Environmental Technology Cost-Savings Analysis Project (ETCAP)

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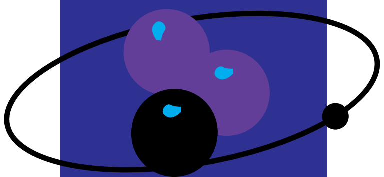

Recovery of Tritium from Tritiated Waste Water Cost-Effectiveness Analysis

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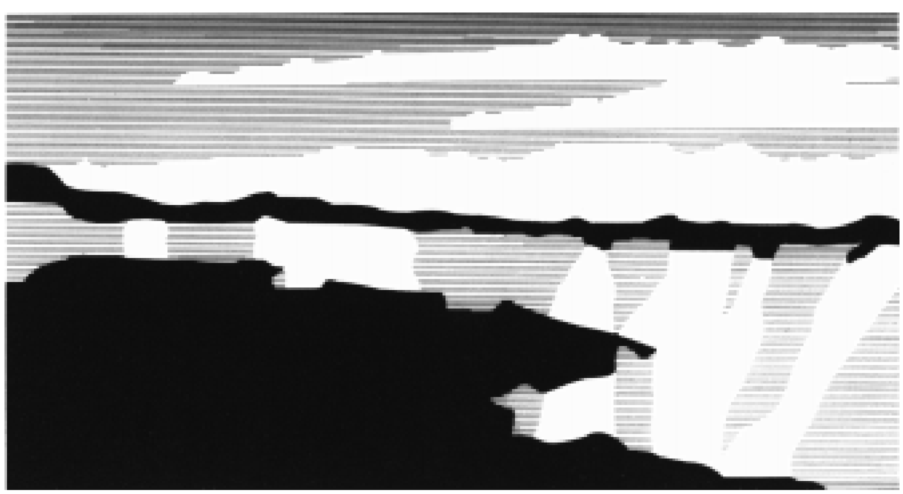

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- Summary of unit costs for the technology options:

Summary of Unit Costs for the Technology Options

Technology	Plant Capacity (steam flow)	Disposal/Treatment Cost of Tritiated Water ($ per liter)
2.1 Cement and Burial		$1,250
2.2 Magnesium Bed Cracking and Cryogenic Distillation		$13,600
2.3 Palladium Membrane Reactor and Cryogenic Distillation	5 liters per minute	$3,760
	7.5 liters per minute	$2,500
	15 liters per minute	$1,250
2.4 Canadian Detritification Services		$800

- Firm cost information about all technology options indicates fairly unambiguously that Canadian detritification services are the lowest cost technology to handle most U.S. tritified waste water.

- The Palladium Membrane Reactor/Isotope Separation System (PMR/ISS) is the best U.S. solution to total pollution prevention because it recovers all of the tritium without generating any new secondary waste streams. The PMR/ISS system has the potential to be the least costly U.S. technological choice (ignoring the Canadian solution) if sufficiently high operating throughputs can be achieved. The PMR/ISS throughputs needed to beat the simple Burial option are about three times the conservative engineering design specifications, but may be achievable upon further research and development.

- The Magnesium system is not competitive with PMR/ISS on either pollution prevention or cost bases.

- The Burial option is currently the lowest cost U.S. technology but does nothing to help with pollution prevention.

- PMR/ISS system costs are driven mainly by operating costs incorporating the expected plan to continue to operate with laboratory type schedules/personnel rather than moving toward a production environment. PMR/ISS costs could probably be lowered substantially by operating environment changes tailored to meet production needs.

- Imputing value to recovered tritium can make PMR/ISS look most economically attractive for processing tritiated water above threshold concentrations dependent on tritium's shadow price. But the amount of recoverable tritium in tritiated waste water is tiny compared to U.S.-weapons-program stockpiles, or likely future U.S.-weapons-program production rates, or the huge commercial market Canadian supply surpluses. Thus, the minuscule tritium supplies from tritiated waste water makes it a stretch of credulity to attribute significant economic value to tritium recovery from these sources.

1. Background

1.1 The DOE Complex Tritiated Water Problem

There are currently more than 200 grams of tritium in about 1800 liters of stored waste water throughout the DOE complex. Los Alamos has about 100 grams in 400 liters of stored tritiated water. Annual new tritiated water generation rates are estimated at more than 100 grams complex-wide in about 1000 liters of water. Tritium concentrations in the water vary widely depending on the source of the water. Tritiated water is many 1000s of times more biologically toxic than tritium gas due to our water-based body's propensity to incorporate tritiated water into its very makeup.

