REACTOR VESSEL SHIELDING WITH RADIOACTIVE WASTE MATERIALS AS BURNABLE POISONS

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INTRODUCTION

An increasing concern in the nuclear industry is damage to reactor pressure vessels as a result of neutron fluence. This phenomena can significantly shorten reactor lifetime and, in some situations, has the potential to become a serious safety concern. As a result, finding methods to alleviate this problem is important to both current and next generation reactors.

One technique currently being explored is to replace some of the outermost fuel pins with absorber pins that serve as an expendable shield for the reactor vessel. However, this concept is not new. The early U.S. Department of Energy (DOE) production reactors at the Hanford Site used materials such as thorium and lithium to protect structural components from excessive neutron flux. In addition this shielding was used to produce special nuclear materials.

While the production of special nuclear materials may no longer be of interest there may still be ways to put neutron shielding materials to good use. One possibility would be to use long-lived waste isotopes, such as ^{99}Tc and ^{129}I, as target materials that would be transmuted into shorter-lived waste forms. This would have the benefit of shielding the reactor vessel and, at the same time, eliminating the need for long-term storage of these problematic isotopes.

The experience gained with the production reactor targets, along with more recent evaluations of waste transmutation, should provide some insight into the potential of this approach.

HANFORD SITE PRODUCTION REACTORS

The Hanford Site production reactors were large, graphite-block moderated reactors that used pressurized water coolant in the fuel tubes. The fuel itself consisted of slugs of natural and enriched uranium. The reactors were surrounded by a biological shield that consisted in part of masonite that was used to absorb neutrons. The masonsite was susceptible to heat damage and degraded over time. Early evaluations of this problem found the damage was primarily a result of thermal neutron flux, with fast neutron flux and gamma radiation being secondary. Cost analysis indicated that reducing the flux in the biological shield was more efficient than periodically replacing the shield. This was accomplished by replacing the outermost (fringe) fuel tubes with tubes of neutron absorbers. The shield flux reduction program was made even more beneficial by using poison materials, such as thorium and lithium, that would be transmuted into a marketable product.

As part of an effort to evaluate the waste streams resulting from the production reactors, detailed models of a variety of different fuel loadings were generated. Some of these loadings included fringe poison tubes and others did not. A comparison of the results from these analyses can give some indication of the effectiveness of the poisons in reducing the shield flux.

The analyses were performed using a three-dimensional, finite difference diffusion code derived from 3DB.[1] The macroscopic cross sections were generated using the WIMS-E code.[2]

Figure 1 shows a schematic of a portion of a production reactor core. Figure 2 shows the calculated thermal flux profiles for two reactor models; one with a poison fringe and one without. As shown, the thermal flux is reduced by approximately a factor of three throughout the reflector region. The biological shield is not included in the reactor model but was immediately adjacent to the outer edge of the reflector.

While the production reactors were very different from modern reactors, there is still an analogy between them as far as fluence

