# Passive Autocatalytic Recombiner (PAR) Requirements for PWRs: Value Impact Assessment

Objective:

Determine whether it is cost-effective to update the existing § 50.44 requirements on combustible gas control to require passive autocatalytic recombiners for all PWRs with large-dry containment buildings.

Under this approach, a backfit would be required of licensees with plants that have large dry containments in that they would have to install PARs and maintain them for the duration of the plant license. This approach would provide control over the potential for containment failure that would otherwise result from combustion of gases produced during severe (core-damage) accidents.

## Introduction to Value-Impact Assessment

This Value-Impact assessment follows the guidelines in [1, 2]. Consistent with these guidelines, the following assumptions are made in the assessment:

- The year chosen as a base is 2002 and all costs are adjusted to reflect 2002 dollars.

- The discount rate used is 7 percent, as recommended in [2].

- The remaining life of the average plant is assumed to be 35 years. This value was determined by adding 20 years (assumption of license renewal) to 15 years remaining on the plant's current license [2].

- Using the 7 percent discount rate and 35-year lifetime, the multiplier used for determining the 2002 cost equivalent for yearly costs over the remaining life of the plant is 13.053 [2].

The "Values" considered in the assessment are:

- Public Health – Accident
- Public Health – Routine
- Occupational Health – Accident
- Occupational Health – Routine
- Property – Offsite
- Property – Onsite

The "Impacts" considered in the assessment are:

- Industry Implementation
- Industry Operation
- NRC Implementation
- NRC Operation

The Base Case for this analysis is a typical PWR with no severe-accident hydrogen control in the containment, The sign convention, consistent with [4], is that -- relative to the Base Case -- increased public and occupational health (e.g., decreased risk to the public, as is the case here) and increased property values are "positive" while reduced public and occupational health (e.g., increased risk to the public) and reduced property values are "negative." Likewise, increased implementation and operation costs for the industry and NRC are "positive" while reduced implementation and operation costs (e.g., reductions in regulatory burdens) for the industry and NRC are "negative."

The equation for determining the Value-Impact is then:

Value-Impact = {sum of all Values} - {sum of all Impacts} =

{(Public Health_Accident) + (Public Health_Routine) + (Occupational Health_Accident) + (Occupational Health_Routine) + (Property_Offsite) + (Property_Onsite)} – {(Industry Implementation) + (Industry Operation) + (NRC Implementation) + (NRC Operation)}

Thus, a positive Value-Impact will support a rulemaking action while a negative Value-Impact will not, independent of whether the rulemaking action is a relaxation or an enhancement.

## Estimation and Evaluation of Values and Impacts for the Action

### Identification of Attributes

Below is a discussion of the Value-Impact attributes for installation and maintenance of PARs in PWRs with large-dry containments. The Base Case for this analysis is a large-dry PWR with no hydrogen control in containment (no recombiners, no hydrogen ignitors).

### Public Health (Accident)

The approach taken here is to take assess the potential risk reduction and compare the dollar equivalent of that risk reduction to the costs described elsewhere in this cost-benefit assessment. The risk reduction assessment can be considered in two parts:

- <u>An estimate of the consequences of those accidents that would be eliminated if PARs were installed.</u> This is usually expressed in person-rem dose out to 50 miles from the plant. Suggested consequences, resulting from various containment failure modes are listed in [2] and repeated here in Table 1. These are used as representative of consequences resulting from containment failures caused by hydrogen burns, consequences that would be eliminated by the backfit.

- <u>An estimate of the reduction in frequency of the occurrence of those consequences, due to the PAR backfit</u>.

Table 1 first shows the consequences, frequency, associated risk and dollar equivalent for early containment failures and late containment failures for typical PWRs with large-dry containments. The second part of the table shows the estimated contribution to containment failures from hydrogen burns, as reflected in the frequency. A 10% contribution to the "Total" from hydrogen burns is assumed. This is based on results from Individual Plant Examination Program (IPE).

**Table 1: Elements for Determining Averted Risk**

| | Consequences (person-rem)[1] | Frequency (1/year)[2] | Risk (person-rem/yr) | 2002 Dollar Equivalent |
|---|---|---|---|---|
| Early Failures: Total | $6 \times 10^{6}$ | $5 \times 10^{-6}$ | 30 | $783,000 |
| Late Failures: Total | $8 \times 10^{5}$ | $3 \times 10^{-5}$ | 24 | $627,000 |
| Early Failures: Hydrogen Contribution | $6 \times 10^{6}$ | $5 \times 10^{-7}$ | 3 | $78,000 |
| Late Failures: Hydrogen Contribution | $8 \times 10^{5}$ | $3 \times 10^{-6}$ | 2.4 | $63,000 |

1 Data from [2], Table 5.3 for "Total" and "Hydrogen Contribution" values
2 Data from [6], Table 12.16 for "Total" values; for "Hydrogen Contribution" values, 10% of the "Total" was assumed based on [7], page 105.

