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7 Baldin Drive
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Secretary of the Commission
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Attention: Docketing and Service Section

Dear Sir:

Enclosed as a comment on Regulatory Guide 1.110, "Cost-Benefit Analysis for Radwaste Systems for Light-Water-Cooled Nuclear Power Reactors" is a paper to be presented at the 25th Annual Meeting of the American Association of Cost Engineers, June 28 to July 1, 1981, Toronto, Canada. The paper disagrees with the regulatory guide's exclusion of the effects of inflation from the cost-benefit analysis and concludes that this exclusion would bias the analysis toward higher radiation exposures.

It is hoped that this comment will be of use to you in revising this regulatory guide.

Sincerely,

Alan D. Burkhart

Alan D. Burkhart, P.E., C.C.E

ADB:ea
Enclosure: "A Cost-Benefit Analysis Method Which Includes A Correction for Inflation" by A. D. Burkhart

Acknowledged by card 6/30/81 mdv

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A COST-BENEFIT ANALYSIS METHOD WHICH INCLUDES A CORRECTION FOR INFLATION

by

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Abstract

The objective of this paper is to develop a method for correcting a cost-benefit analysis for inflation at a constant rate. The U. S. Nuclear Regulatory Commission's Regulatory Guide 1.110, "Cost-Benefit Analysis for Radwaste Systems for Light-Water-Cooled Nuclear Power Reactors", March 1976, is the method to which this correction is applied. An algebraic expression is derived to replace the well known Capital Recovery Factor.

The Capital Recovery Factor converts a capital expenditure to an annual basis accounting for the time-value of money. If i denotes the (nominal) interest rate in percent per year, n denotes the number of years in the capital recovery period, and k represents a constant percent per year decrease in purchasing power of the dollar, a De-escalated Capital Recovery Factor (DCRF) can be found. By solving for the sum of a uniform series, it can be shown that the DCRF is given by the expression:

$$\frac{(1+i)^n}{1+k} \times \frac{i - k}{(1+i)^n - (1+k)^n}$$

The De-escalated Capital Recovery Factor identifies the real annual cost in base year dollars rather than a nominal dollar cost. If the inflation rate is zero, the expression reduces to the standard Capital Recovery Factor.

It can further be shown that the real cost of money without inflation, r, is found from the expression:

$$(1+i) = (1+k)\ (1+r)$$

This formula clearly shows the effect of the "inflation premium" on the cost of money.

The NRC Regulatory Guide describes how to equate the "value" of one man-rem of radiation exposure to the capital expense involved in reducing the radiation exposure. In this manner, the licensee can demonstrate that he has met the criterion for reducing radiation exposure to "as low as reasonably achievable (ALARA)". The intent of the cost-benefit analysis is to identify those cases where an expenditure of capital is justified because the "savings" in radiation exposure more than offsets the expense, i.e. a favorable cost-benefit analysis.

However, the procedure proposed by the NRC ignores the effects of inflation (as do most elementary problems in engineering economics). Given the premise that the effects of inflation on the value of the exposure and the cost of equipment are the same, the exclusion of the effects of inflation is not reasonable because the costs are not incurred at the same time. The NRC method does not account for the decrease in purchasing power of the dollar over this time difference. In fact, as is shown in a comparison between removable concrete panels and shielded doors for infrequent access to radiation areas, the failure to include inflation in the analysis, biases the comparison against the expenditure of capital to reduce radiation exposure.

Discussion

A multitude of situations and regulations require cost-benefit analyses to be performed to select proper alternatives. One such case is the U.S. Nuclear Regulatory Commission (NRC) criterion for reducing radiation exposure to personnel to "As Low As Is Reasonably Achievable" (ALARA) (Reference 1).

The NRC's Regulatory Guide 1.110 (Reference 2) provides a method for licensees to demonstrate that the ALARA criterion has been satisfied by their liquid and gaseous radioactive waste system designs. The NRC's method specifies that annual radiation exposures be determined and valued at $1,000 per man-rem or man-thyroid-rem. The essence of the analysis is a comparison of the benefit (in dollars) of eliminating this annual radiation exposure with the annual cost of the equipment needed to accomplish this reduction. If the benefit is greater than the cost, the analysis and the ALARA criterion require the licensee to include the equipment in its design.

