Preliminary Fuel Cycle Analysis of the -UB_2 Composite Fuels in Pressurized Water Reactors

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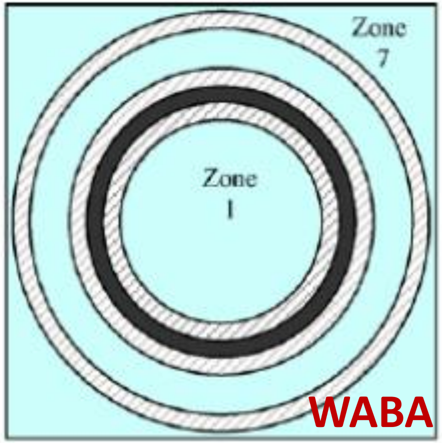
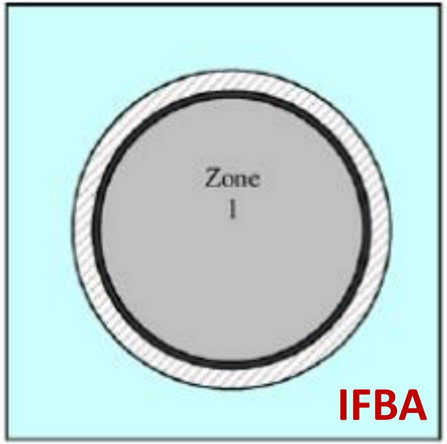
Burnable Absorbers (BA)

- BA is a common approach employed in LWRs to hold down the excess reactivity.
- Boron is commonly employed as BA in forms of soluble boric acid dissolved in PWR coolant.
- Two alternative boron based solid BAs recently invented by Westinghouse:
  - Wet Annular Burnable Absorber (**WABA**): annular pellets of alumina-boron carbide (Al_2O_3-B_4C) contained within two concentric Zircaloy-4 tubes
  - Integral Fuel Burnable Absorber (**IFBA**): coatings of thin layers of zirconium diboride (ZrB_2) over the outer surfaces of the conventional UO_2 fuel pellets





Source: *Nuclear Engineering and Design* 241(1), 193-202, 2011

Limitations

WABA

- BA rods displace fuel rods from the fuel assembly, which results in reduced heavy metal (HM) loading and shorter fuel cycles.

IFBA

- Adding a coating material to the surface of the fuel rod inevitability worsens the heat transfer between the fuel and the coolant, which results in a higher fuel center-line temperature.
- The coating may lead to early burn out of the BA and induce undesirable reactivity peaks, which also increases the fuel temperature

A Potential Solution - UB_2 Composite Fuels

Novel composite fuels with uranium diboride (UB_2) as the secondary phase improve the safety and the economic performances of PWRs

- These composite fuels have higher thermal conductivities than the conventional UO_2 fuel, which limits the fuel temperature.
- With BA more distributed in fuel rods, instead of several dedicated BA rods, the composite fuel decreases the power peaking factor, and thereby the peak fuel temperature.
- The use of these composite fuels avoids the potential early burnout of the BA coatings, which offers potentially longer fuel cycles.

Objectives of this Study

Analyze the neutronically economic viability of

- UO_2-UB_2,
- U_3Si_2-UB_2, and
- UN-UB_2

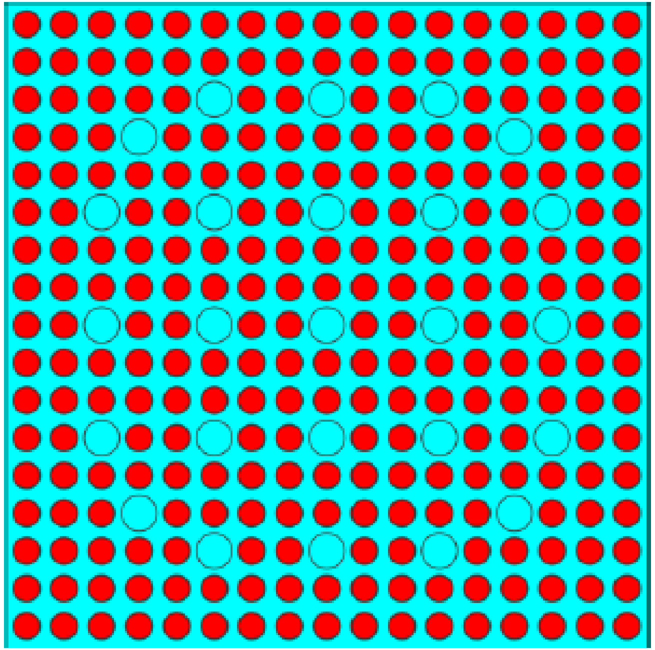
high g-U/cm^3 composite fuels via standard fuel cycle analyses in PWRs.

