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Atoms for Peace and Development

IAEA RTA Key Element 5: Nuclear Fuel and Fuel Cycle Performance

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VIC, 10 – 14 JUN 2019

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OUTLINE

- Nuclear Fuel Cycle
- RTA Key Element 5: Nuclear Fuel and Fuel Cycle Performance
- RTA TABLE FOR KEY ELEMENT 5
  - How to complete?
  - Examples

Day 3: Wednesday, 12 June 2019		
10:00	**IAEA RTA Key Element 5:** Nuclear Fuel and Fuel Cycle Performance [IAEA NP-T-1.10, Pg. 42] **Case Study**	Ms Tatjana Jevremovic **Teams**

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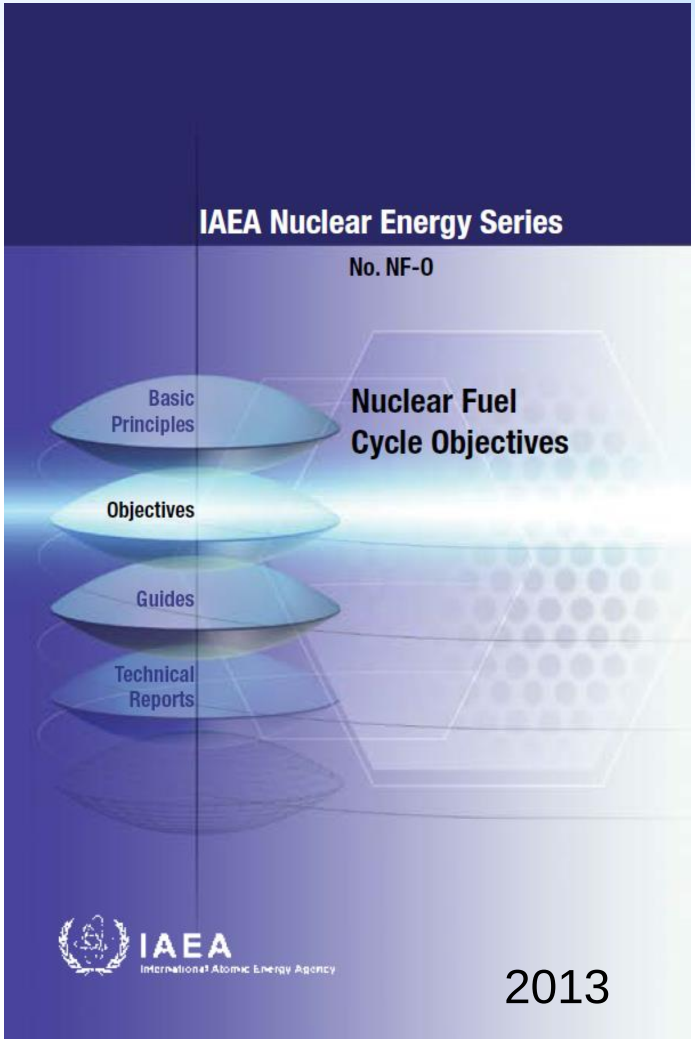
Nuclear Fuel Cycle (NFC)

NFC covers:

1. Resources
2. Fuel engineering and performance
3. Spent fuel management and reprocessing
4. Fuel cycles
5. Research reactors: Nuclear fuel cycle

