When is it justified to delay the implementation of safety improvements after they have been approved?

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Abstract: After safety improvements have been approved, actual implementation can often be delayed significantly in the nuclear sector. This situation can be unsatisfactory for safety experts conscious of the safety benefits foregone during such a delay. They rightly assimilate this to a cost in terms of safety. The present paper proposes a cost-benefit analysis of this question. Two different types of delay benefits are distinguished: the time value of delaying the implementation on the one hand; and possible reductions in implementation costs. These two benefits are first approached separately after which a general formula is proposed and discussed. Delays generally appear difficult to justify, except when cost reductions are substantial and delays are limited.

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Implementation delays can be quite substantial after safety improvements have been decided upon. This is challenging for safety experts, especially those who have been researching and advocating the improvements. They may feel that protracted delays carry heavy safety costs. On the other hand, managers responsible for carrying out the works face technical constraints and more immaterial competing objectives.

This paper proposes a cost-benefit analysis of such delays — one aspect for consideration in broader complex and delicate discussions. The analysis involves the safety costs of delaying implementation, on the one hand; and on the other hand, two largely independent types of benefits involved in a possible delay:

1. The time value: when implementation delays do not result in lower implementation costs, the potential benefit only lies in postponing the considered expenses — economists use the expression “time value”. A first simplified cost-benefit analysis simply compares the time value and the safety cost.
2. Cost optimization: when implementation delays offer the possibility of reducing costs, it can be justified to delay the implementation of a safety modification. Intuitively, the reduction in costs must be attractive and the delay reasonable. In order to examine a “pure” cost optimization, this situation is analyzed when there is no time value (this obtains when the interest rate is zero).

The paper first addresses these two specific cases which provide a good understanding of the trade-offs involved; a general cost-benefit formula is then derived and conclusions are drawn.

1. DELAYS ARE NOT JUSTIFIED WITHOUT COST REDUCTIONS

This result is obtained without difficulty, using minimal formalism with the following notations:

G is the yearly safety benefits: the considered safety modification typically yields a gain in terms of accident probabilities, for instance a reduction in yearly failure probability of 10^{-8}/year. This safety gain is translated into monetary terms resulting in a value G.

N is the number of years of production left for the plant.

i is the interest rate or discount rate; from a public point of view, i would be the social discount rate while from a private point of view, it would be the financial yield the operator can obtain by disposing of the funds made available by the delay.

n is the number of years of delay between the decision to go forward with the considered safety modification and its actual implementation in the plant.

C is the cost of the modification under scrutiny.

The total safety benefit in case of immediate implementation is the discounted sum of benefits from now until year N that is:

$$\sum_{1}^{N} \frac{G}{(1+i)^t}$$

And the value of the safety modification is:

$$V_0 = \sum_{1}^{N} \frac{G}{(1+i)^t} - C$$

Similarly, for a delay of n years, safety benefits would be:

$$\sum_{n+1}^{N} \frac{G}{(1+i)^t}$$

And the value of the safety modification becomes:

$$V_n = \sum_{n+1}^{N} \frac{G}{(1+i)^t} - \frac{C}{(1+i)^n}$$

Comparing the two options boils down to considering the difference $D = V_0 - V_n$. If the difference D is positive, then implementation should not be delayed because the net benefit of immediate implementation V_0 is larger than the benefit with delayed implementation V_n. In other words, if D is positive the delay would imply safety costs higher than the time value, i.e. higher than the financial benefit (e.g. the return which would be obtained by wisely investing C on financial markets). D is the potential loss involved in the delay. If D is negative, then the delay yields benefits larger than the safety costs.

We have:

$$D = \sum_{1}^{n} \frac{G}{(1+i)^t} - C\left[1 - \frac{1}{(1+i)^n}\right] \qquad (1)$$

and simple calculations lead to (appendix 1):

$$D = \frac{C}{i}\left[1 - \frac{1}{(1+i)^n}\right]\left(\frac{G}{C} - i\right) \qquad (2)$$

for which a first order approximation, generally acceptable since i is small, is:

$$D = nC\left(\frac{G}{C} - i\right)$$

In both expressions, the sign of D is that of (G/C – i) or G – iC, the difference between the annual safety gain and the annual yield of the funds the safety modification requires to be implemented.

This result is remarkable: it does not depend upon n. In other words, if it is justified to delay the safety modification by *one* year, then it is also justified to delay it by n years *whatever the value of n*! This is easily conceived through the following argument: if G – iC is negative, works should be delayed by one year because financial yield iC is larger than safety benefits G. When one asks the question again, one year later, the answer has not changed! One should again postpone implementation by one year; and so forth *ad infinitum*.

In still other words, if it is justified to implement the safety modification, then it should be implemented immediately (remember: no cost reductions are expected).