Note: because no production of the UN-UB_2 composite has been reported at the time of writing the summary, this work also makes suggestions for the focus of potential future experiments on UN-UB_2 .

PWR Fuel Assembly (Neutronics Model)

The Westinghouse's AP1000 reactor was considered as the reference design in this work, and the 17 x 17 fuel assembly was modeled via Serpent according to its specifications

Parameter	Value
Array size (-)	17 x 17
Number of fuel rods (-)	264
Number of guide/instrument tubes (-)	25
Power density (MW/MTU)	40.2
Rod pitch (cm)	1.26
Assembly pitch (cm)	21.522
Cladding outside radius (cm)	0.475
Gas gap outside radius (cm)	0.4178
Pellet outside radius (cm)	0.4096
Guide/instrument tube outside radius (cm)	0.6121
Guide/instrument tube inside radius (cm)	0.5715



2-D **Serpent** model of the 17 × 17 fuel assembly

Reference Case – IFBA Assembly

Loading pattern of the 156 IFBA rods.

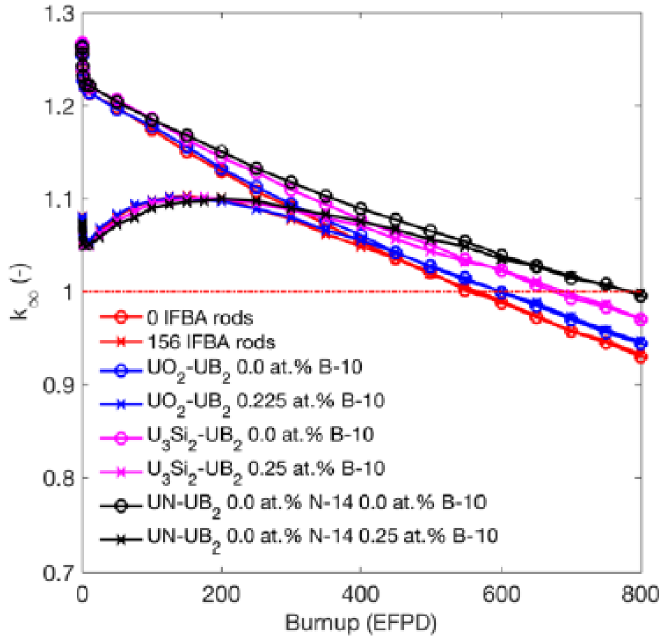
- Loading patterns with various numbers of IFBA rods were modeled as the bounding cases in the study
- Natural boron was considered for both the soluble boric acid and the ZrB_2 coating of the IFBA rods
- Assumed 1.57 mg/inch of ^{10}B in the IFBA rods, where the thickness of the ZrB_2 coating was 0.000508 cm
- Assumed initial ^{235}U enrichment as 3.4 wt.% for the assembly

Impact on k_∞ and Fuel Cycle Length

- All the three composite fuels were able to increase the fuel cycle length of the 0-IFBA-rods assembly when employing 100% enriched ^{11}B and ^{15}N (absorption free isotopes).