Fuel and fuel cycle performance are important to Retasland



NFC for Water Cooled Reactors

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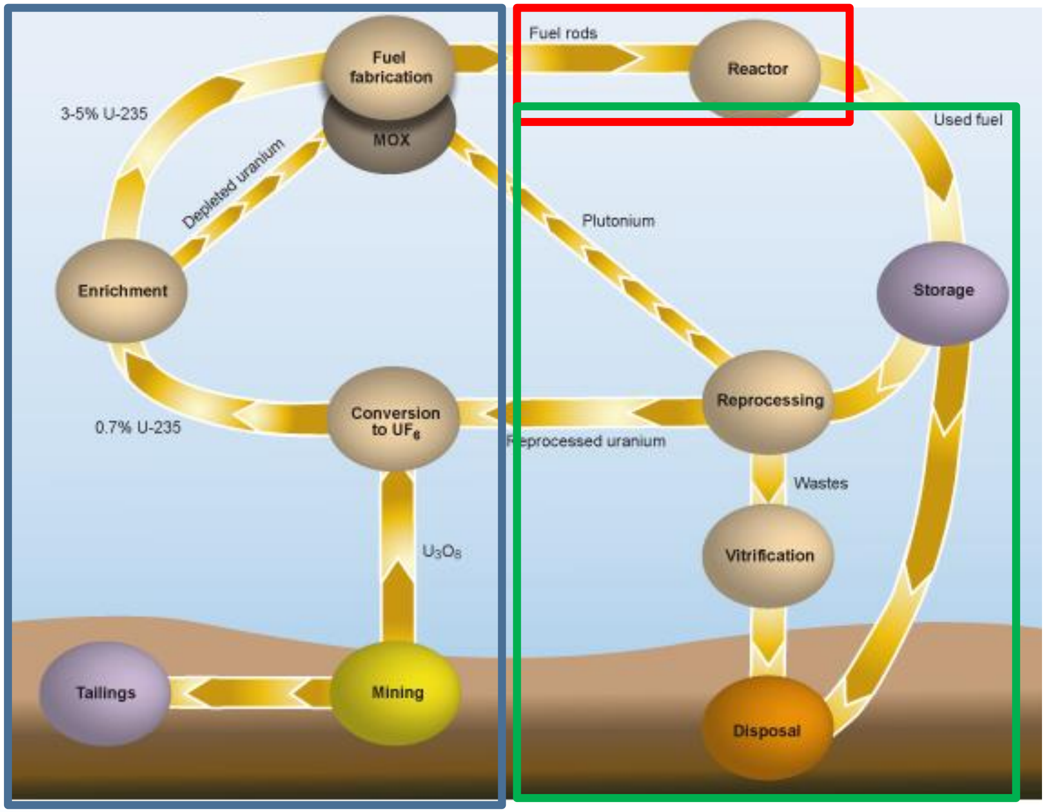
Front end

At the reactor



Back end

http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/nuclear-fuel-cycle-overview.aspx

Material balance in the nuclear fuel cycle

Typical for the annual operation of a 1,000 MWe nuclear power reactor typical of many operating today, using 4.5% enriched fuel and with 45 GWd/t burn-up:

Mining	Anything from 20,000 to 400,000 tonnes of uranium ore
Milling	249 tonnes of uranium oxide concentrate (which contains 211 tonnes of uranium)
Conversion	312 tonnes of uranium hexafluoride, UF_6 (with 211 tU)
Enrichment	35.9 tonnes of enriched UF_6 (containing 24.3 t enriched U @ 4.5%) – balance is 'tails' @ 0.22%
Fuel fabrication	27.6 tonnes UO_2 (with 24.3 t enriched U)
Reactor operation	8760 million kWh (8.76 TWh) of electricity at 100% output, hence 24 tonnes of natural U per TWh
Used fuel	27.6 tonnes containing 280 kg transuranics (mainly plutonium), 26 t uranium oxide (<1.0% U-235), 1 tonne fission products.

The following figures assume the annual operation of 1,000 MWe of nuclear power reactor capacity such as in the new **AP1000 or EPR**, with 5% enriched fuel and higher (65 GWd/t) burn-up:

Mining	Anything from 20,000 to 400,000 tonnes of uranium ore
Milling	192 tonnes of uranium oxide concentrate (which contains 163 tonnes of uranium)
Conversion	241 tonnes of uranium hexafluoride, UF_6 (with 163 tU)
Enrichment	25 tonnes of enriched UF_6 (containing 16.85 t enriched U) – balance is 'tails' @ 0.22%
Fuel fabrication	19.1 tonnes UO_2 (with 16.85 t enriched U)
Reactor operation	8760 million kWh (8.76 TWh) of electricity at 100% output, hence 18.6 tonnes of natural U per TWh
Used fuel	19.1 tonnes containing 200 kg transuranics (mainly plutonium), 18.3 t uranium oxide (<1.0% U-235), <0.6 t fission products

