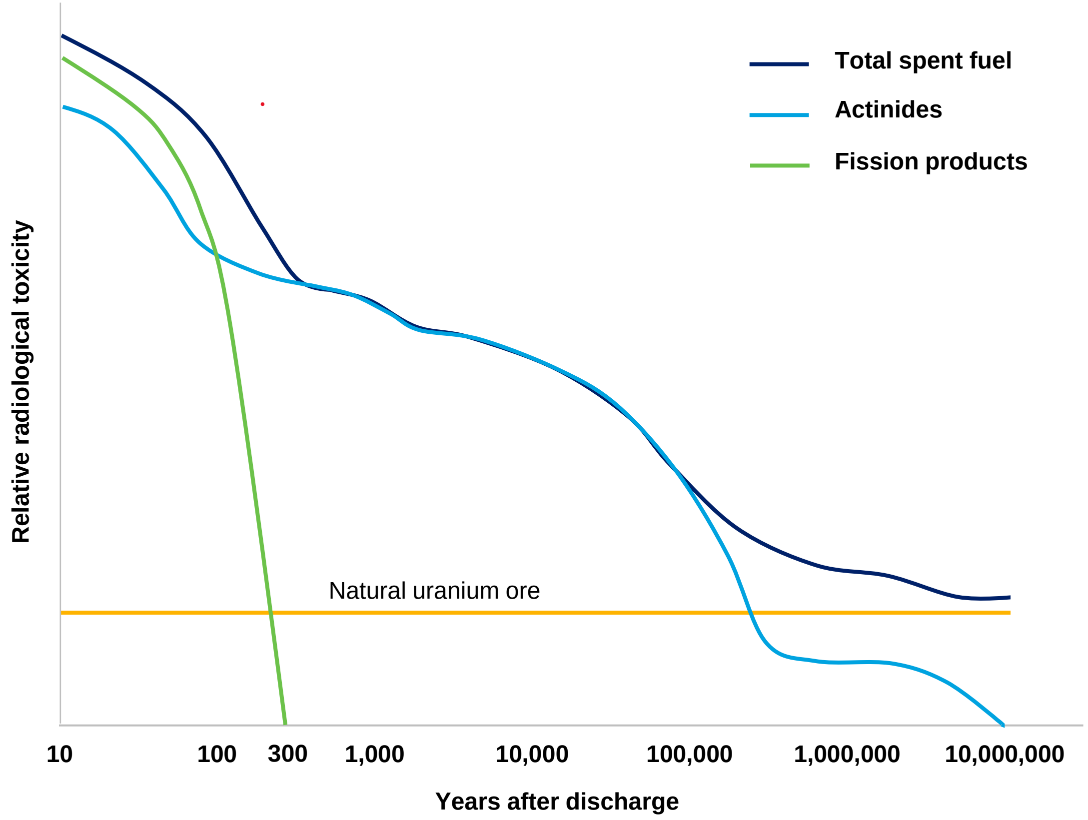
- High temperature, molten salt reactor
- 300-500 MWe per unit
- Uses recycled nuclear waste as fuel without removal of transuranics
- Can produce grid-scale power and high-temperature heat – to produce hydrogen for low-carbon fuels to decarbonize transport and industry
- Small land footprint (20 acres for reactor and all ancillary buildings)



2. SSR-W reactor / WATSS recycling process

Fuel and waste strategy

- SSR-W primarily fueled by transuranic elements (everything above uranium) from CANDU or other LWR oxide fuel
- Significant liability savings possible depending on final waste configuration and disposal strategy
- Because SSR-W can tolerate impurities, recycling process is simpler, less expensive
- Pyroprocessing, exclusively based on chemical redox potential



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3. Current status of chlorine nuclear data