A rough estimate of the contribution from external events is to double the values for internal events [13]. Thus, the total dollar equivalent risk reduction from eliminating containment failure due to hydrogen burns is 2 x ($78,000 + $63,000) or $282,000. This, of course, assumes that the PARs are 100% effective at mitigating the early and late containment failures assumed to be from hydrogen combustion for both internal and external events.

**Public Health (Routine)**

There is no change in the Public Health (Routine), when comparing this proposed backfit to the base case (no hydrogen control) since this backfit does not involve any change to normal operational (routine) releases from the plant.

**Occupational Health (Accident)**

This attribute is a value and is estimated consistent with the methodology described in Section 5.7.3 of [2]. The approach here was to estimate the positive value of the reduced risk of the proposed backfit compared to the base case (no hydrogen control). The risk reduction is a result of the backfit case preventing early and late containment failure due to hydrogen combustion. The frequency, of which, was estimated in Table 1. The reduction is due to lower dose consequences from Accident Scenario 2 as compared to Accident Scenario 3. These accident scenarios are described in Section 5.7.3.1 of [2]. The immediate dose for the base case was estimated to be $1.2 \times 10^{-2}$ person-rem/yr and $3.5 \times 10^{-3}$ person-rem/yr for the backfit case. The long-term dose for the base case was estimated to be 6.9 x $10^{-2}$ person-rem/yr and 2.7 x $10^{-2}$ person-rem/yr for the backfit case. The monetary value of occupational health (accident) risk avoided per facility due to immediate doses, after discounting was $220. The monetary value of occupational health (accident) risk avoided per facility due to long-term doses, after discounting was $790.

Thus the total cost for occupational health (accident) is $0.001M.

**Occupational Health (Routine)**

This attribute is a value which accounts for radiological exposures to workers during normal facility operations (i.e., non-accident situations). Assuming that the PARs will be maintained as commercial grade type components, periodic testing and maintenance would be conducted to ensure proper functioning of the PARs. This would involve the removal of a catalyst bed, placing it in an enclosure, passing a known concentration of hydrogen over the bed, and measuring the temperature difference. This work is assumed to be conducted outside containment; however, a portion of time would be required inside containment to remove, then reinstall the catalyst bed, as well as to clean the unit.

Workers who are in close proximity to the hydrogen recombiners are exposed at an average rate of 10 mrem/hour (PWRs) [2]. Although this value is based on the existing hydrogen recombiners, it is assumed that the value would be similar for PARs. Each containment (plant) would contain, on the average, 40 half-size PARs. It is assumed that testing would occur during refueling outages only, and that only a portion of the PARs would be tested during each outage. It is estimated that approximately 30 minutes would be spent inside containment for each PAR, and that at least two workers would be involved. If one-fourth of the PARs are tested during an outage, the exposure time would equate to five hours/worker, or ten person-hours. The total anticipated exposure per outage would be 100 mrem, or 66 mrem/year, assuming an 18-month refueling cycle. This equates to an impact of approximately $1,700 over 35 years, using the $2,000/person-rem conversion factor. This amount does not account for exposure time in containment due to the erection of scaffolding or other such equipment for the purposes of accessing the PARs. Additionally, the amount does not account for additional exposure from other components that might be in close proximity to the PARs. The location and accessibility of the PARs are plant-specific, and therefore, exposure related to accessing the PARs cannot be easily derived. Therefore, it is expected that actual worker exposures would be greater which makes it less likely that PARs could be justified.

**Offsite Property**

The Offsite Property benefit (cost reduction) due to this backfit is estimated consistent with the methodology described in Section 5.7.5 of [2]. From NUREG/CR-6349 [5], the offsite property consequences are typically of the same magnitude as health consequences for early containment failures and are typically less than half the health consequences for late failures. Thus, referring to Table 1, the dollar equivalent reduction in offsite property risk (including external events) is:

$78,000 (internal) + $78,000 (external) + 0.5 x $63,000 (internal) + 0.5 x $63,000 (external) = $219,000

**Onsite Property**

There would be a slight positive value in the Onsite Costs, if the approach taken for occupational health (accident) were used. This value is a result of the backfit case preventing early and late containment failure due to hydrogen combustion. Based on the results of occupational health (accident) and because the cleanup, decontamination, and long-term replacement power costs are so similar for the two cases, onsite property costs were not calculated for the purpose of this value impact assessment.