Tritiated water can either be processed for recovery of tritium or disposed of at a radioactive waste disposal site. Costs of processing tritiated water generally do not depend on tritium concentrations, but are related mostly to the volume of water that must be treated or buried. Los Alamos has burial costs which appear to be very low to local generators due to our accounting system, so tritiated water is either buried if tritium concentrations are high, or more simply evaporated if tritium concentrations are very low. Complex-wide, however, burial costs are much higher, and the cost effectiveness of future processing options are not well defined.

Aside from motivations springing from direct cost savings, a LANL waste reduction strategy is mandated by regulatory program drivers. Hazel O'Leary's Draft Secretarial Directive and March 1996 DOE Pollution Prevention Plan calls for a 50% reduction in rad waste by the year 2000 compared to a 1993 baseline. Related goals have been codified in the University of California/DOE contract, Appendix F, which requires annual 5% LLW reductions for all ongoing operations.

1.2 The Value of Recovered Tritium

The cost effectiveness of tritiated water processing technologies that recover tritium may be additionally credited back with the value of the recovered tritium. No tritium is currently being produced in the U.S. for the weapons program because there is a surplus in stock and a shrinking need as the START I treaty down-sizes our weapons stockpile. This trend will continue with START II. However, the 12.4 year half-life of tritium implies that new production will have to start about 10 years from now. Cost estimates for new production are not well defined but are of the order of magnitude of about $100,000 per gram. Thus the existing 200 grams of tritium in tritiated waste water may have a distant, future shadow value of the order of $20 million. While this might seem impressive, the tritium quantity involved represents a small fraction of the stockpile requirements, and it is likely that new production systems will be designed with capacities that make the potential tritiated waste water recovery contributions insignificant.

There is a commercial market for tritium to be used in luminous watches and signs, medical isotopes, and research laboratories. The U.S.-DOE stopped serving this market in 1989. The Canadians (Ontario Hydro International) sell tritium commercially for $24,000 per gram ($33,000 in Canadian dollars). This price is quite arbitrary because annual market sales are only about 100 grams, but 2500 grams of tritium supply is produced annually as a byproduct of detritiating water from the Canadian heavy-water power reactors. The 200 grams of tritium in U.S.-DOE tritiated waste water would have a value of about $5 million at this commercial price. But it is fatuous to think that this is a realistic value given that Ontario Hydro is storing an annual surplus production of tritium more than 10 times our total 200-gram waste water stock.

2. Descriptions of the Technology Options and Cost Analyses

2.1 Cement and Burial

Tritiated water produced at Los Alamos is typically buried as LLW if it has a high concentration of tritium, or evaporated and released to the environment through a stack if tritium concentrations are low. The cost of treatment and burial is mostly absorbed by ongoing operations. Even at $30 to $50 per cubic foot for TA-54 LLW burial costs, the 100 liters or so annual volume of tritiated waste water production results in negligible local burial costs. Interim storage in containers at the Tritium System Tests Assembly (TSTA) or elsewhere incurs no significant space or other charges for the small volumes involved. This process, however, does nothing to advance DOE or Los Alamos pollution prevention goals.

The current negligible on-site burial costs at Los Alamos are not representative of DOE-complex costs. Two thirds of the volume of current DOE legacy tritiated waste water, 1200 liters, is water from the Mound Plant. DOE-HQ has a $1.5 million cost estimate to immobilize this Mound water through cementation and ship it to Nevada for burial. This is a unit cost of $1,250 per liter. This report takes the $1,250 per liter cost as appropriate for the Cement and Burial option for disposing of tritiated water. In order to be cost effective, any other option must treat the waste water at a lower cost, or have enough compensating benefits (value of tritium as a commodity, or regulatory/public perception goal achievement) to overcome any cost premium.

2.2 Magnesium Bed Cracking and Distillation

DOE currently processes tritiated water at the Savannah River Plant using a magnesium bed system. This is the current baseline technology for treating, rather than disposing of tritiated water. The technique results in the generation of a tritium-contaminated magnesium oxide waste stream which still requires treatment as LLW and is, therefore, not a strong contributor to pollution prevention objectives. The cost of the magnesium bed system has recently been estimated at $1.5 million for the treatment of 110 liters of tritiated water from Princeton. This is a unit cost of $13,600 per liter. This number is about three times the cost of the new Palladium Membrane Reactor system (PMR/ISS) discussed in Section 2.3. The factor of three cost disadvantage of Magnesium vs. PMR/ISS is agreed upon by Magnesium system operators and others as being likely to be typical for comparisons between the systems. The basic engineering cost driver is that the magnesium beds have to be replaced frequently (~monthly) at a high cost, whereas, the palladium system will function for years without replacement.