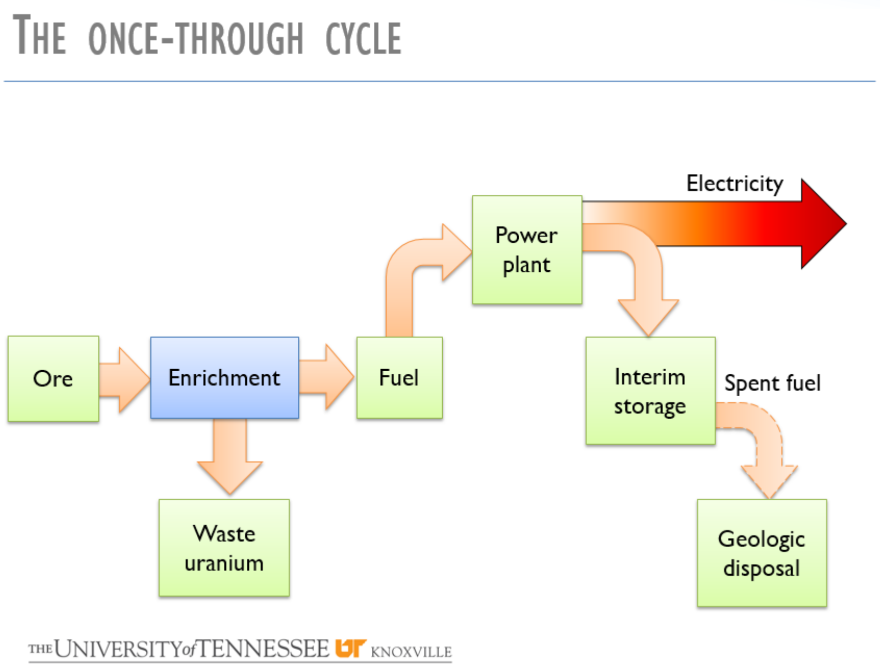
Open and Closed NFC

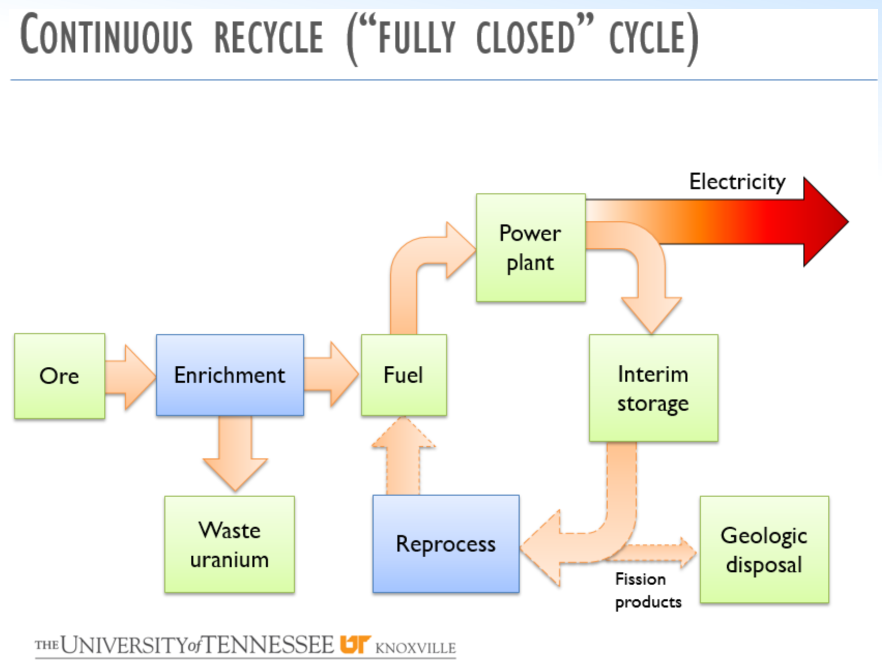
https://www.iaea.org/sites/default/files/nfc0811.pdf

The **cycle** starts with the mining of **uranium** and ends with the disposal of **nuclear** waste:

- If spent nuclear **fuel** (SNF) is not reprocessed, NFC is referred to as an 'open' or 'once-through' **fuel cycle**
- If spent **fuel** is reprocessed, and partly reused, NFC is referred to as a '**closed**' **nuclear fuel cycle**
  - SNF is reprocessed to **recover fissile materials** for future use

Open and Closed NFC





Which country's electricity production from NPPs is over 50%?

Which country has closed NFC?

