

Chapter 8: Conclusion & recommendations

“ It is easier to denature plutonium than to denature the evil spirit of man.”

~ Albert Einstein ~

Overview

The research has been concluded and comments and recommendations are given to suggest future research and development. Thorium-based fuels cycles are at present not established in PWRs and require further investigation and refinement before implementation in 2028. The identified areas that need further investigation and research are described.

8.1 Introduction

The research has been concluded and recommendations are given to suggest future research and development. Thorium-based fuels cycles are not at present established in PWRs and require further investigation and refinement before implementation in 2028.

8.2 Recommendations

The optimal concentration of thorium, plutonium and uranium in (Th/Pu)O₂-fuel and (Th/U)O₂-fuel needs to be determined for the core properties of the planned reactors. The optimally enriched B¹⁰ soluble boron should be determined for the new reactors. The fuel fractions and boron enrichment could be determined by using computer simulation software.

The possibility to add additional water holes to the new reactors should be investigated. Different options for core loadings and in-core fuel management strategies using thorium-based fuels in PWRs should be explored.

A more in-depth economic evaluation should determine the implications of the modifications suggested in section 3.4 on the capital costs. The operation and maintenance cost for thorium-based fuel cycles (especially for modifications suggested in section 3.4.) should be calculated and compared with conventional uranium cycles. The effect of 24-month fuel cycles on the maintenance schedules should be investigated, because 24-month maintenance cycles may not be feasible or economical. Ideally, the optimal discharge burnup and cycle length for thorium-based fuels in PWRs should be determined. The optimum cycle length will rely on outage costs and the worth of the energy added by the 18- or 24-month cycles (Secker *et al.*, 2005).

The research project developing and planning the construction of a fuel fabrication and reprocessing facility should be well underway. The applications for funding and support to implement the entire front end and reprocessing step should already be in progress.

Increased burnup and extended fuel cycles of thorium-based fuels require advanced fuel cladding and research should focus on investigations aimed at enhancing the fuel claddings.

The strategies that were eliminated or temporarily rejected in section 3.3 due to the need for further research and development are considered again.

- Annular fuel pellets
- Tight pitch lattices
- Increase fuel radius
- Additional control rods
- Oxide dispersion strengthened steels and SiC as advanced cladding materials
- The PRATT fuel design.

The manufacturing of U^{233} -based fuels (in the future) must be done completely remotely in a gamma-shielded environment, which is a very expensive technique. The heavy gamma shielding should be investigated and simplified. Research should focus on streamlining the U^{233} -based fuel fabrication process and reducing the reprocessing cost of such fuels, by simplifying this process, or by a combination of all these factors (Lung & Gremm 1998).

Several added costs would be required to implement fuel using high enrichments, including modification to fabrication facilities, -shipping containers and -plant facilities to be able to

store high-enrichment fuel. The cost of changing existing fuel production facilities to enrich fuel higher than 5% is between \$55 and \$75 million (Secker *et al.*, 2005).

Fuel-licensing studies (for the introduction of new fuel designs) need to be done and the funding thereof need to be addressed. The plant modification and dose rate factors accompanied by thorium should be taken into account.

The option to develop thorium-based fuels, not only for SA, but also internationally, should be investigated and pursued.

8.3 Conclusions

The most important thorium-based fuel options were identified. The modifications and strategies to use thorium-based fuels in PWRs have been evaluated and a thorium-based fuel option has been proposed. The thorium-based fuel options were compared economically with uranium in the PWR. An evolutionary strategy of introducing thorium-based fuels into existing- and future reactor technologies is developed.

Thorium-based fuels can supplement uranium to diversify the nuclear fuel sources and increase the current sustainability. Thorium-based fuels can incinerate plutonium, enhance burnup and extend refuelling cycles, which adheres to current governmental initiatives. SA can utilize local resources (thorium, currently a waste material) to enhance fuel utilization.

The thorium-based fuel implementation strategy contributes to the strategic plan of government and can pay for front-end fuel facilities by simply saving on fuel cycle costs and refuelling outage costs. The proposed strategy can assist SA to become fuel independent, help Eskom to keep the power on for longer and create more local job opportunities. Safety is increased with higher proliferation resistant fuels, and advanced reactor technologies.

The bulk of thorium introduction options in PWRs are reactor physics investigations. Thorium fuel fabrication and irradiation experience cannot yet be characterized as commercially 'ready'. To achieve practical and commercial implementation of thorium-based fuels, further R&D in core design, fuel cycle optimisation and several technological developments are necessary (IAEA, 2012).