TRANSMUTATION OF MINOR ACTINIDES IN A CANDU THORIUM BURNER

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ABSTRACT

The paper investigates the prospects of exploitation of rich world thorium reserves in CANDU reactors. Large quantities of plutonium have been accumulated in the nuclear waste of civilian LWRs and CANDU reactors. Reactor grade plutonium can be used as a booster fissile fuel material in form of mixed ThO^2/PuO^2 fuel in a CANDU fuel bundle in order to assure reactor criticality.

Two different fuel compositions have been selected for investigations: ① 96 % thoria (ThO_2) + 4 % PuO_2 and ② 91 % ThO_2 + 5 % UO_2 + 4 % PuO_2. The latter is used for the purpose of denaturing the new ^{233}U fuel with ^{238}U. The behavior of the criticality k_∞ and the burn-up values of the reactor have been pursued by full power operation for > ~ 8 years. The reactor starts with k_∞ = ~ 1.39 and the criticality drops down asymptotically to values $k_\infty > 1.06$, still tolerable and useable in a CANDU reactor. Reactor criticality k_∞ remains nearly constant between the 4th year and 7th year of plant operation and then a slight increase is observed thereafter, along with a continuous depletion of thorium fuel. After the 2nd year, the CANDU reactor begins to operate practically as a thorium burner.

Very high burn up can be achieved with the same fuel (> 160 000 MW.D/MT). The reactor criticality would be sufficient until a great fraction of the thorium fuel is burnt up, provided that the fuel rods could be fabricated to withstand such high burn up levels. Fuel fabrication costs and nuclear waste mass for final disposal per unit energy could be reduced drastically. There is a great quantity of weapon grade plutonium accumulated in nuclear stockpiles. In the second phase of investigations, weapon grade plutonium is used as a booster fissile fuel material in form of mixed ThO_2/PuO_2 fuel in a CANDU fuel bundle in order to assure the initial criticality at startup.

Two different fuel compositions have been used: ① 97 % thoria (ThO_2) + 3 % PuO_2 and ② 92 % ThO_2 + 5 % UO_2 + 3 % PuO_2. The latter is used for denaturized the new ^{233}U fuel with ^{238}U. The temporal variation of the criticality k_∞ and the burn-up values of the reactor have been calculated by full power operation for a period of 20 years. The criticality starts by k_∞ = ~ 1.48 for both fuel compositions. A sharp decrease of the criticality has been observed in the first year as a consequence of rapid plutonium burnout. The criticality becomes quasi constant after the 2nd year and remains above $k_\infty > 1.06$ for ~ 20 years. After the 2nd year, the CANDU reactor begins to operate practically as a thorium burner.

Nuclear waste actinides can also be used as a booster fissile fuel material in form of mixed fuel with thorium in a CANDU reactor in order to assure the initial criticality at startup. In the third phase, two different fuel compositions have been found useful to provide sufficient reactor criticality over a long operation period: ① 95 % thoria (ThO_2) + 5 % minor actinides MAO_2 and ② 95 % ThO_2 + 5 % MAO_2 + 5 % UO_2. The latter allows a higher degree of nuclear safeguarding thorough denaturing the new ^{233}U fuel with ^{238}U. The temporal variation of the criticality k_∞ and the burn-up values of the reactor have been calculated by full power operation for a period of 10 years. The criticality starts by $k_\infty > 1.3$ for both fuel compositions. A sharp decrease of the criticality has been observed in the first year as a consequence of rapid plutonium burnout in the actinide fuel. The criticality becomes quasi constant after the 2nd year and remains close to $k_\infty = \sim 1.06$ for ~ 10 years. After the 2nd year, the CANDU reactor begins to operate practically as a thorium burner.

Finally, in the fourth phase, a CANDU reactor fueled with a mixed fuel made of thoria (ThO_2) and the totality of nuclear waste actinides has been investigated. The mixed fuel composition has been varied in radial direction to achieve a uniform power distribution and fuel burn up in the fuel bundle.

The best fuel compositions with respect to power flattening as well as long term reactivity have been found by mixing thoria with 14 % minor actinides in form of MAO_2 in the central fuel bundle and decreasing radially MAO_2 content at discrete levels down to 2 % at the periphery. Furthermore, as alternative fuel, 5 % UO_2 has been added to the mixed fuel for the sake of a higher degree of nuclear safeguarding through denaturing the ^{233}U component with ^{238}U. The temporal variation of the criticality k_∞ and the burn-up values of the reactor have been calculated for a period of 10 years, operated at full power. The criticality starts at time zero near to $k_\infty = \sim 1.24$ for both fuel compositions. A sharp decrease of the criticality has been observed during the first year as a consequence of rapid plutonium burnout in the actinide fuel. The criticality becomes quasi constant after the 2nd year after sufficient ^{233}U is accumulated and remains close to $k_{\infty,end} = \sim 1.06$ over ~ 10 years. Quasi-uniform power generation density has been realized in the fuel bundle throughout the reactor operation.