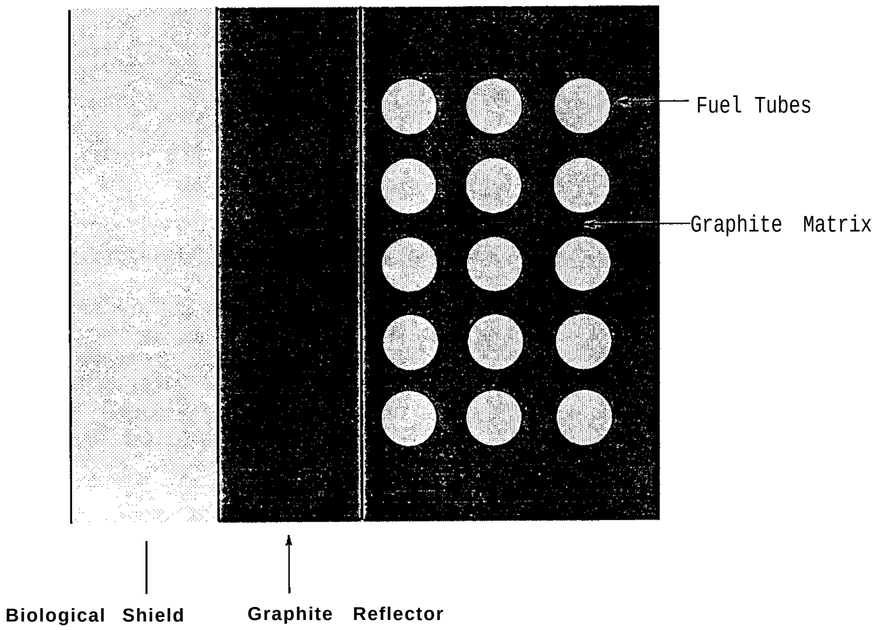

Figure 1. Portion of Hanford Production Reactor Core.

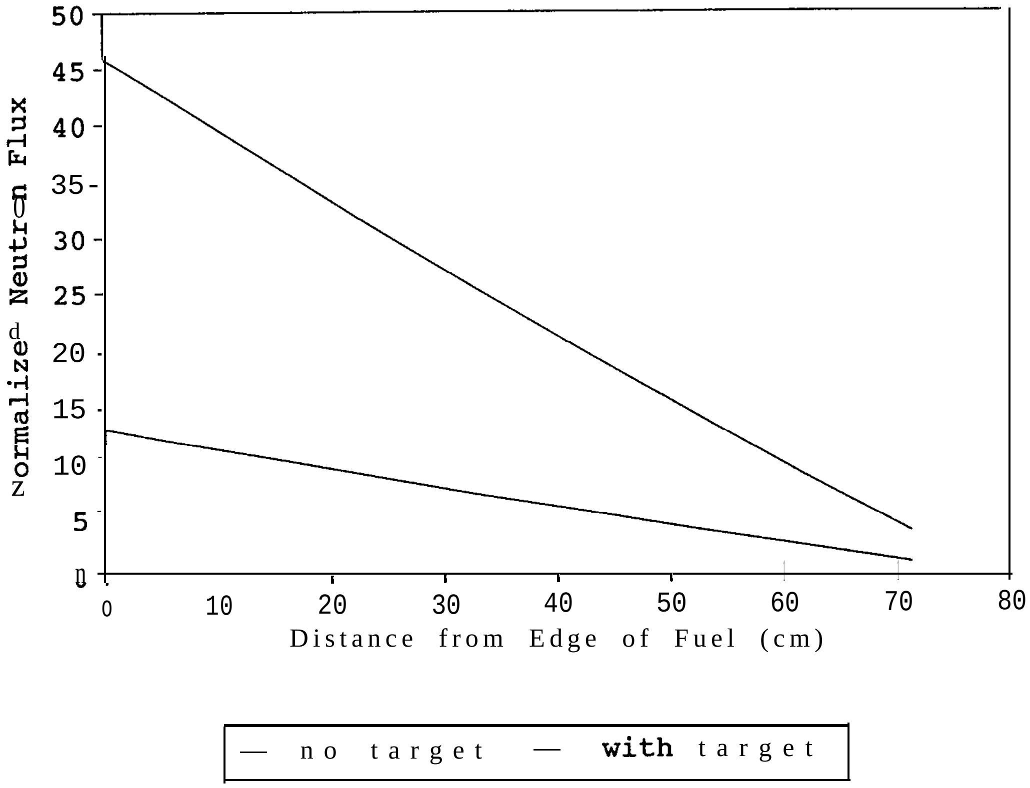

Figure 2. Edge Shielding Effectsin K Reactor. (Lithium Targets)

induced structural damage is concerned. Typical commercial reactors employ welded steel pressure vessels to contain the core. These pressure vessels are exposed to high neutron fluxes that cause structural damage and reduce the useful lifetime of the reactor. Judicious choices of alloys can reduce but not eliminate this problem. Some current reactors are faced with possible reduction in lifetimes because of uncertainty over the weld materials resistance to neutron damage and, in the future, it will be desirable to extend reactor lifetimes beyond what are currently being achieved. To resolve either of these problems it will be necessary to employ some method to reduce the fluence in the pressure vessel. Providing a layer of poison at the outer core boundary would be one way to accomplish this.