2.3 Palladium Membrane Reactor and Cryogenic Distillation

The Tritium Systems Test Assembly group at Los Alamos has developed a Palladium Membrane Reactor/Isotope Separation System (PMR/ISS) to treat tritiated water. A waste-free effluent is produced composed of CO and CO_2 which can be directly stacked to the environment. It is simple to operate and reliable using well-established technologies (palladium permeator and catalytic reactor, and cryogenic distillation). Tritium is recovered for storage and recycle with a recovery efficiency of 99.999999%. Cost is believed to be about one third that of the current baseline Magnesium treatment technology, and may be even better once scale-up of the prototype has been accomplished. The PMR/ISS technology exceeds pollution prevention goals by eliminating all pollution. It also recovers tritium for storage and future use, capturing any value associated with a shadow price for tritium.

Figure 1 **Palladium membrane reactor.**

This report develops a cost estimate based on a proposed $1.5 million budget to scale up the current PMR prototype from 0.5 liters per minute (steam) to 5.0 liters per minute (steam). The existing ISS cryogenic distillation system capital cost is not included because it is expected to serve for many years to come without replacement and already has adequate capacity. The new PMR scale-up is amortized over 10 years, bringing new annual capital costs to $173,000. Capital costs are not a significant driver. Operating costs are taken from the estimate prepared to treat the same 1200 liters of Mound water mentioned in Sections 2.1 and 2.4. These operating costs are $3.5 million over 4 years, or $1,140,000 per year. The unit cost derived from this 1200-liter processing campaign is $3,760 per liter (water). This is only about one third of the Magnesium system unit cost, but about three times the Cement and Burial unit cost.

PMR/ISS unit costs are strongly influenced by plant capacity factors. Most of the cost is driven by operating cost, and if the plant can operate at higher throughputs, unit cost can be driven down proportionately. The 5 liter per minute (steam) engineering design is believed to be quite conservative, and if testing shows greater capacity, costs will drop significantly. The existing ISS is the bottleneck item in process design flow rate and when put to a real test is expected to be able to support a throughput greater than 5 liters per minute. At 7.5 liters per minute, plant unit cost would fall to $2,500 per liter (water). If a rate of 15 liters per minutes could be achieved then the PMR/ISS unit cost per liter of tritiated water would break even with Cement and Burial.

2.4 Canadian Detritification Services

Ontario Hydro International offers detritification service for tritiated waste water and the contact is:

Rob Machacek
Telephone: 416-506-4945
FAX: 416-506-4684
E-mail: rf.machacek@hydro.on.ca

They have a plant which detritifies water from Ontario Hydro's 20 heavy-water CANDU power reactors, and with excess capacity to handle future nuclear power plant additions and overseas clients. The water treatment plant is part of the Darlington Complex (Figure 2) and has a capacity of 3000 tons of water per year. The process applied to U.S. tritiated light water is to upgrade the water for use in the heavy-water reactors, where it is blended with existing reactor water, and then detritification occurs when the reactor water is routinely processed through the Darlington water treatment plant. This service has been performed for Brookhaven National Laboratory (Long Island, NY) and the National Institute for Standards and Technology [(NIST), Gaithersburg, MD]. The tritiated water is just plain eliminated from further consideration — it vanishes from the U.S. domain. The service meets all U.S.-DOE pollution prevention goals by forgoing any disposal. Canada, by law, will not supply any tritium for weapons use, and they already have a huge excess supply for the commercial market. So, any intrinsic value of recovered tritium is lost.

Ontario Hydro International currently has a bid out to process the same 1200 liters of Mound tritiated water discussed in Sections 2.1 and 2.3. Mr. Machacek says the bid is a little less than $1 million, and that it may be lowered a bit as recent discussions with Canadian trans-

Figure 2 **Darlington complex in Ontario, Canada.**
(photo courtesy of Robert Machacek, Ontario International Hydro)

portation regulators have been favorable. The bid reflects a unit price of this detritification service at about $800 per liter. This is much less than any of the other options.

Mr. Machacek indicated that there is some public acceptance problem in Canada with accepting U.S.-weapons-program tritium for processing. However, the existence of a firm bid for the Mound water indicates that it is not a show stopper. He also expressed a preference for low concentration tritiated water and indicated that the negotiated price would be a function of both volume and concentration — although the concentration caveat seemed to be more related to transportation issues than treatment at Darlington.

The actual cost to Ontario Hydro International for the Canadian service is much less than the price set for it. The price is set through a business negotiation. With the excess capacity of their water treatment plant, and the very low actual additional out-of-pocket expenses associated with accepting relatively tiny quantities of U.S. tritiated light water; it is likely that the Canadians have the ability to undercut almost any cost of processing we could realistically achieve. This makes the Canadian option a potent one. But it also gives the U.S.-DOE an incentive to achieve lower potential tritiated water U.S. processing costs, in order to bolster our competitive negotiating position.