The Regulatory Guide 1.110 procedure uses a

Capital Recovery Factor (CRF) to convert the capital expenditure (construction cost) of alternatives to an annual basis. The Capital Recovery Factor provides the time-value of money (annual fixed charge) for one year assuming a multi-year plant investment. (An analogy can be made to a homeowner's mortgage: the Capital Recovery Factor computes the amount of the annual repayment; e.g. for a $50,000 mortgage, i = 10%, n = 30 years, the annual repayment is $5,304). The Capital Recovery Factor is given by the formula:

$$CRF = \frac{i\,(1+i)^n}{(1+i)^n - 1} \tag{1}$$

where i = interest rate
n = capital recovery period

However, the above formula ignores the escalation or decrease in the purchasing power of the dollar over the capital recovery period. (Again by analogy to the homeowner's mortgage, the homeowner finds that the $5,304 he repays in the last year of mortgage is worth much less to him, and to the bank, than in the first years of the mortgage.) For a fixed escalation rate a De-escalated Capital Recovery Factor (DCRF) can be derived as shown in the Appendix. It is given by the formula:

$$DCRF = \frac{(1+i)^n}{1+k} \times \frac{i-k}{(1+i)^n - (1+k)^n} \tag{2}$$

where i and n are as given above and

k = escalation rate.

If i = 10% per year
n = 30 years
k = 8% per year

then CRF = 0.1061

and DCRF = 0.0437

(Returning to the analogy of the homeowner's $50,000 mortgage, the DCRF shows that for 8% escalation the average annual repayment cost to the homeowner is $2187 in base year dollars instead of $5,304).

Another way of viewing the effect of inflation on the time-value of money is the following relationship implicit in the derivation of the DCRF:

$$1 + r = \frac{1+i}{1+k} \tag{3a}$$

where r = the real cost of money.

The fraction $\frac{1+i}{1+k}$ shows shows that for a given (nominal) interest rate, i, inflation reduces the cost of money to borrowers. If the equation is rewritten as

$$(1+i) = (1+k)(1+r) \tag{3b}$$

one can also see that for lenders to achieve a fixed return, r, they must apply the inflation premium (1+k) to determine the nominal interest they must charge.

Finally, all of the standard time-value of money relationships apply if the real cost of money, r, is used instead of the nominal interest rate, i:

$$r = \frac{1+i}{1+k} - 1 \tag{3c}$$

If i = 10%
k = 8%

then r = 1.85%

Returning to the cost-benefit analysis, it is obvious that inclusion or exclusion of the effect of inflation will change the results of the analysis. In the case of i = 10%, k = 8% and n = 30 years, the CRF is 0.1061 but the DCRF is 0.0437. Thus, the annualized cost of the capital expenditure when the effect of inflation is included is $\frac{0.0437}{0.1061}$ or 41% of the expected cost when inflation is ignored.

The NRC's Regulatory Guide 1.110 states "...the Commission has not outlined any procedures for including the effects of inflation in the analysis.... Since the worth of a man-rem or man-thyroid-rem to the public is subject to the same fluctuations in value as the cost of equipment to reduce radioactive emissions, the NRC staff believes this approach to be reasonable." (Reference 2) Although it is reasonable (at least as a first approximation) to expect that the effects of inflation on both the cost of equipment and the value of a man-rem or man-thyroid-rem of radiation exposure will be the same, the NRC approach is not reasonable because the costs are not incurred at the same time. The NRC method does not account for the decrease in purchasing power of the dollar over the time difference between the two expenditures. Utilizing the DCRF rather than the CRF would correct this error.

Alternately, the decrease in the purchasing power of the dollar can be accounted for by using the real cost of money, r, instead of the nominal interest rate, i. Since the cost-benefit analysis is made on an annual basis, the only factor that involves the time-value of money is the annualized capital cost. When the standard CRF is computed using the real cost of money, r, in place of the interest rate, i, the annualized capital cost is corrected for the effects of inflation.

The NRC's exclusion of the effects of inflation from the cost-benefit analysis in fact biases the comparison against the expenditure of capital to reduce radiation exposure. For the example values given previously (i = 10%, n= 30 years, and k = 8%) ignoring inflation is similar to reducing the value of a man-rem or man-thyroid-rem of radiation exposure from $1,000 to $410 (or by 41%).