Summary of fuel cycle length and HM loading

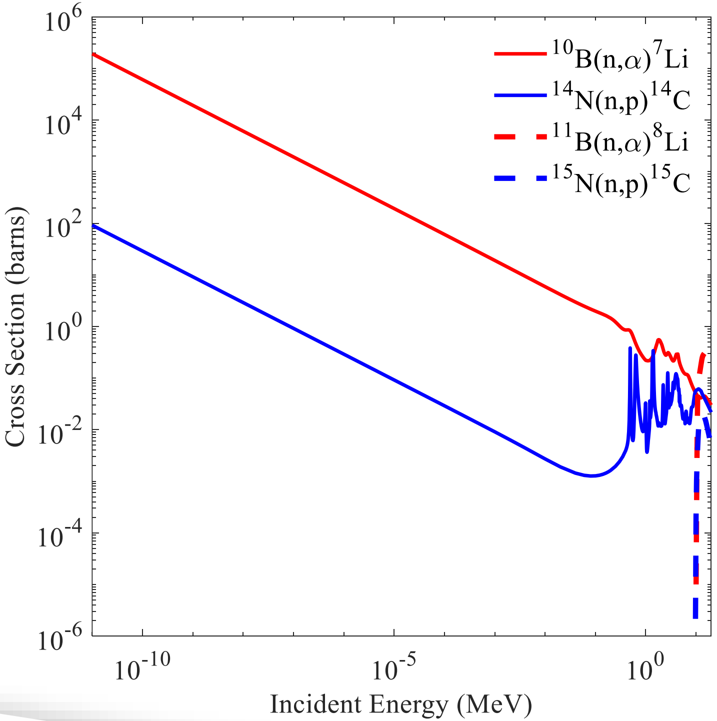
Fuel type	EFPD	+	HM loading (g)	+
0-IFBA	556	-	1254	-
UO_2-UB_2	597	7%	1323	5%
U_3Si_2-UB_2	675	21%	1479	18%
UN-UB_2	782	41%	1680	34%



k_∞ vs EFPD of the various composite fuels

- They are also capable to function similarly to the 156-IFBA-rods assemblies for the holding down of the initial excess reactivity.

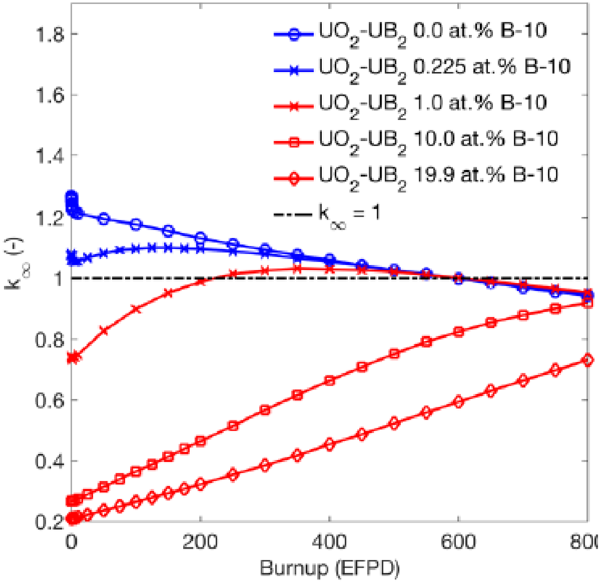
Understanding the Physics



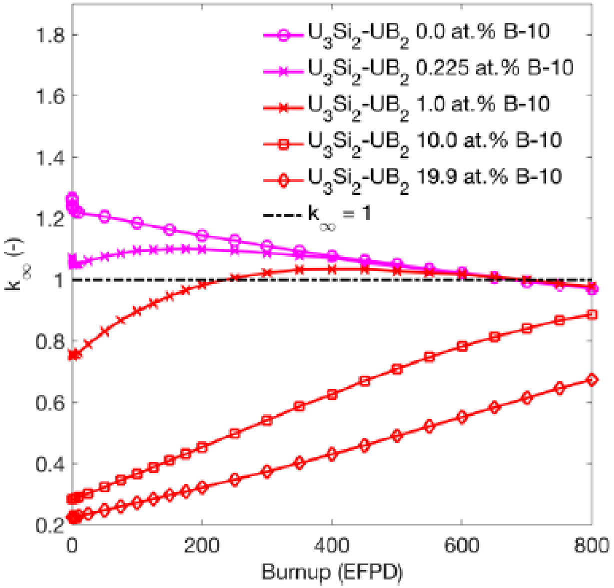
- Natural Boron
  - B-10: **19.9 at.%**
  - B-11: **80.1 at.%**
- Natural Nitrogen
  - N-14: **99.6 at.%**
  - N-15: **0.4 at.%**
- B-11 and N-15 have insignificant cross section for neutron absorption in energy < 10 MeV

Nuclear data are from the IAEA NDS website based on ENDF/VIII.

