Advanced Fuel Cycle Programme

The effect of nuclear data uncertainties and sensitivities on the potential use of uranium nitride fuels in current and future light water reactors

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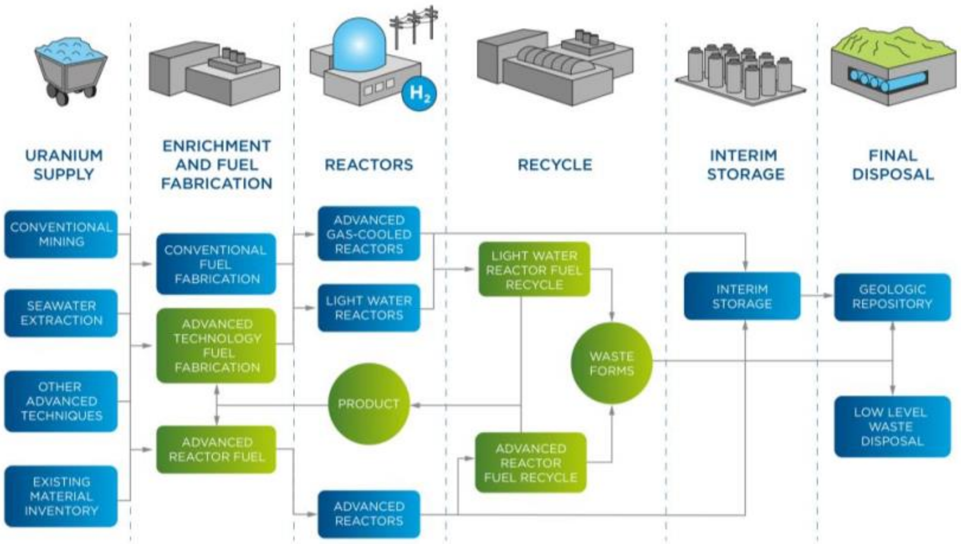
About AFCP

Advanced Fuel Cycle Programme

- £46m investment by UK Government into nuclear science and technology
- Supporting research across the fuel cycle, including enabling capabilities
- Involvement of over 90 organisations across the UK including universities and businesses
- Capability and capacity building



Schematic modified from image in US DoE Quadrennial Technology Review 2015

Drivers for Advance Fuels

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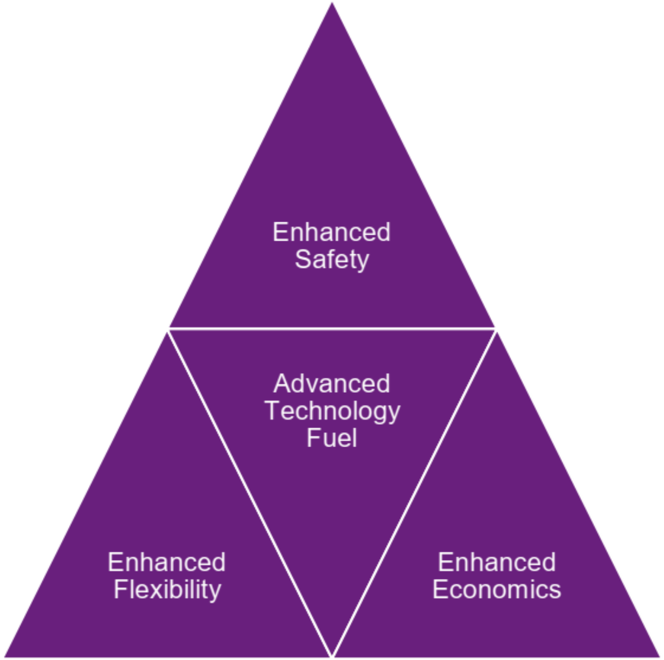
- Originally considered as accident tolerant fuels
- Initial focus on safety, however UK research programmes aligned with Westinghouse have moved to recognise what would drive operators to adopt ATF
- Fuel needs to be attractive to reactor operators, so production routes and total cost need to be comparable with UOx
- Lends itself to fuels that can reach higher burnup to account for higher cost



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Background

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Our work

- UN fuel is one option being considered but novel with no publicly available justification of simulation performance
- Review of the current nitrogen nuclear data including *sensitivity studies of the uncertainties of nuclear data on results and how properties compare to UO_2 fuels*
  - *Fuel manufacture and transport; k-eff/k-inf*
  - *Reactor operation; k-inf, nitrogen enrichment, uranium enrichment and length of fuel life (fall off of k-inf)*
  - *Spent fuel; spent fuel composition, ^{14}C*

Our team

- Robert Mills
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- *Christopher Groves*