Method

The cost-benefit analysis method proposed by the NRC in Regulatory Guide 1.110 includes tables and information to compute the Total Annual Cost (TAC) of additional radioactive waste system equipment as follows:

1. Obtain the direct cost of equipment and materials.

2. Obtain the direct labor cost and correct it for the proper geographical area.

3. Add these two costs to obtain the Total Direct Cost (TDC).

4. Multiply TDC by the appropriate Indirect Cost Factor (ICF) to obtain the Total Capital Cost (TCC). (The ICF allows for the following items:

   construction facilities, equipment and services;

   engineering and construction management services;

   other owner's costs;

   interest during construction)

5. Multiply the TCC by the appropriate CRF to obtain the Annual Fixed Cost (AFC).

6. Add the Annual Operating Cost (AOC) and the Annual Maintenance Cost (AMC) to the AFC to obtain the TAC.

If the TAC is less than the "benefit" determined by multiplying the radiation exposure reduction by the "value" of a man-rem or man-thyroid-rem, the analysis favors the installation of the equipment.

Example

The following sample problem demonstrates how the cost-benefit analysis is performed and compares the results when the effects of inflation are included or excluded. This particular problem involves radiation exposures to plant operating personnel instead of members of the public. Therefore, a value of $5,000 per man-rem was selected; otherwise, the analysis is consistent with the NRC's method, corrected to include the effects of inflation.

A shielded door is being considered to replace a removable concrete shield panel; either arrangement provides infrequent access for plant personnel to a radiation area. The door would eliminate the labor and radiation exposure involved in removing the concrete panel. Except for the labor involved in removing the panel, the Annual Operating and Maintenance Costs (AOC and AMC) are considered negligible in both cases.

Item	Door	Panel	Difference (Door less Panel)
Total Direct Cost (TDC)	\$80,000	\$3,000	\$77,000
Access frequency	Twice per year	Twice per year	-
Radiation Level	25 millirem/hour	25 millirem/hour	-
Labor required per access	40 manhours	40 manhours	(40 manhours)
Labor rate	\$11.00/manhour	\$11.00/manhour	-
Annual Operating Cost (AOC)	0	\$880	(\$880)
Radiation Exposure	0	2 man-rem	(2 man-rem)

TCC = TDC x ICF ICF = 1.75
= \$77,000 x 1.75
= \$134,750

AFC = TCC x CRF CRF = 0.0437
= \$134,750 x 0.0437 for r = 1.85%, n=30yr.
= \$5,895

TAC = AFC + AOC + AMC
= \$5,895 - \$880 + 0
= \$5,015

Benefit = 2 man-rem x \$5,000/man-rem = \$10,000

The Total Annual Cost (TAC) for the door is \$5,015 which is less than the "benefit" of \$10,000. Therefore, the analysis favors the shielded door.

If the effect of inflation is not included, the CRF (i=10%, n=30 years) would be 0.1061 and

TAC = TCC x CRF + AOC + AMC
= \$134,750 x (0.1061) - \$880 + 0
= \$14,294 - \$880
= \$13,414

The analysis would then favor the concrete panel (and the associated radiation exposure).

Conclusions

An algebraic expression for a De-escalated Capital Recovery Factor (DCRF) was developed for inflation, k, at a constant rate. The expression, $\frac{(1+i)^n}{1+k} \times \frac{i-k}{(1+i)^n - (1+k)^n}$ reduces to that for the Capital Recovery Factor (CRF), $\frac{i(1+i)^n}{(1+i)^n - 1}$, when k is equal to zero.

The real cost of money, r, when the effect of inflation is accounted for, is given by the expression:

$$r = \frac{1+i}{1+k} - 1 \qquad (3c)$$

The effect of including or excluding the inflation correction was demonstrated in a cost-benefit analysis of a capital expenditure to reduce radiation exposure. The effect of inflation must be used to prevent biasing the comparison in favor of higher radiation exposures to be consistent with the criterion of reducing exposure to "as low as reasonably achievable".