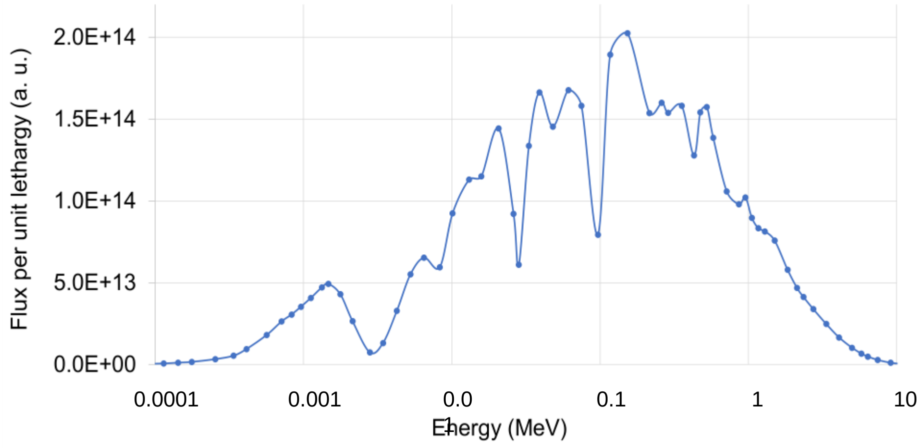
Chloride salts

- Molten salt reactors often assume fluoride salts (MSRE experience)

- Advantages for fast systems in using chlorides, due to the harder spectrum:

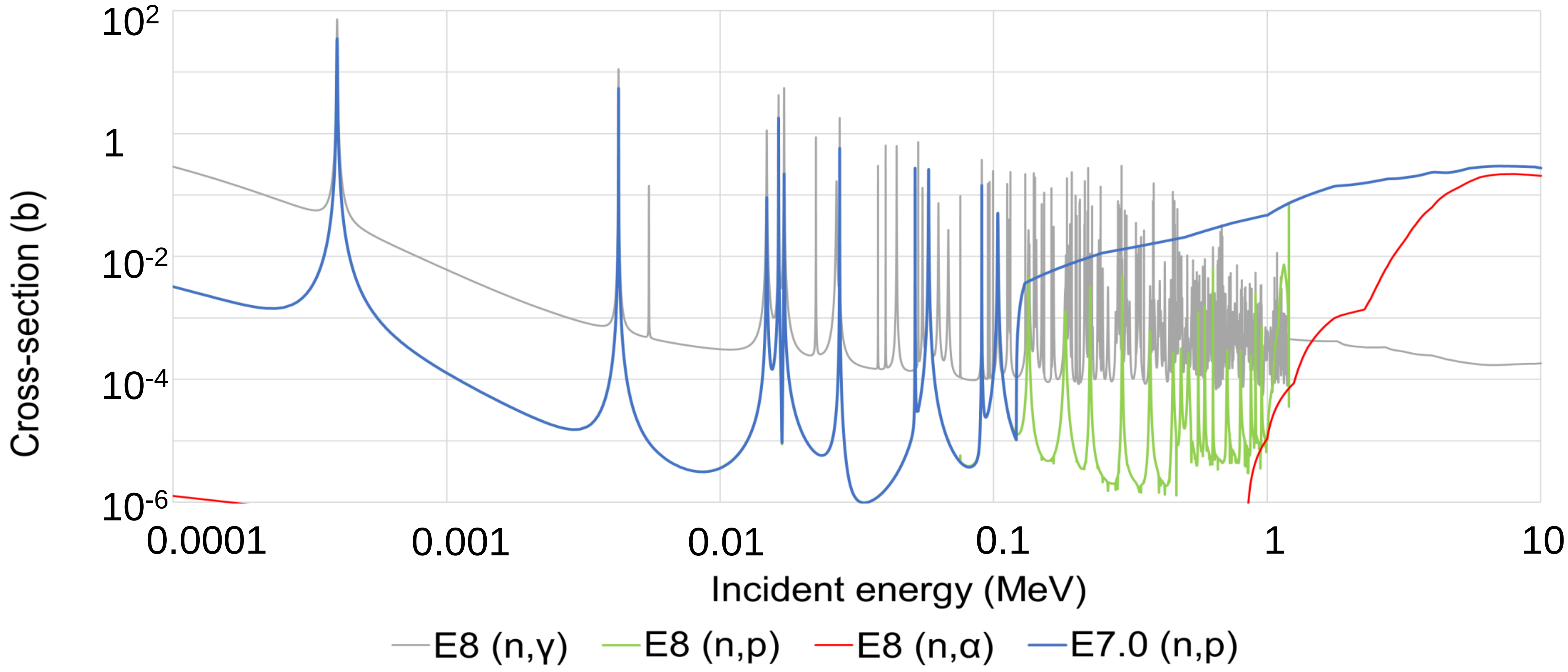
    - Better actinide burning

    - Better U-Pu fuel cycle performance



3. Current status of chlorine nuclear data

Cl-35 cross sections



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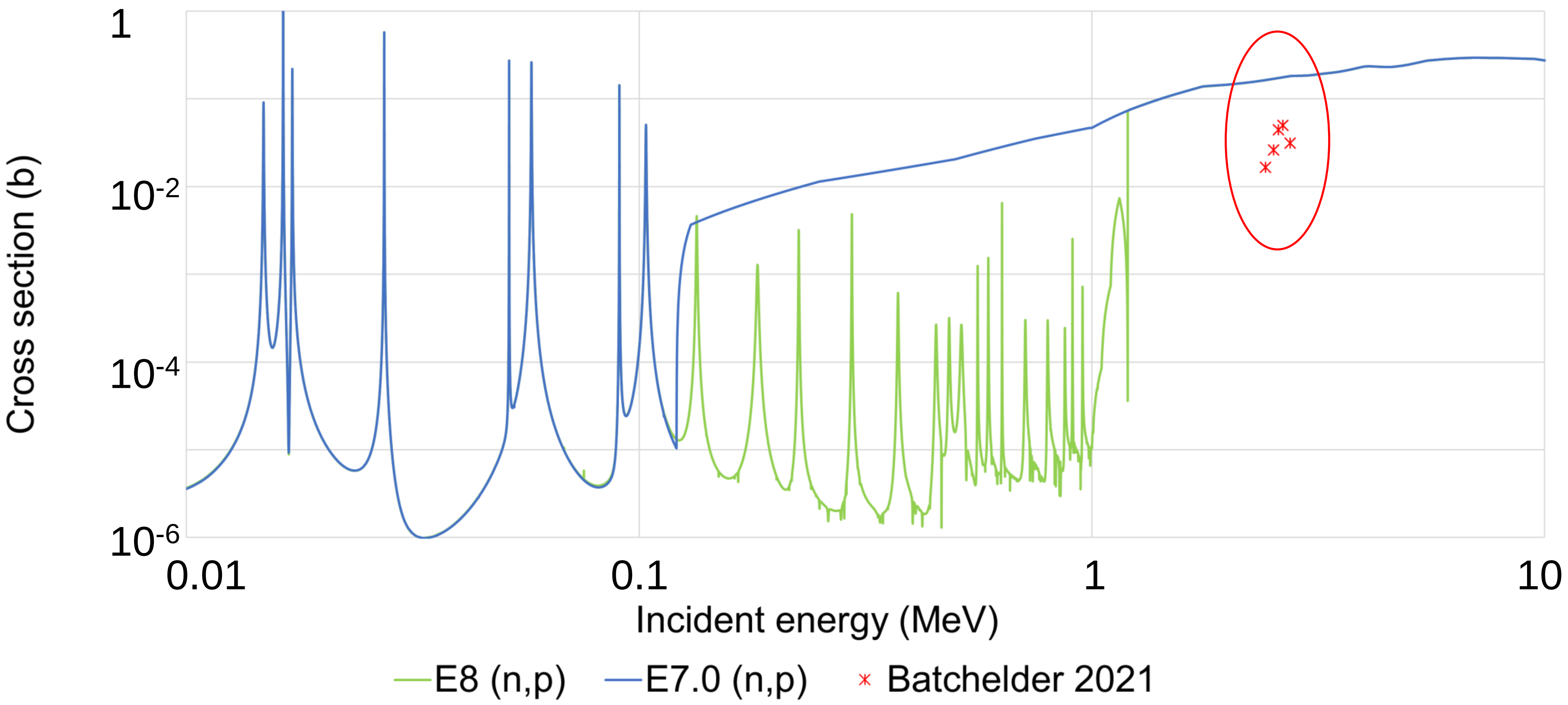
Cl-35 cross sections