**Industry Implementation**

This attribute is an impact which accounts for the projected net economic effect on the affected licensees to install or implement mandated changes. It is estimated that an average of 40 half-sized PARs would be installed in each large, dry (PWR) containment. The average purchase price per half-sized PAR is estimated to be $24,000 [11]. Although the ability exists to produce PARs domestically, currently, PARs are imported from Europe. The amount above is based on the cost of an imported PAR. Thus, the purchase cost equates to $960,000. Should a catalyst bed need to be replaced (due to test failure), a replacement bed would cost approximately $350 [11]. A few beds are likely to be purchased at the time the PARs are purchased. Therefore, an additional cost of $1,000/plant is likely.

The engineering associated with installation of the PARs will vary depending on the intended location of the PARs and whether extensive modifications will be necessary to accommodate the PARs. Based on information provided in past SAMA evaluations, a recent response to a Request for Additional Information related to SAMA evaluations, and information obtained from Indian Point 2, engineering costs ranged from $35,000 to $400,000 [11, 12]. The projected likely cost for engineering and qualification (2-over-1) of the PARs is $150,000/plant.

Installation costs will also vary depending on the area of the country (differing labor rates) in which the plant is located. At Indian Point 2, it cost approximately $100,000 to install two full-sized PARs [11]. Although the cost for installation is not expected to increase by 20 times, it is expected to increase by a factor of five (based on economy of scale). Thus, total labor costs are expected to be $500,000 per plant.

The PARs, most probably, will be maintained as commercial grade components. It is assumed that testing and surveillance would be conducted to ensure proper functioning of the PARs. A testing/surveillance procedure would need to be developed. Industry estimates for development of a procedure and its implementation (i.e., training) are a minimum of $30,000 [4]. However, the procedure for testing the PARs is not as complex as other procedures (such as emergency operating procedures), and has already been developed for Indian Point 2. The effort at Indian Point 2 cost approximately $2,000 [11]. However, this included the training of only two individuals. Since for the purposes of this analysis 40 PARs are going to be installed, it is likely that more than two individuals would be trained. Therefore, the estimated cost for developing and implementing the testing procedure at a typical large, dry PWR is estimated to cost $3,000.

The catalyst beds need to be tested in a testing enclosure complete with sensing instrumentation and a computer. The current cost for such a testing apparatus is $10,000. Each plant would require a testing apparatus.

Thus the total cost for industry implementation is $1.624 M.

**Industry Operation**

This attribute is an impact which measures the projected net economic effect due to routine and recurring activities required by the proposed action on all affected licensees.

The only expected operation costs associated with the PARs after installation will be due to testing. One catalyst bed per PAR should be tested periodically. It is estimated that it will take a technician 0.5 hour to remove a catalyst bed, observe the PAR for any fouling (accumulation of dirt, debris, dusts), then reinstall it after testing [11]. The total time estimated for performing the test, including transportation time, paper work, etc., is one hour per PAR [11]. This process involves two persons. Therefore, the total labor cost involved with testing is estimated to be $200/PAR. This equates to approximately $1,300 per year per plant based on an 18-month refueling cycle. Using the multiplier of 13.053 to determine the year 2002 cost equivalent, the cost is $17,000.

The testing involves the passing of a known concentration of hydrogen gas across the catalyst bed. A cylinder of hydrogen would be required to perform the testing. At Indian Point 2, it cost approximately $100/PAR for the hydrogen [11]. Therefore, at a PWR considered by this analysis, the cost for hydrogen per year is estimated to be $700. Again, using the multiplier of 13.053 to determine the year 2002 cost equivalent, the cost is $9,000.

The last expected cost associated with operation of the PARs is a calibration of the testing unit once every six years. This cost is expected to be approximately $1,000 per calibration. If this calibration took place once every year over the remaining life of the plant the year 2002 cost equivalent would be $13,053. Using a remaining life of 35 years, approximately six calibrations will be necessary for a year 2002 cost equivalent of $2,000.

Thus the total cost for industry operation is $0.028 M.

**NRC Implementation**

This attribute is an impact which measures the projected net economic effect on the NRC to place the proposed action into operation.

The proposed action (installation of PARs) would necessitate a rulemaking as well as revision to or development of regulatory guidance. The cost for a simple rulemaking is estimated to be $300,000. More complex rules can cost upwards of $1,000,000. It is likely that this rulemaking would generate many comments, thus, necessitating staff review and response to the comments. Therefore, a cost of $500,000 is estimated for the rulemaking or $8,000 per reactor assuming 60 units.

