Update on Use of Enriched Boric Acid in Domestic Pressurized Water Reactors

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ABSTRACT

The economics of operating pressurized water reactors (PWRs) dictate use of more and more aggressive duty cycles. Increased energy production can be achieved by using increased enrichment of the nuclear fuel, which in turn requires increased amounts of neutron poison to maintain reactivity control. The added boric acid reduces the pH of the coolant, which can adversely affect the integrity of the primary materials of construction, for example by initiating primary water stress corrosion cracking (PWSCC). The pH must therefore be elevated through the addition of an alkali such as LiOH. However, above a certain concentration, lithium will also have an adverse effect on the reactor materials, effectively limiting the amount of LiOH, and hence the amount of boric acid, that can be added to the coolant.

The isotope of boron that is the effective thermal neutron absorber is ^{10}B. This isotope comprises only 19.6% of natural boron (the remainder is ^{11}B). If the boric acid is enriched in the ^{10}B isotope (enriched boric acid – EBA), then the maximum amount of chemical shim can be increased without exceeding the chemistry limits set by the acidity of boric acid or the concentration limit of lithium. With sufficient isotopic enrichment, it therefore becomes possible to operate the entire PWR fuel cycle with constant pH at the favored value of 7.2 – 7.4.

In addition, greater amounts of chemical shim are required when utilizing alternative, high-reactivity fuels such as mixed uranium/plutonium oxide (MOX) fuels. It is estimated that EBA must be used for PWRs when the core loading exceeds approximately 50% MOX fuel.

This technical update provides a status report discussing the purpose for use of EBA, domestic use of MOX and EBA, and the status of manufacturing MOX fuel in the USA.

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PURPOSE FOR USE OF EBA

The economics of operating pressurized water reactors (PWRs) dictate use of more and more aggressive duty cycles. Increased energy production can be achieved by using increased enrichment of the nuclear fuel, which in turn requires increased amounts of neutron poison to maintain reactivity control. In the conventional PWR, natural boron, as boric acid, is introduced to the primary coolant to serve as a neutron absorber, or chemical shim. The added boric acid reduces the pH of the coolant, which can adversely affect the integrity of the primary materials of construction, for example by initiating primary water stress corrosion cracking (PWSCC). The pH must therefore be elevated through the addition of an alkali such as LiOH. However, above a certain concentration, lithium will also have an adverse effect on the reactor materials, effectively limiting the amount of LiOH, and hence the amount of boric acid, that can be added to the coolant.

Studies have shown that optimum PWR chemistry from the viewpoint of material integrity is to operate at a constant pH throughout the fuel cycle, preferably as high as pH=7.4, but certainly at pH=7.2. The advantages of this chemistry strategy have recently been demonstrated at the Comanche Peak PWR of TXU. However, it should be noted that achieving such a high pH early in the fuel cycle requires addition of LiOH beyond the conventional limits on lithium concentration. Hence the more customary practice is to begin the fuel cycle at a lower pH dictated by the lithium concentration limit, then holding the pH constant at 7.2 (or 7.4) for as much of the fuel cycle as possible once the high BOC boric acid concentration has been reduced.

The isotope of boron that is the effective thermal neutron absorber is ^{10}B. This isotope comprises only 19.6% of natural boron (the remainder is ^{11}B). Boron-10 has a cross section of 4017 barns for absorption of thermal neutrons, whereas the cross section of ^{11}B is less than 1 barn. If the boric acid is enriched in the ^{10}B isotope, therefore, the maximum amount of chemical shim can be increased without exceeding the chemistry limits set by the acidity of boric acid or the concentration limit of lithium. With sufficient isotopic enrichment, it therefore becomes possible to operate the entire PWR fuel cycle with constant pH at the favored value of 7.2 – 7.4.

Greater amounts of chemical shim are required when utilizing alternative, high-reactivity fuels such as mixed uranium/plutonium oxide (MOX) fuels. For there fuels, therefore, use of EBA becomes necessary for appropriate reactivity control within the constraints of primary water chemistry. It is estimated that EBA must be used for PWRs when the core loading exceeds approximately 50% MOX fuel.