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4. Sensitivity to Cl nuclear data and resulting uncertainty

- Sensitivity of SSR-W to recent changes in Cl-35 nuclear data can be demonstrated by a simple calculation of *k*-eff using different data libraries:

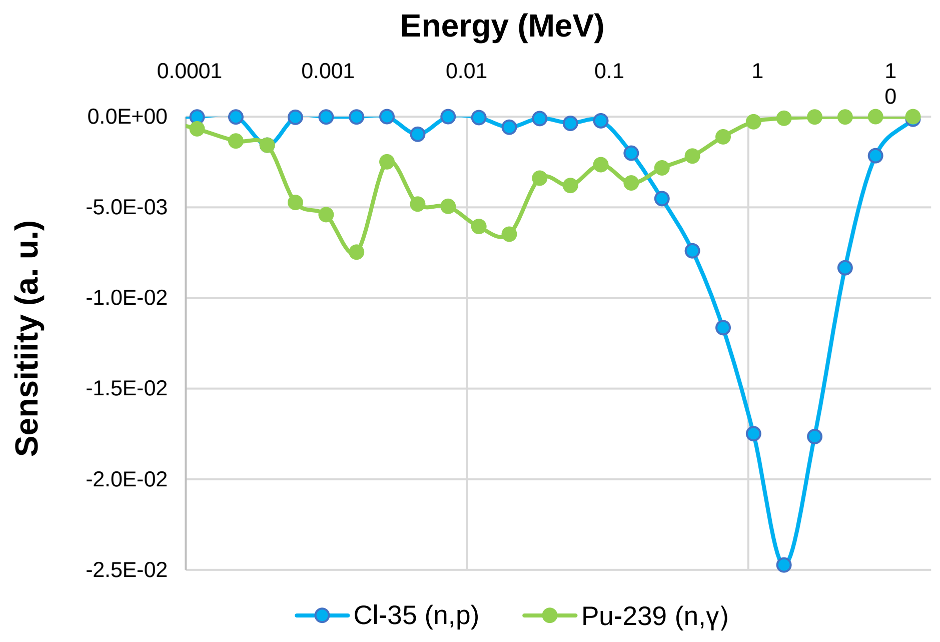
	ENDF/B-VII.0		ENDF/B-VIII.0	
	k-eff	Diff (pcm)	*k*-eff	Diff (pcm)
All nuclides	1.0086	-	1.0476	3901
Only Cl-35	1.0086	-	1.0484	3981

4. Sensitivity to Cl nuclear data and resulting uncertainty

- In general, sensitivity coefficient can be calculated for an integral parameter, *R*, due to variation of a cross section:

$$S_R = \frac{\partial R}{\partial \sigma} \times \frac{\sigma}{R}$$

- Code PERSENT used to do this for SSR-W core, using ENDF/B-VII.0 data



4. Sensitivity to Cl nuclear data and resulting uncertainty

- Given sensitivity coefficients and appropriate covariance data uncertainties can be estimated using well-known sandwich rule:

$$\Delta \mathrm{R}^2 = S_R^+ D S_R$$

- However, covariance data in the ENDF/B libraries is incomplete – and where uncertainties are available, they do not appear consistent with recent measurements for Cl-35
- Total uncertainty due to nuclear data (excluding Cl-35 contribution) in k-eff is estimated to be **630 pcm**, using **ENDF/B-VII.0** – using **TENDL-2021**, accounting for Cl, gives a total uncertainty of around **1000 pcm**.