To test the viability of this approach for commercial-type reactors, a computer model was constructed of a typical light water reactor assembly. Calculations were performed with a standard fueled assembly and with varying amounts of lithium in the outermost pin positions. Figure 3 shows a schematic of a simple reactor assembly. As can be seen in Figure 4, a single row of lithium pins reduced the boundary flux by about 40%. Adding a second row had no significant effect. This is a smaller effect than was seen in the production reactors but that is not surprising as the lithium slugs in the production reactors were much larger than typical commercial reactor fuel pins.

Figure 5 compares the effect of the lithium pins to that of the more conventional steel . As can be seen, the effects of these two target materials are virtually identical.

Many neutron absorbers are considered ‘throw away’ materials. That is, no benefit is gained from them except the shielding effect, and after they are burned up they must be disposed of (with all the associated costs thereof). It would be better if some additional use could be made of these materials as was done in the production reactors. Irradiated lithium and steel targets may have some practical applications but other possibilities should be considered as well. For instance, medical isotopes could be generated in the poison pins. This is problematic, however, as the exposure times required for medical isotopes are generally shorter than typical commercial reactor cycle times. Another possibility would be to burn certain long lived radio-active wastes in the poison tubes. This is of interest because some of the most troublesome waste isotopes are easily burned in a nuclear reactor.

The radioactive waste generated by nuclear reactors consists of a mixture of many different isotopes. Current plans call for geologic isolation as the primary means of disposing of this waste. Some of the long-lived isotopes, however, present problems because of their high mobility in water. Isotopes such as ^{99}Tc and ^{129}I are both long lived and readily transported in water. In the event of groundwater penetration of a waste site, unacceptable amounts of these materials might be transported offsite. Because of these concerns it may be desirable to separate these materials out of the waste and dispose of them in a different manner.

One method of disposing of these nuclides is to expose them to a neutron flux in a reactor where they are transmuted to nonradioactive or short-lived isotopes.

Previous studies[3,4] have explored the effectiveness of burning these isotopes in a thermal reactor. Studies were performed where assemblies were modeled as containing ^{99}Tc or ^{129}I in the form of pins or a homogeneous poison. The results of those studies indicate that significant amounts of these waste isotopes can be readily transmuted in a standard commercial reactor.

To test the effectiveness of ^{99}Tc and ^{129}I as shield materials, calculations were performed with these isotopes in the poison pins. The results of these calculations are compared to steel in Figure 6. The ^{129}I produced a shielding effect that was essentially the same as that of steel, while the ^{99}Tc was approximately 10% better than the steel.

CONCLUSIONS

A problem has been identified that must be addressed in current and future reactor designs; pressure vessel degradation caused by high neutron fluence. This problem is analogous to the problems faced by the old Hanford Site production reactors, where the biological shield was degraded by high flux. In the production reactors this problem was solved by replacing some of the outermost fuel with neutron absorbing materials. A similar approach has been evaluated for typical light water reactors. Neutronics calculations indicate that a substantial reduction in the boundary flux can be achieved by such a method.

An additional benefit can be realized by using the poison pins for the disposal of the waste isotopes ^{99}Tc and ^{129}I.

REFERENCES

1. R. W. Hardie, W. W. Little, Jr., "3DB, A Three-Dimensional Diffusion Theory Burnup Code," BNWL-1264, Pacific Northwest Laboratory, Richland, Washington (March 1970).

2. M. E. Gibbins, M. J. Roth, and C. J. Taubman, "A General Introduction to the Use of the WIMS-E Modular Program," AEEW-R 1329, Reactor Physics Revision, AEE Winfrith, England, 1982.