Appendix

Derivation of Capital Recovery Factors

I. Capital Recovery Factor Without Escalation

S = future sum
P = present sum
R = end-of-period payment
n = number of periods
i = interest rate

A. Effect of compound interest:

A present sum, P, will compound to a future sum, S, if interest is credited at the end of each period.

$$S = P\,(1 + i)^n \qquad (4)$$

B. Uniform Series:

Given a uniform series of end-of-period payments, R, n payments will grow to a future sum, S, with interest rate equal to i.

```
                                          ↓
                                          S
0   1   2   3   4   5........n-2    n-1   n
.   .   .   .   .   .         .      .    .
    ↑   ↑   ↑   ↑   ↑         ↑      ↑    ↑
    R   R   R   R   R         R      R    R
```

$$S = R(1+i)^{n-1} + R(1+i)^{n-2} + \ldots + R(1+i)^2 + R(1+i) + R \qquad (5)$$

Multiply Eqn.(5) by (1+i).

$$S(1+i) = R(1+i)^n + R(1+i)^{n-1} + \ldots + R(1+i)^3 + R(1+i)^2 + R(1+i) \qquad (6)$$

Subtract Eqn.(5) from Eqn.(6)

$$S(1+i) - S = R(1+i)^n - R \qquad (7)$$

$$S = R\,\frac{(1+i)^n - 1}{i} \qquad (8)$$

C. Capital Recovery Factor:

$$S = R\,\frac{(1+i)^n - 1}{i} \qquad S = P(1+i)^n$$

$$CRF = \frac{R}{P} = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad (9)$$

II. Capital Recovery Factor With Escalation

S' = future sum, year n dollars
S = de-escalated future sum, year zero dollars
P = present sum, year zero dollars
i = interest rate
k = escalation rate
R = end-of-period payment, year zero dollars
R' = end-of-period payment, escalated dollars

A. Effect of Compound Interest with Escalation

$$S' = P\,(1+i)^n \qquad (10)$$

However, since the future sum, S', is paid in year n, it is worth less in terms of year zero dollars, i.e. it must be de-escalated.

$$S = \frac{S'}{(1+k)^n} \qquad (11)$$

$$S = \frac{P\,(1+i)^n}{(1+k)^n} \qquad (12)$$

B. Uniform Series (End-of-Period Payments with a Constant Value in terms of Year Zero Dollars)

$$R' = R(1+k)^m \quad m = \text{year of payment after year zero} \qquad (13)$$

$$S' = R(1+k)\,(1+i)^{n-1} + R(1+k)^2(1+i)^{n-2} + \ldots + R(1+k)^{n-1}(1+i) + R(1+k)^n \qquad (14)$$

Multiply Eqn.(14) by $\frac{1+i}{1+k}$

$$\frac{S'\,(1+i)}{1+k} = R(1+i)^n + R(1+k)\,(1+i)^{n-1} + \ldots + R(1+k)^{n-2}\,(1+i)^2 + R(1+k)^{n-1}\,(1+i) \qquad (15)$$

Subtract Eqn.(14) from Eqn.(15)

$$S'\,\frac{(1+i)}{(1+k)} - S' = R(1+i)^n - R(1+k)^n \qquad (16)$$

$$S' = R(1+k) \times \frac{(1+i)^n - (1+k)^n}{i - k} \qquad (17)$$

C. Deescalated Capital Recovery Factor

$$S' = P(1+i)^n = R(1+k) \times \frac{(1+i)^n - (1+k)^n}{i - k}$$

$$DCRF = \frac{R}{P} = \frac{(1+i)^n}{1+k} \times \frac{i - k}{(1+i)^n - (1+k)^n} \qquad (18)$$

at k = 0% DCRF reduces to $\frac{(1+i)^n\,i}{(1+i)^n - 1}$ or CRF

References

1. U. S. Nuclear Regulatory Commission; Rules and Regulations, Title 10 - Chapter 1 Code of Federal Regulations, Part 50, "Licensing of Production and Utilization Facilities", Appendix I, "Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low As Is Reasonably Achievable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents"; Washington, D.C.; 1975.

2. U. S. Nuclear Regulatory Commission; "Cost-Benefit Analysis for Radwaste Systems for Light-Water-Cooled Nuclear Power Reactors"; Regulatory Guide 1.110; March, 1976.

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