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4. Sensitivity to Cl nuclear data and resulting uncertainty

Uncertainty due to nuclear data and salt density

- Total uncertainties compared to those derived assuming 1% uncertainty in salt densities:

Integral R	Estimated relative SD from cross sections (%)	Estimated relative SD from fuel and coolant salt densities (%)
k-eff	0.63	0.097
β	0.54	0.003
Λ	1.55	0.455
α_r (core radial expansion)	2.68	0.393
α_{ρ_f} (fuel density)	1.25	0.279
α_{ρ_c} (coolant density)	3.93	0.269

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5. Discussion

- Uncertainty due to salt density is significant but smaller than from nuclear data
- Improved evaluations of chlorine nuclear data would be valuable for chloride fast reactor design – including complete covariance data (consistent with experimental data)
- Moltex (with TerraPower) prepared an entry for Cl-35 in the NEA's High Priority Request List for Nuclear Data, which was recently accepted:
  - https://oecd-nea.org/dbdata/hprl/hprlview.pl?ID=540

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5. Discussion

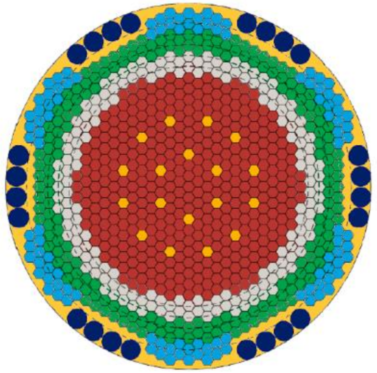
❑ MOLTEX SSR-W (300 MWe): TAR preliminary results - ENDF/B-VII.1: keff

Table. Target accuracy requirement on top-10 most important reactions. **Correlations** in TAR exercise - set A, **ENDF/B-VII.1**: **keff**

Rank #	Reaction	Energy Group	Current (%)	Target (%)	Rel. Unc. Reduction (%)
1	Cl35 (n,p)	2	6.6	0.9	37.4
2	Cl35 (n,p)	3	12.0	1.6	14.9
3	Pu239(n,gamma)	4	8.4	1.3	12.0
4	Cl35 (n,p)	1	8.4	1.2	8.9
5	Pu239(n,gamma)	3	10.4	2.0	4.6
6	Fe56(n,elastic)	3	9.2	1.9	4.3
7	Fe56(n,gamma)	3	16.8	2.8	1.8
8	Pu240(n,gamma)	2	59.3	4.2	1.8
9	Cl35(n,p)	4	11.1	3.7	1.5
10	Fe56(elastic)	2	5.4	1.9	1.3

Total keff unc. due to ND with ENDF/B-VII.1: 836 + with unc. Cl35(TENDL2021)

TAR MOLTEX keff value : 300 pcm



UQ in keff

- **ENDF/B-VII.1 : 584 pcm**
- ENDF/B-VIII.0: 922 pcm
- JEFF-3.3 :1090 pcm

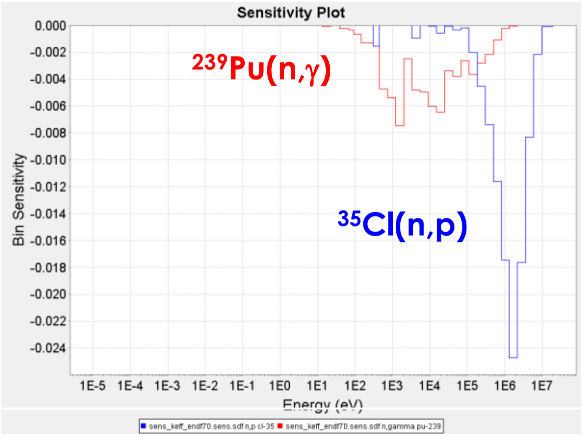


Figure. Energy-dependent sensitivity profile for ^{35}Cl(n,p) and ^{239}Pu(n,γ) in MOLTEX SSR-W

Ref.: *UPM & MOLTEX Clean Energy, TAR Exercise in MOLTEX SSR-W, Preliminary results, Jan. 2022*
Workshop for Applied Nuclear Data Activities (WANDA 2022), O.Cabellos (UPM)

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5. Discussion

Summary

- Key output integral parameters of SSR-W show high sensitivity to chlorine nuclear data
  - Results in significant uncertainty (although lack of complete covariance data in most libraries complicates quantification of uncertainty)
  - Will be the case for any molten chloride fast reactor
- Nuclear data uncertainty must be accounted for rigorously in design, commissioning and operation
- Improvement in Cl nuclear data could be very valuable in supporting development and deployment of highly promising molten chloride fast reactor technology

Thank you

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