3. S. H. Finfrock and D. L. Heer, "Spectrum Effects on Technetium Burn in a Thermal Reactor," Transactions of the American Nuclear Society, June 7, 1992, pp 180-181, WHC-SA-1449-S, 1992, Westinghouse Hanford Company, Richland, Washington.

4. D. W. Wootan, J. W. Daughtry, S. H. Finfrock, J. Greenborg, R. A. Karnesky, J. V. Nelson, R. P. Omberg, H. Toffer, and A. E. Walter, "A Comparative Assessment of the Destruction of Selected Fission Products in Fast and Thermal Reactors," International Conference on Design and Safety of Advanced Nuclear Power Plants, Volume 1, pp 3.7-1 - 3.7-9, Tokyo, Japan, 1992, WHC-SA-1436-FP, Westinghouse Hanford Company, Richland, Washington, 1992.

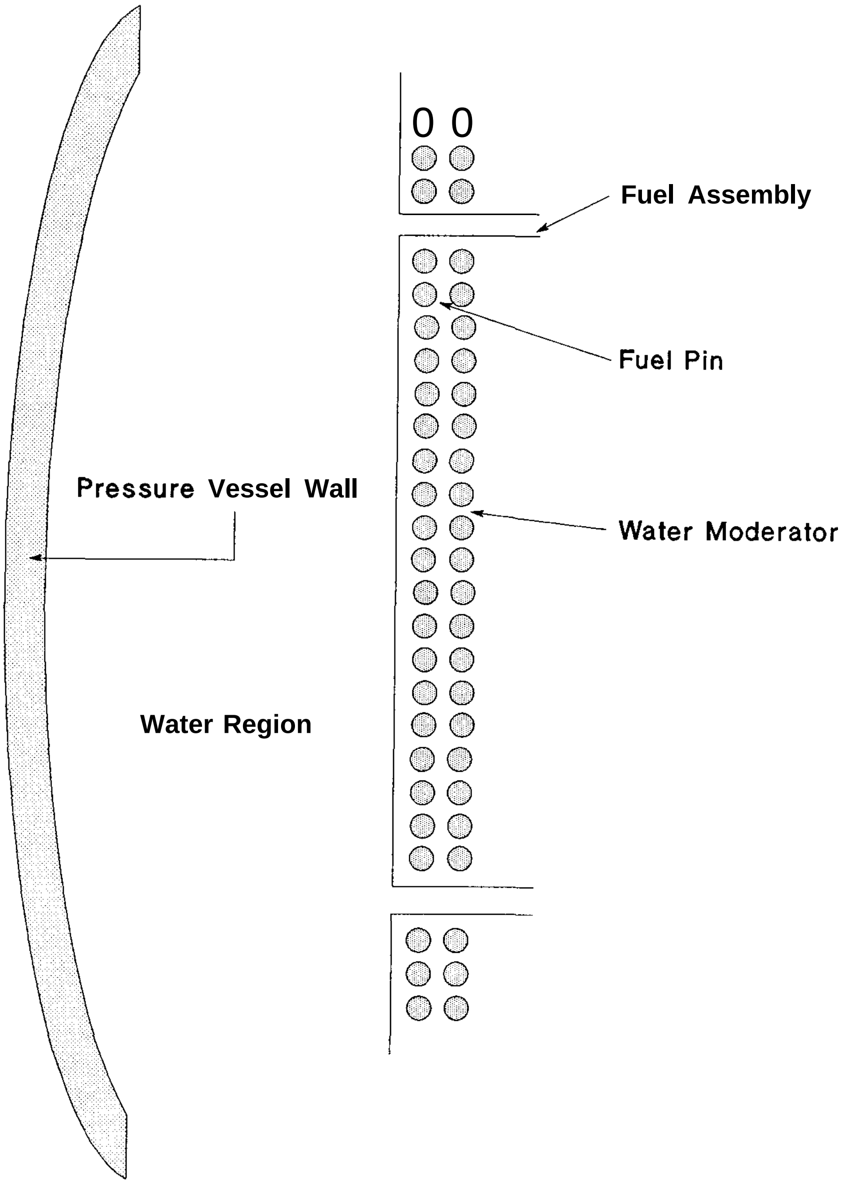

Figure3. Portion of Standard Light-Water Reactor Core.