**NRC Operation**

This attribute is an impact which measures the projected net economic effect on the NRC after the proposed action is implemented. As a result of the proposed action, there will be an increased effort during inspections. This Increase is expected to be small, and not quantified in detail for the purposes of this analysis. An additional inspection cost of about $1,000/year is not unreasonable. Thus, the 2002 cost equivalent is $13,000.

## Presentation of Results

### Results for PARs

For PWRs with large dry containments, a requirement would be added to install and operate PARs.

**Table 2: Results for PARs for PWRs with Large Dry Containments**

| Quantitative Attribute | | | Present Value Estimate ($M)/reactor (rounded to nearest $K) |
|---|---|---|---|
| Health (value) | Public | Accident | 0.282 |
| | | Routine | 0.000 |
| | Occupational | Accident | 0.001 |
| | | Routine | -0.002 |
| Property (value) | Offsite | | 0.219 |
| | Onsite | | 0.000 |
| Industry (impact) | Implementation | | 1.624 |
| | Operation | | 0.028 |
| NRC (impact) | Implementation | | 0.008 |
| | Operation | | 0.013 |
| **NET Value (Values minus Impacts)** | | | **-1.173** |

The Industry Value-Impact – the "per unit" Value-Impact times 60 units – is about -$70M. From Table 2, the Value-Impact is calculated to be:

$500K (Value) - $1,673K (Impact) or -$1.173M/plant.

<u>Thus the net value is negative, suggesting that the proposed action is not cost-beneficial.</u>

### Consideration of uncertainties

The important uncertainties are those which would adversely affect the preliminary results of this Value-Impact assessment. Thus the uncertainties discussed here are those that would increase the magnitude of the "Values," listed in Table 2 or decrease the magnitude of the "Impacts" listed in Table 2.

- A suggested sensitivity analysis [2] is to change the discount rate from 7% to 3%. This affects the operational impacts and the public-accident and offsite-property values and is summarized in Table 3. The new Value-Impact is -$0.869M.

**Table 3:Results for PARs for PWRs with Large Dry Containments**: Discount Rate Sensitivity

| Quantitative Attribute | | | Present Value Estimate ($M)/reactor (rounded to nearest $K) 3% Discount Rate assumed |
|---|---|---|---|
| Health (value) | Public | Accident | 0.468 |
| | | Routine | 0.000 |
| | Occupational | Accident | 0.002 |
| | | Routine | -0.003 |
| Property (value) | Offsite | | 0.364 |
| | Onsite | | 0.000 |
| Industry (impact) | Implementation | | 1.624 |
| | Operation | | 0.046 |
| NRC (impact) | Implementation | | 0.008 |
| | Operation | | 0.022 |
| **NET Value (Values minus Impacts)** | | | **-0.869** |

• The key components of the public accident health value are (taken from Table 1):

| | Consequences (person-rem) | Frequency (1/year) |
|---|---|---|
| Early Failures: Hydrogen Contribution | $6 \times 10^{6}$ | $5 \times 10^{-7}$ |
| Late Failures: Hydrogen Contribution | $8 \times 10^{5}$ | $3 \times 10^{-6}$ |

The consequences listed are average values. They will be larger for some high-population sites and lower for low-population sites. As an example, for Zion (high population site) the consequences of an early hydrogen burn failure are estimated to be $1.8 \times 10^{7}$ person-rem [7], or three times larger than the value used in the analysis. (Other plants, of course, have values lower than the values used in the analysis.) Even if the high Zion values were used (a factor of three increase in consequences), the Value-Impact for PARs would still be negative, i.e., about -$600K. The frequencies shown are 10% of the average frequencies for early and late containment failures for PWRs with large-dry containments (average of all the IPE results). As discussed in the section on "Public Health (Accident)," frequencies given for hydrogen-related failures are considered conservative. Uncertainties would, for the most part, reduce the values further.

An uncertainty that would drive the Value-Impact to even larger negative values is the consideration of time added to an outage for the installation of the 40 PRAs. The analysis above assumes that the installation can be done with no impact on an outage. One day of added outage due to the backfit would add between $500K and $1,000K to the industry implementation costs.

## Summary

In summary, the analysis indicates that the fleet of PWRs with large-dry containments would not benefit from a PAR backfit. The Value-Impact equals -$1,173,000/PWR or about -$70,000,000 for the fleet of PWRs. The previous study on hydrogen control for PWRs with large-dry containments [7] also concluded that a 100% effective hydrogen control system (Hydrogen Ignitor System), a system more effective in mitigating accidents than PARs (with the exception of accommodating loss of all electric power), is not beneficial.

## References


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