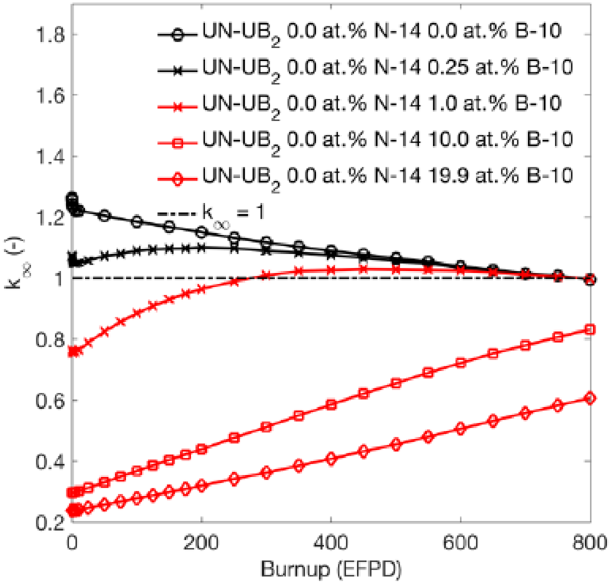
Impact of the ^{10}B Concentration on k_∞



UO_2-UB_2

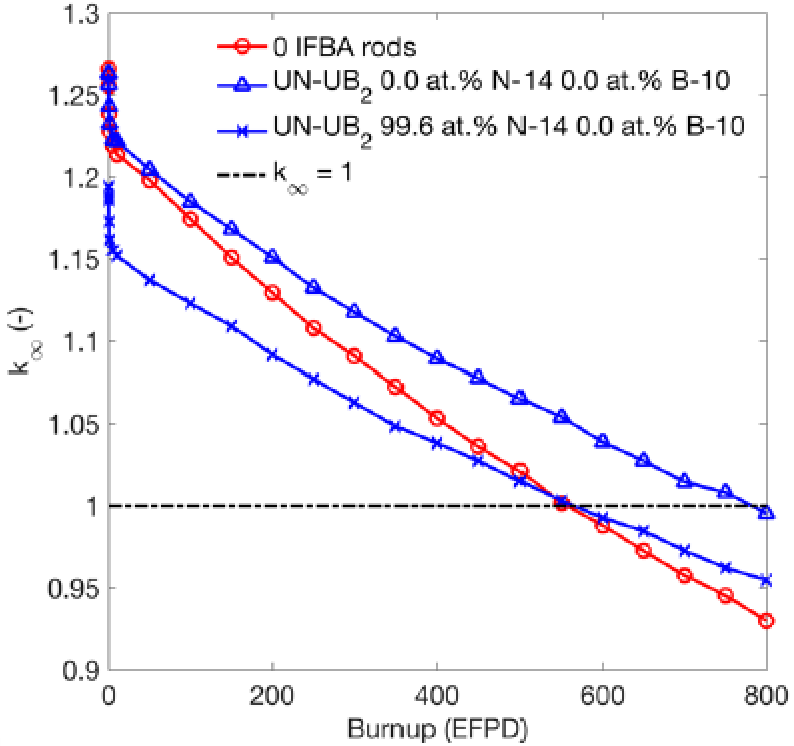


U_3Si_2-UB_2



UN-UB_2

Impact of the ^{14}N Concentration on k_∞



Summary

- All the calculations in this work were performed by assuming 30 wt.% of the UB_2 phase in the composite fuels.
- A significant amount of UB_2 is required in the UO_2-UB_2 composite to achieve a higher HM loading for an extended fuel cycle length.
- UB_2 is added to U_3Si_2 and UN primarily to make them less reactant with high-pressure steam, rather than to increase the HM loading.
- In future work, the minimum amount of UB_2 required to adequately mitigate the UN-steam reaction should be experimentally determined.

Thanks & Questions?

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