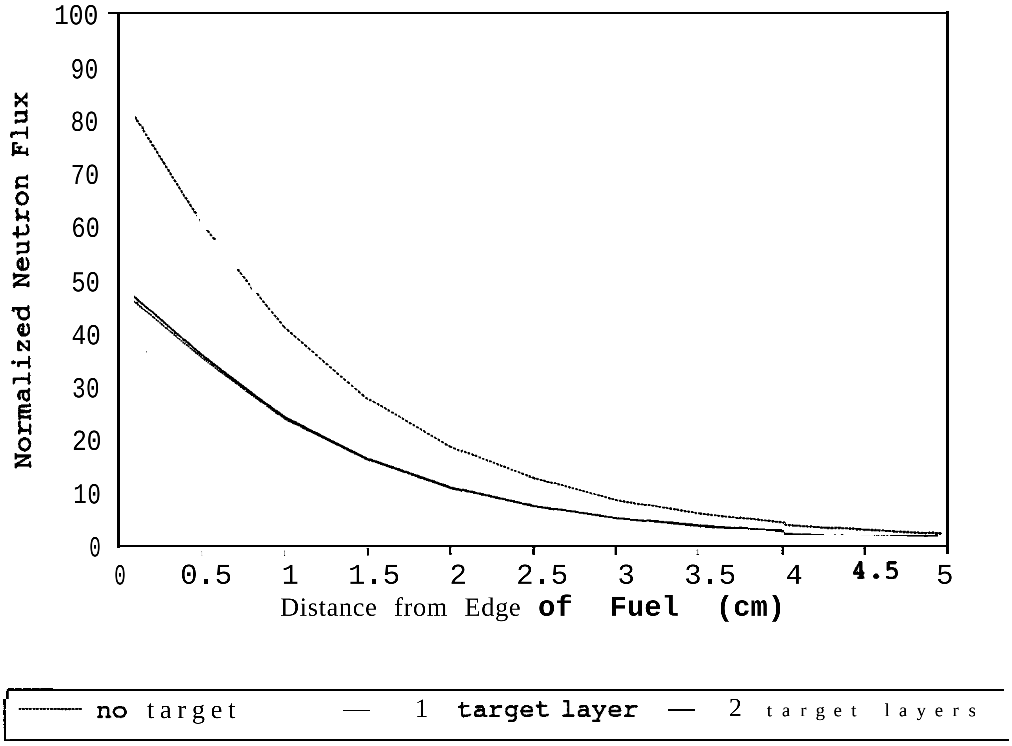

Figure 4. Edge Shielding Effects in an LWR. (Lithium Targets)