In the USA, an overall goal of using MOX is the consumption and destruction of the weapons-grade plutonium that was amassed during the Cold War. International agreements are in place that the former Soviet Union countries will likewise dispose of their store of weapons-grade plutonium. Another benefit of MOX is that its use has potential for providing a renewable source of fissile material for use in future power generation.

Currently, MOX fuel is routinely used only in Europe, and these plants utilize EBA for reactivity control[1]. The EBA used in these plants is generally enriched to 27-30% ^{10}B. Over 30 European reactors are currently using MOX, and another 20 have been licensed to do so. Most reactors that use MOX make up approximately 1/3 of their core with MOX assemblies, although in some cases as much as 50% MOX has been loaded. Japan is also planning extensive use of MOX fuel; estimating that 1/3 of its reactors will use MOX by 2010.

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[1] Cf: EPRI Report #1003124, An Evaluation of Enriched Boric Acid in European PWRs, October 2001.

2

DOMESTIC USE OF MOX AND EBA

It should be obvious that the enrichment process will increase the cost per unit mass of EBA-based boric acid significantly compared to boric acid made with natural boron[2]. A detailed cost analysis is required for each particular case to determine whether recovery and reuse of EBA is favored over the use-and-replace option. As pointed out above, chemistry optimization with natural boric acid is possible for PWRs loading conventional enriched uranium oxide fuel[3]. Therefore, considering the relatively low market price of uranium fuels, there has been little incentive in the USA to expend the engineering and capital cost required to use, recover, and reuse EBA. But use of EBA must be considered in the future, contingent on the widespread adoption of mixed U/Pu oxide (MOX) fuel.

Whichever EBA addition/recovery option is chosen, a Utility contemplating use of EBA must also engineer the plant's control system to reflect the varying demand for neutron poison as the fuel cycle progresses[4].

At present, Duke Energy is evaluating use of MOX fuel in its Catawba 1 reactor. One incentive is the very favorable price for MOX fuel promoted by the US Government. The NRC issued a permit to Duke Energy on 5 March 2005 to use up to four MOX assemblies in either Unit 1 or Unit 2 of the Catawba PWRs. The Utility loaded four lead-test MOX assemblies during the Spring 2005 refueling outage of Catawba 1, using fuel manufactured by Framatome ANP (now Areva). The fuel cycle commenced on 5 June 2005. Contingent on favorable technical and regulatory results from this limited exposure of MOX fuel, the Utility is anticipating a batch loading of MOX in the Spring 2015 refueling outage.

The few MOX assemblies currently under irradiation in the Catawba 1 core do not require modification of the plant's primary chemistry, thus use of EBA is not required, and the Utility is operating the cycle under the conventional water chemistry guidelines of Ref. 3. However, if the batch loading of MOX contemplated for 2015 is sufficiently large, use of EBA will most likely be required, and the Utility must evaluate the options and complete engineering and plant modifications during the intervening time interval.

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[2] Cf: The Boron Report, Vol 1 No. 2, August 2002. Eagle-Picher Industries, Inc.
[3] Cf: EPRI report #1002884, PWR Primary Water Chemistry Guidelines, Rev. 5, Vol. 1 & 2, September 2003.
[4] Cf: US Patent #5,271,052, 14 December 1993.

3

STATUS OF MANUFACTURING MOX FUEL IN THE USA

Four plants are currently producing MOX fuel in commercial quantities. Two of these are in France, one in Belgium, and one in the UK. The total consumption of plutonium for manufacturing reactor fuel now exceeds 400 metric tons[5].

In the USA, the NRC has issued the Final Environmental Impact Statement for a proposed MOX fuel fabrication facility at the Savannah River Site in South Carolina[6]. The NRC staff issued the Final Safety Evaluation Report on the proposed construction, and on 30 March 2005 issued a Construction Authorization to the Duke Cogema Stone & Webster consortium that applied to construct and operate the MOX facility at the Savannah River Site.

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[5] Nuclear Issues Briefing Paper 43, July 2003.

[6] Mixed Oxide Exchange, Vol 5 No.1, NUREG/BR-0284, March 2005.

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