Front End of NFC

- Technology requirements, supply chain, cost, and experience for manufacturing NPP fuel.
- Key factor is whether the fuel is
  - procured, or
  - fabricated indigenously
- Focus is then on
  - services offered and supply assurance, or
  - technology transfer
- This could change over the plant's lifetime

At the Reactor

- What is the design fuel cycle length, outage time, and fuel shuffling scheme?
- What alternative fuel options exist (e.g. MOX*)?
- What are the design and licensing factors that limit burnup?
- What is the supply chain? How many manufacturers?

* Plutonium from reprocessed fuel can be made into mixed oxide (MOX) fuel, in which uranium and plutonium oxides are combined.

Back End of NFC

- Technology requirements, volume, cost, and experience for storing and disposing NPP fuel.
- Key factor is whether the fuel will be
  - returned after cooldown, or
  - disposed indigenously
- Focus is then on
  - services offered on back end, or
  - disposal technology requirements
- This highly depends on NFC type (open or closed)

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IAEA NP-T-1.10, Pg. 42

RTA Key Element 5: Nuclear Fuel and Fuel Cycle Performance

All operations associated with the production of nuclear energy, including: mining and processing of uranium or thorium ores; enrichment of uranium; manufacture of nuclear fuel; operation of nuclear reactors (including research reactors); reprocessing of spent fuel; all waste management activities (including decommissioning) relating to operations associated with the production of nuclear energy; and any related research and development activities.

- **Importance factor range suggested: Medium**
- The importance factor recognizes that fuel costs are small in comparison to capital costs for the facility.
- Once the facility is in operation, however, the performance of the fuel and the fuel cycle, and the in-plant management of fuel can have a major impact on plant operation and operating costs. Therefore, the comparative offerings and technology holder experience with regard to fuel and fuel cycle performance is important.

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- ***Evaluation expectations and relative comparisons***:
  - Availability of fuel supply
  - The technology holder's experience:
    i. in fabricating fuel
    ii. with in-reactor fuel performance with similar fuel
    iii. with the fuel shuffle plans necessary to achieve the proposed cycle length
  - Support in dealing with spent fuel.

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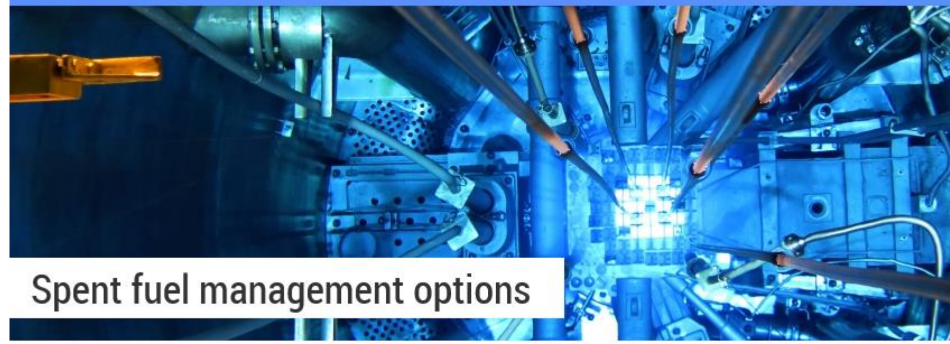
Spent Nuclear Fuel



Spent fuel management options

Spent fuel management options

- News
- Events
- Publications

Related pages

- Storage

Managing the spent fuel arising from nuclear power plants until its disposal is an important step of the nuclear fuel cycle and constitutes the so-called back-end. While one third of the spent fuel accumulating globally is reprocessed, most of it is stored until a decision is taken on the end-point strategy (processing or disposal).

The nuclear fuel cycle ends with the safe, secure and sustainable management of the spent fuel, which includes its storage after withdrawal from the core of the nuclear power plant, followed by either its processing/recycling or final disposal. Safe, secure, proliferation resistant and economically efficient nuclear fuel cycles that minimize waste generation and environmental impacts globally contribute to the sustainability of nuclear energy.

https://www.iaea.org/topics/spent-fuel-management

Spent Nuclear Fuel

All WCRs store the SNF, when it is unloaded from the reactor, under water in a pool on the reactor site

The interim storage of spent fuel at Clab, Sweden (courtesy of SKB)

https://www-pub.iaea.org/MTCD/Publications/PDF/P1799_web.pdf

Spent Nuclear Fuel (SNF)

- Originally, it was planned that SNF would be shipped off-site after a few years of cooling under water in a pool on the reactor site

- The fuel would then be reprocessed or disposed for longer term storage to allow further cooling before direct disposal

- The majority of States implement direct disposal of spent fuel (open NFC).
- Several States with the largest nuclear programmes (France, China, Japan, the Russian Federation and the United Kingdom) implement reprocessing nuclear fuel and recycling the separated material (closed NFC).
- Germany and the United States of America have changed their policy from reprocessing and recycling to direct disposal and are currently planning spent fuel repositories.

Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes, IAEA Nuclear Energy Series No. NW-T-1.24, 2013

SNF: Closed Nuclear Fuel Cycle

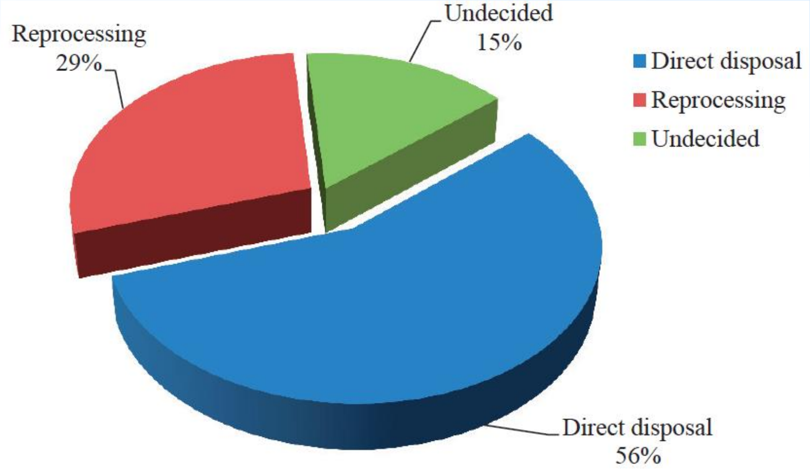
- Spent fuel undergoing reprocessing can be separated into three main components: uranium, plutonium, and waste containing fission and activation products.
- Uranium and plutonium can be reused as nuclear fuel for reactors, while the fission and activation products are waste products, which are vitrified and stored for further handling and disposal.
- Secondary waste from reprocessing and the metal components of the fuel are conditioned in a stable matrix for storage and ultimate disposal.

States which currently operate reprocessing facilities on a significant scale include France, India, Japan, the Russian Federation and the United Kingdom

AREVA reprocessing plant, France (courtesy of AREVA)

SNF: Open Nuclear Fuel Cycle

Summary of existing spent fuel by planned disposition (IAEA NES NW-T-1.14, 2018



- In practice, reprocessing is currently carried out in only a few programmes, and disposal of SNF has not yet taken place.
- The need for storage has thus increased.

Spent fuel disposal canisters, Posiva, Finland (courtesy of Posiva)

- After several decades of interim storage and packaging (figure below), SNF will be disposed of in a deep geological repository.

Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes, IAEA Nuclear Energy Series No. NW-T-1.24, 2013

Open Nuclear Fuel Cycle
Wet and Dry Storage

Wet and dry storage systems have been proven over decades:

Wet storage facility at the Olkiluoto NPP (Finland)

Dry storage facility at the Dukovany NPP (Czech Republic)

Open Nuclear Fuel Cycle
Wet and Dry Storage

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- There are no major technical issues affecting the safety and security of spent fuel storage.
- However, there are some specific challenges:
  - A **pool** at the reactor storage that collects fresh fuel with high thermal output calls for **increased passive safety measures to ensure sufficient cooling**, even in highly improbable calamity situations.
  - **Pool storage requires that a large facility** be constructed at the outset to allow for future accumulation of spent fuel, so that **much of the storage space remains unused for a long period**.
  - **Maintenance can become expensive** if disposal lies far into the future.
  - For **dry storage**, there are some **concerns about the long-term integrity of the fuel**, and it will **require a follow-up programme** to ensure that the **fuel can be removed** from the containers **after many years**.