In practice, usual orders of magnitude suggest that implementation delays are not justified by the time value alone and safety modification should be implemented immediately when the decision is agreed upon if no cost savings can be expected. Safety modifications are often acceptable as long as the cost is lower than 10 times the safety benefit which is roughly equivalent to considering that most safety modifications provide benefits for more than 10 years:

$$G/C > 10\%.$$

On the other hand,

$$i < 10\%.$$

Indeed, from the authority point of view, i is the social discount rate which, in most countries is in the range 3 – 4%. From the operator point of view, this is also the case as long as real rates of return are lower than 10%; for example, in France, a figure of 8% has been used in the past (it could be lower nowadays considering general economic conditions).

The time value (iC) is generally low in comparison to the value of safety (G). In other words, the efficiency (G/C) of safety modifications which are agreed upon is generally above the discount rate i.

2. A DELAY CAN BE JUSTIFIED WITH SIGNIFICANT COST REDUCTIONS

For the sake of clarity, we now disregard the modest time values treated in the previous section. The potential loss D then simply boils down to: D = nG - ΔC. indeed there is no discount rate, the non-discounted sum of benefits foregone during the n year delay is simply nG and the benefit of postponing works is the cost reduction ΔC. Looking at things slightly differently, in this simplified case the value of immediate implementation is NG – C while the value of the delay would be (N-n)G – (C-ΔC) and the difference is D = nG - ΔC.

If D is positive, it is beneficial to implement the modification immediately because the safety gain nG is larger than the foregone cost-reduction ΔC. If D is negative it is preferable to delay the works in order to benefit from the cost-reduction because it is substantial and higher than the safety gains.

It is convenient to write D as:

$$D = nC\left(\frac{G}{C} - \frac{\Delta C}{nC}\right) \tag{3}$$

As in the previous case, the sign of D features the efficiency ratio G/C; the cost reduction ΔC only intervenes through its ratio ΔC/C; and contrary to the previous case, the number of years of delay n plays a crucial role. Even when a one year delay is beneficial, nothing guarantees that a two-year delay would still be justified. Furthermore, when n is large, delays can no longer be justified because the second term tends towards zero.

In practical terms,

- as we have seen above, G/C > 10% for most economically viable safety modifications; therefore, cost reductions should be larger than 10% for a one-year delay to be acceptable; larger than 20% for a two-year delay; and so forth; a 10 year delay cannot be justified
- if G/C > 1 then even a one year delay cannot be justified; if G/C > 50% then a two-year delay cannot be justified; and so forth.

It therefore appears that the window of opportunity for economically justifiable delays is not immense: it requires that safety benefits be moderate and simultaneously that cost reductions be significant.

Notice that the decision does not depend upon the safety modification cost C. The sign of D is not affected by C; however, the *size* of C directly affects the *size* of D. Therefore indeed, when C is small, the question is irrelevant in practice and delays need not be considered. In contrast, when C is large, the stakes justify an in-depth analysis, but this should involve neither C nor ΔC, but the percentage savings ΔC/C.

Neither does the decision depend upon N, the number of years of potential future operation. Indeed total safety gains are close to NG, but the decision only depends upon the efficiency G/C.

3. A GENERAL FORMULA

Considering the general case allows the two types of above results to be taken into account. Formula (1) becomes:

$$D = \sum_{1}^{n} \frac{G}{(1+i)^t} - C + \frac{C - \Delta C}{(1+i)^n} \qquad (4)$$

which yields:

$$D = \frac{1}{r}\left[1 - \frac{1}{(1+i)^n}\right][G - i(C - \Delta C)] - \Delta C \qquad (5)$$

The expression $\frac{1}{i}\left[1 - \frac{1}{(1+i)^n}\right] = n^*$ represents n years discounted at rate i[1].

D then becomes:

$$D = n^*\left(\underbrace{G}_{\text{Safety}} \; \underbrace{- i(C - \Delta C)}_{\text{Time value}} \; \underbrace{- \frac{\Delta C}{n^*}}_{\text{Cost savings}} \right) \qquad (6)$$

This expression directly involves costs measured in currency. The value of cost savings appears as $\Delta C/n^*$ which again suggests that implementation delays cannot be protracted without affecting the economic benefit of the delay.

Expression (6) can usefully be presented using dimensionless ratios:

$$D = n^* C \left[\frac{G}{C} - i\left(1 - \frac{\Delta C}{C}\right) - \frac{\Delta C}{n^* C}\right] \qquad (7)$$

This leads to six major conclusions:

1. For many safety modifications, a delay is never justified. If G/C is larger than 100% (the yearly safety gain is larger than the safety modification cost), postponing implementation of the safety modification is never justified in practice because the second term of the expression is low (see hereafter) and the third term is lower than 1.
2. For the majority of other safety modifications, only limited implementation delays can be justified. In practice for a delay of n* years to be justified, it is necessary that G/C < 1/ n*; for example, a delay of 10 discounted years can only be justified with G/C < 0.1.