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Cases to be considered

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- Cases
  - Fuel production – damp powders (consider maximum cases only)
  - Fuel production – Fuel assembly in air
  - Fuel transport – Fuel assembly in water
  - Burnup in reactor – Fuel assembly in boronated “hot” water (US EPR design)
- Consider
  - UO_2 with 4 and 5% Wt% ^{235}U/W 95% TD
  - UN with 3.5, 4.0, 4.5 and 5.0% ^{235}U/W 95% TD with 0, 90, 98, 99 and 99.5% ^{15}N/N enrichments
  - 92 cases
- Codes
  - MCNP6.2.0
    Monte Carlo tracking
  - WIMS10RU1
    Deterministic – many methods
- Data
  - ENDF/B-VII
  - JEF-2.2

Note

- Nitrogen data the same, but other data (U235, U238, Pu239, O) differs.
- For burnup use standard rating, but UN has 1.4 more U than UO_2, so could give 40% extra fuel life even if identical k-inf profile with burnup.

Effect of ^{14}N enrichment on K-inf of fuel

Storage/ transport at room temperature

K-inf (DRY)	Nitrogen enrichment ^{15}N wrt N				
^{235}U wrt U Wt%	0	0.9	0.98	0.99	0.995
3.5	0.664	0.677	0.679	0.679	0.679
4	0.707	0.725	0.727	0.726	0.726
4.5	0.749	0.770	0.771	0.772	0.771
5	0.789	0.812	0.814	0.813	0.814

UO2
4% 0.691
5% 0.773

K-inf (WET)	Nitrogen enrichment ^{15}N wrt N				
^{235}U wrt U Wt%	0	0.9	0.98	0.99	0.995
3.5	1.291	1.392	1.402	1.404	1.404
4	1.321	1.416	1.425	1.427	1.427
4.5	1.347	1.437	1.445	1.446	1.447
5	1.367	1.452	1.460	1.461	1.463

UO2
4% 1.450
5% 1.488

Change of K_{inf} with burnup in reactor

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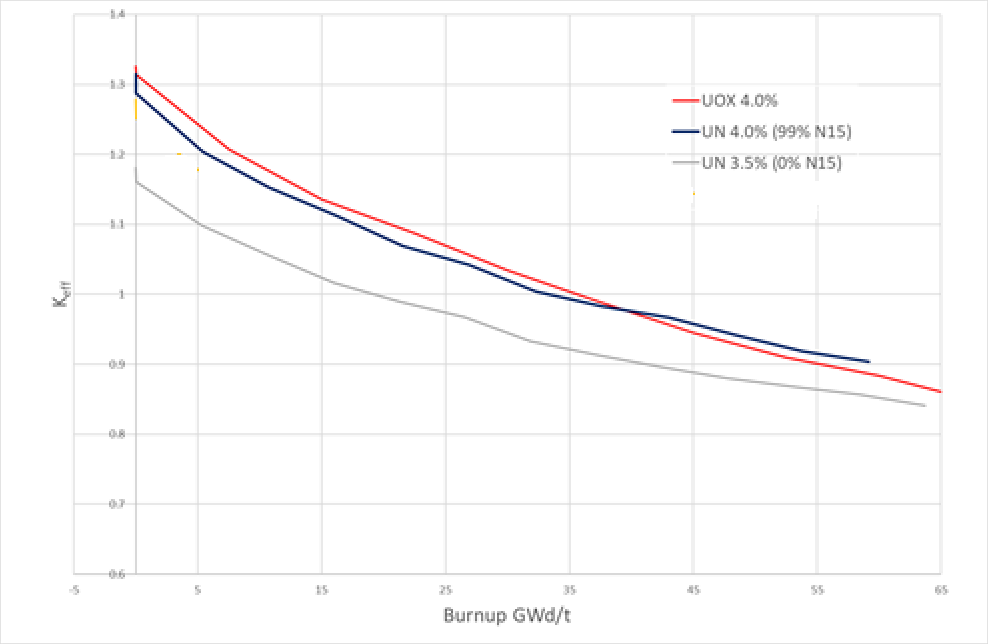
- An important parameter determining a fuel assembly's effective life in a reactor how k-inf changes with burnup.
- Preliminary results shown using MCNP
- Further work needs to be done to consider how various uranium enrichments, nitrogen enrichments etc. alters economics, but will depend on accuracy of simulation results