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RTA Key Element 5: Table

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Key element: 5. Nuclear Fuel and Fuel Cycle Performance (Suggested Medium Importance)						%
14 Key topics	%	Rationale for percentage	HTR-PM	NuScale	SMART	Rationale for score
Considerations related to the design, procurement and operating experience for the nuclear fuel — materials, fabrication, operational expectations and experience						
Flexibility of plant operation with respect to different fuels, including higher enrichment levels or mixed oxide (MOX) fuels						
Services offered for the front end and back end supply						

2 1 4 3

%	Represents the importance of the key topic
Rationale for percentage	Requires explanation for quantified importance
Rationale for score	Requires explanation of the scoring range:
	5 High achievement of criteria
	3 Medium achievement of criteria
	1 Low or no achievement of criteria, or no information available

RTA Key Element 5: Table

Key element: 5. Nuclear Fuel and Fuel Cycle Performance (Suggested Medium Importance)							%
Key topics	%	Rationale for percentage	HTR-PM	NuScale	SMART	Rationale for score	
Considerations related to the design, procurement and operating experience for the nuclear fuel — materials, fabrication, operational expectations and experience		Design, procurement and operating experience of the nuclear fuel is of great importance					
Flexibility of plant operation with respect to different fuels, including higher enrichment levels or mixed oxide (MOX) fuels		Flexibility regarding different fuel is important because it allows the plant to use alternative fuels					
Services offered for the front end and back end supply		The front end and back end are important to obtain the fuel and to ultimately dispose of the spent fuel					

1

RTA Key Element 5: Table

Key element: 5. Nuclear Fuel and Fuel Cycle Performance (Suggested Medium Importance)							%
Key topics	%	Rationale for percentage	HTR-PM	NuScale	SMART	Rationale for score	
Considerations related to the design, procurement and operating experience for the nuclear fuel — materials, fabrication, operational expectations and experience	15	Design, procurement and operating experience of the nuclear fuel is of great importance					
Flexibility of plant operation with respect to different fuels, including higher enrichment levels or mixed oxide (MOX) fuels	10	Flexibility regarding different fuel is important because it allows the plant to use alternative fuels					
Services offered for the front end and back end supply	10	The front end and back end are important to obtain the fuel and to ultimately dispose of the spent fuel					

2 1

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RTA Key Element 5: Table

Key element: 5. Nuclear Fuel and Fuel Cycle Performance (Suggested Medium Importance)							%
Key topics	**%**	**Rationale for percentage**	**HTR-PM**	**NuScale**	**SMART**	**Rationale for score**	
Considerations related to the design, procurement and operating experience for the nuclear fuel — materials, fabrication, operational expectations and experience	15	Design, procurement and operating experience of the nuclear fuel is of great importance				5. Fuel is same material used in currently operating reactors 3. Fuel is different material to the one used in currently operating NPPs, but design, procurement and operating experience (DPOE) are well established 1. No info or fuel is different material to the one used in currently operating NPPs, and DPOE are not well established	
Flexibility of plant operation with respect to different fuels, including higher enrichment levels or mixed oxide (MOX) fuels	10	Flexibility regarding different fuel is important because it allows the plant to use alternative fuels				5. Use of MOX in addition to UO_2 3. Use of limited amounts of MOX in addition to UO_2 1. No info or no flexibility	
Services offered for the front end and back end supply	10	The front end and back end are important to obtain the fuel and to ultimately dispose of the spent fuel				5. Many services offered for the front end and back end supplies 3. Services offered for the front end or back end supply 1. No info or no services offered for the front end and back end supplies	

2 1 3

RTA Key Element 5: Table

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Key element: 5. Nuclear Fuel and Fuel Cycle Performance (Suggested Medium Importance)							%
Key topics	%	Rationale for percentage	HTR-PM	NuScale	SMART	Rationale for score	
Considerations related to the design, procurement and operating experience for the nuclear fuel — materials, fabrication, operational expectations and experience	15	Design, procurement and operating experience of the nuclear fuel is of great importance	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	5. Fuel is same material used in currently operating reactors 3. Fuel is different material to the one used in currently operating NPPs, but design, procurement and operating experience (DPOE) are well established 1. No info or fuel is different material to the one used in currently operating NPPs, and DPOE are not well established	
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Services offered for the front end and back end supply	10	The front end and back end are important to obtain the fuel and to ultimately dispose of the spent fuel	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	5. Many services offered for the front end and back end supplies 3. Services offered for the front end or back end supply 1. No info or no services offered for the front end and back end supplies	

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Case Study Toolkit

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Thank you!