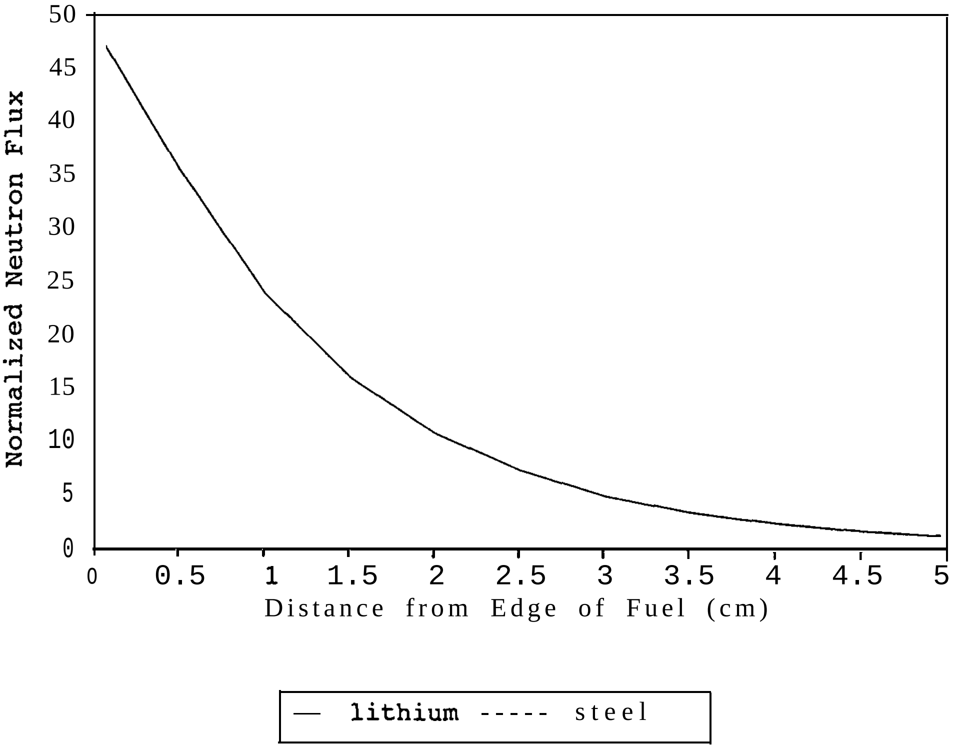

Figure 5. Edge Shielding Effects in an LWR. (Lithium versus Steel Targets)

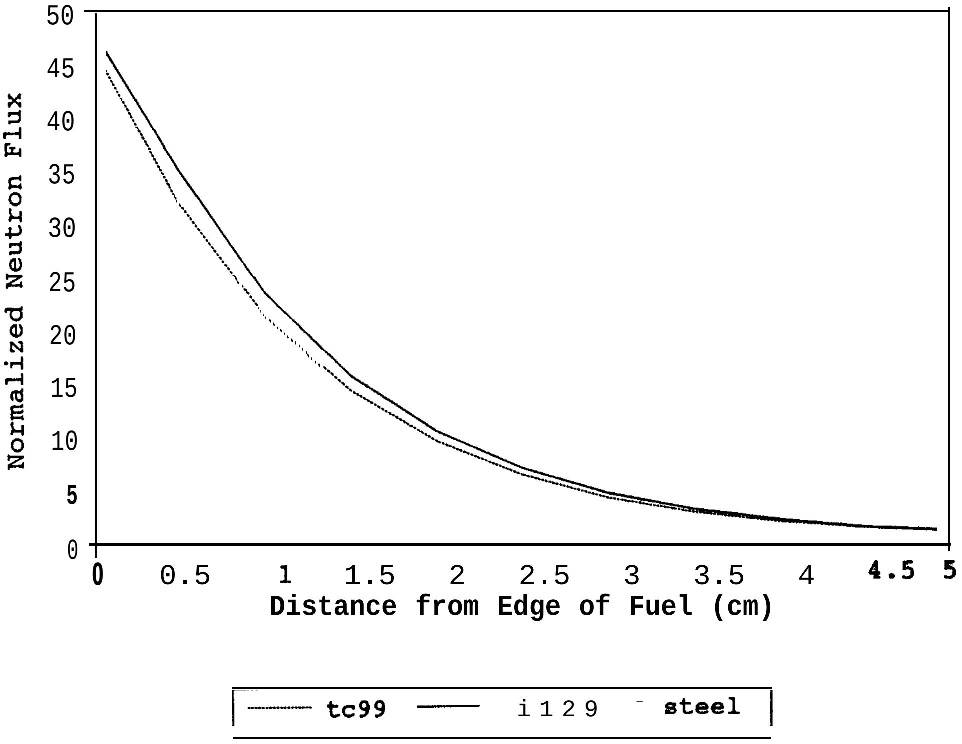

Figure 6. Edge Shielding Effects in an LWR. (isotope Targets)