Initial estimate of changes between UOX and UN

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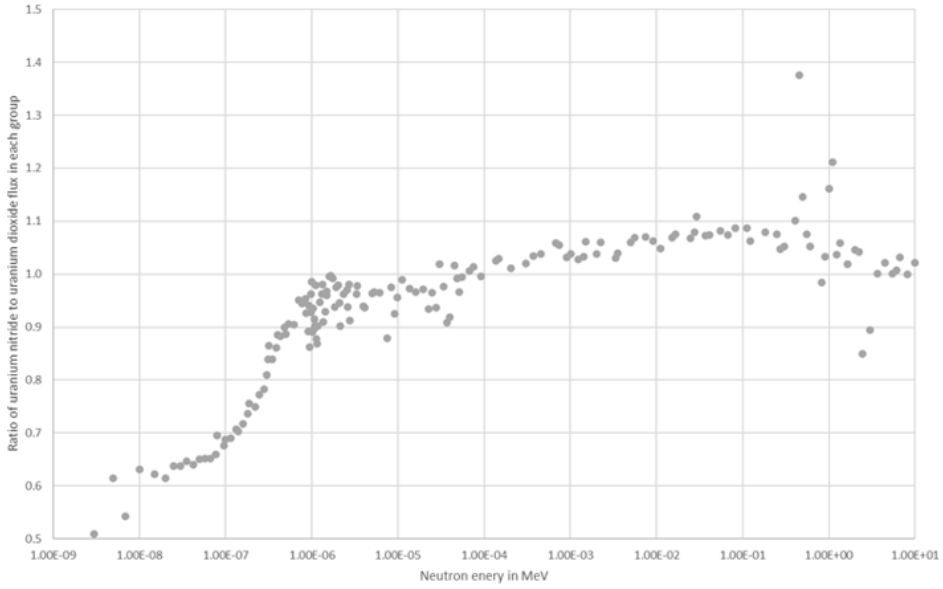
- An important parameter determining fuel performance is the neutron flux.
- Preliminary results show differences between UN and UOX in WIMS 172 group structure using MCNP.
- This is a result of changes in absorption and scattering between O and N, but also affected by different uranium number densities.



Change in neutron flux in uranium nitride fuel compared to uranium oxide fuel in the middle of irradiation.

Initial sensitivity study using MCNP

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- Using MCNP sensitivity options the k-inf of UN fuel with 4% enriched uranium and 98% enriched $^{15}N/N$ was modelled and the preliminary effect on k determined to identify largest uncertainties.

MCNP calculation of k-eff sensitivities for nitrogen reactions for 4.0% $^{235}U/U$, 98% $^{15}N/N$ case

	Energy	(9.118keV - 20MeV)	(0.625eV - 9.118 keV)	(0.0 eV - 0.625 eV)
Nuclide	Cross section	Sensitivity	Sensitivity	Sensitivity
N14	N14 (elastic)	5.5982E-04	1.2248E-03	1.4504E-03
	N14 (inelastic)	-3.5407E-05	0.0000E+00	0.0000E+00
	N14 (n, gamma)	-2.2228E-07	-7.7567E-06	-3.2497E-05
	N14 (n, p)	-1.4353E-04	-1.8914E-04	-7.9242E-04
	N14 (n, alpha)	-2.5155E-04	0.0000E+00	0.0000E+00
N15	N15 (elastic)	1.2474E-03	8.9756E-03	-6.8093E-04
	N15 (inelastic)	-5.2464E-04	0.0000E+00	0.0000E+00
	N15 (n, gamma)	-4.1625E-06	-2.1679E-07	-5.1202E-07
	N15 (n, p)	-1.6360E-06	0.0000E+00	0.0000E+00
	N15 (n, alpha)	-1.0886E-05	0.0000E+00	0.0000E+00

Relative uncertainties from the ENDF/B-VII.1(^{15}N) and BROND-3.1 libraries (^{14}N).

Uncertainties		(9.118keV - 20MeV)	(0.625eV - 9.118 keV)	(0.0 eV - 0.625 eV)
N14	elastic	4.2%	1.5%	1.2%
	inelastic	22.6%	0.0%	0.0%
	n,gamma	16.4%	2.0%	2.0%
	n,p	25.0%	2.0%	1.6%
	n,alpha	20.0%	0.0%	0.0%
N15	elastic	2.0%	4.0%	4.0%
	inelastic	60.0%	0.0%	0.0%
	n,gamma	30.0%	50.0%	80.0%
	n,p	60.0%	0.0%	0.0%
	n,alpha	60.0%	0.0%	0.0%

Estimated pcm variation based on ND uncertainties		(9.118keV - 20MeV)	(0.625eV - 9.118 keV)	(0.0 eV - 0.625 eV)
^{14}N	elastic	2.4	1.8	1.7
	inelastic	0.8	0.0	0.0
	n,gamma	0.0	0.0	0.1
	n,p	3.6	0.4	1.3
	n,alpha	5.0	0.0	0.0
^{15}N	elastic	2.5	35.9	2.7
	inelastic	31.5	0.0	0.0
	n,gamma	0.1	0.0	0.0
	n,p	0.1	0.0	0.0
	n,alpha	0.7	0.0	0.0

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Conclusions

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- A study of nuclear data uncertainties has been carried out using current nitrogen data – identical in JEFF and ENDF.
- No measured data exists to compare simulations.
- The results show significant effects of nitrogen enrichment – a quantity to be determined for potential fuels.
- Initial studies suggest major uncertainties result from scattering on ^{15}N, which is based upon no direct experimental data. Note that only two measurements of direct ^{14}N scattering are available.

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Thank you for your attention