[1] It can be developed as: $n^* = n\left(1 - \frac{n+1}{2} r + \varepsilon(r^2)\right)$

3. The benefit of cost savings rapidly declines with the number of years of delay. The third term relative to cost savings is always lower than one, for example with $\Delta C/C = 50\%$, it is worth 50% for $n^* = 1$, but only 25% for $n^* = 2$.
4. The time value is generally small. The second term relative to time values is lower than i; for example for $i = 4\%$ (point of view of the safety authority) and $\Delta C/C = 50\%$, it is only worth 2%; in general, it should play a secondary role in the decision.
5. The cost of the safety modification plays no direct role in the decision. As far as the decision is concerned, it only intervenes through the efficiency G/C and the rate of cost savings $\Delta C/C$. C determines the stakes involved in the decision; if C is large and the decision is incorrect the loss is large.
6. The discount rate plays a minor role.

4. CONCLUSION: THE ROLE OF THE EFFICIENCY G/C

As is clear by now, the efficiency G/C should play a major role in the decision to delay or not delay the implementation of a safety modification. While the authority and the operator can often agree on the cost C, they may well differ in their estimation of the safety gain G.

(i) In legal terms, the utility would only be responsible for a limited portion of total accident costs. While it could be held accountable for on-site costs and for some so-called direct consequences, it is highly improbable that image costs and impacts on electricity production, domestic and worldwide, would be borne by the utility. In practice, it may only have a limited financial capacity to pay for its own damages not to mention compensation of direct victims.

We refer to IRSN estimates of accident costs in France [1] which show that for a severe but not major nuclear accident, image costs and costs related to electricity production (domestic) would represent more than three quarters of the total cost in France. Even for a major accident, these components would account for more than half the cost. If therefore utilities were to consider their limited involvement in compensation for accident losses, they might largely underestimate accident costs and therefore safety benefits.

(ii) There could also be a tendency among utilities to consider failure probabilities limited to initiators which directly involve their own responsibility. Along this line of thinking, they could advocate that “acts of God” are beyond their responsibility and are not to be included. On the contrary, authorities considering the interest of the nation globally should include all causes of failure. Thus there might be another difference in appreciation of safety benefits due to the authority considering failure probabilities higher than those assumed by the utility.

(iii) And there is a third consideration related to risk aversion with respect to nuclear accidents. Risk aversion might be higher among representatives of the nation who would naturally be concerned with the fate of victims. Utility managers could exhibit lower risk aversion due to their familiarity with nuclear and because they might disregard the entire scope of consequences.

For these three reasons, safety gains considered by the nuclear authority could be more than 10 times higher than those considered by the utilities. This would naturally be reflected in different values of the safety efficiency G/C. For instance, while utilities would naturally exhibit a willingness to pay or safety modifications with efficiencies down to 5 to 10%, authorities might consider these same modifications to have efficiencies of 50% to 100% and higher.

Therefore, utilities may argue for delays in a perfectly candid way, on the basis of parameter estimates which are perfectly justified from their own point of view, white authorities should enforce immediate or rapid implementation when keeping in mind the social benefits of safety.

Disclaimer
The ideas presented in this paper are those of the author and may not represent positions held by IRSN.

Appendix

$$\sum_{1}^{n}\frac{1}{(1+i)^t}=\frac{1}{(1+i)}+\frac{1}{(1+i)^2}+\cdots+\frac{1}{(1+i)^n}$$

$$=\frac{1}{(1+i)}\left[1+\frac{1}{(1+i)}+\frac{1}{(1+i)^2}+\cdots+\frac{1}{(1+i)^{n-1}}\right]$$

$$=\frac{1}{(1+i)}\frac{1-\frac{1}{(1+i)^n}}{1-\frac{1}{1+i}}=\frac{1}{i}\left(1-\frac{1}{(1+i)^n}\right)$$ from which (2) follows immediately.

This represents the number of discounted years. Based on $(1+i)^{-n}=1-ni$, the first order development reduces to n; in other words, the first order corresponds to no discounting.
The second order approximation is $\mathrm{n}-\frac{\mathrm{n}+1}{2}i$, the discounted number of years is lower than n. Here are a few values for this reduction:

Reduction in number of years due to discounting

Number of years	Discount rate i 2%	4%	6%	8%
2	-2%	-3%	-5%	-6%
4	-1%	-3%	-4%	-5%
6	-1%	-2%	-4%	-5%
8	-1%	-2%	-3%	-5%
10	-1%	-2%	-3%	-4%

In particular, when n is « large », the percentage reduction is close to r/2.

Reference

[1] Pascucci-Cahen, L., and Momal, P. Massive radiological releases profoundly differ from controlled releases. Eurosafe 2012.