3. Confidence in Technologies' Viability and Cost

3.1 Extent of Knowledge About Technologies' Technical Performance

All of the technologies discussed in this study are proven and in use at present. Magnesium is the current baseline for treating rather than disposing of tritiated water. Cement and Burial is common for disposal with a well developed infrastructure. Canadian detritification is a large-scale, routine operation — including some actual commercial treatment of U.S. light water. The PMR/ISS system that is the focus of this report has been technologically demonstrated at a scale of 0.5 liters per minute and has been acknowledged by the Magnesium system operators as being a superior technology both technically and in cost performance. The PMR/ISS system has not yet been proven at a scaled-up size, but the nature of the scale-up is simply a multiplication of the number of the existing PMRs so there is very high confidence that it is technologically robust. The existing ISS is believed to already be scaled to handle a larger throughput than the initial plan for 5 liters per minute feed from the scaled-up PMR. The remaining uncertainty is how much better the ISS will prove to be than the conservative engineering assumptions.

3.2 Level of Confidence in Cost Parameters

Costs in this report are based upon real engineering estimates or bids. Derived unit costs may not be very precise in general terms because the estimates are based on specific projects with specific quantities and time scales in mind. Differing project plans might easily alter these specific costs. Variances in the concentrations of tritium, in particular tritiated water streams, might change handling, shipping, or other requirements enough to change the technology of choice or the costs involved. The Canadian detritification services are based on business considerations not closely tied to actual process costs. We guess that all of these potential project changes could easily result in 20-50% variances in unit costs.

4. Cost-Sensitivity Analyses

There are three major parameters that play off of each other in determining the comparative economic viability of the various technology choices.

(1) PMR/ISS Recovery Plant Capacity Realized
(2) Tritium Shadow Price
(3) Tritium Concentration in Water

The lowest cost U.S. technology is Cement and Burial (or simple evaporation and release through a stack in the case of very low concentrations of tritium). If sufficiently high throughput rates can be achieved with the PMR/ISS without raising operating costs, then it is possible to reach an economic break-even point with costs equal to Cement and Burial. If PMR/ISS can achieve a 15-liter-per-minute rate (three times the nominal engineering design of 5 liters per minute) then its unit cost is equal to Cement and Burial at $1,250 per liter of water. Several rates of PMR/ISS throughputs are shown on the first part of Figure 3 to illustrate the sensitivity of unit cost to realized PMR/ISS plant capacity.

4.1 Graphical Cost Sensitivity Trilogy

In Section 1.2, *The Value of Recovered Tritium*, we pointed out that the amount of recoverable tritium in U.S. tritiated waste water is minuscule compared to U.S.-weapons-program stockpiles, or likely future U.S.-weapons-program production rates, or the huge current commercial market Canadian supply surpluses. Thus, the minuscule tritium supplies from tritiated waste water makes it a stretch of credulity to attribute significant economic value to tritium recovery from these sources. Nonetheless, if one wishes to credit back recovered tritium value based on current commercial prices ($U.S.) of $24,000 per gram, or a speculative APT future cost of production of $100,000 per gram, or any other value; Figure 3 shows how the tradeoff among technological choices can be evaluated.

The cost of recovering tritium in the PMR/ISS system is independent of the tritium concentration and depends only on water volume. But the value of tritium in any particular volume of water depends on the concentration of tritium in the water. As more concentrated tritium is present, the total value of recovered tritium increases for every liter of water. The first part of Figure 3 shows the comparative unit processing costs per liter of water of all the technologies. The second part shows the value of tritium recovered as a function of price per gram and concentration. The recovered tritium vertical value scale is the same as the vertical processing cost scale of the first part but the origin (zero point) is moved up to be on the same level as the cost of Cement and Burial. This shows the value that recovered tritium contributes to making up the excess of recovery processing costs above the baseline. (The baseline being the cheapest U.S. technology of simple disposal. The Canadian detritification services represent an even lower base cost, but are negotiable and not used as the base case in Figure 3.) The added value achieved at any selected price can be read off the price line.

The price line intersection by a projection of any technology's processing cost can be projected down onto the third part of Figure 3. The third part shows the actual distribution of tritium concentrations found in the TSTA and TSFF tritiated water in storage at Los Alamos. Mound, Princeton, and Savannah River Site tritiated waters have different distributions of concentrations. From this part of Figure 3 it can be seen what level of tritium concentration can be economically processed for recovery. Low concentrations, to the left of the projection down from the price line, do not pay to recover — those to the right will produce net value/savings at the selected price.

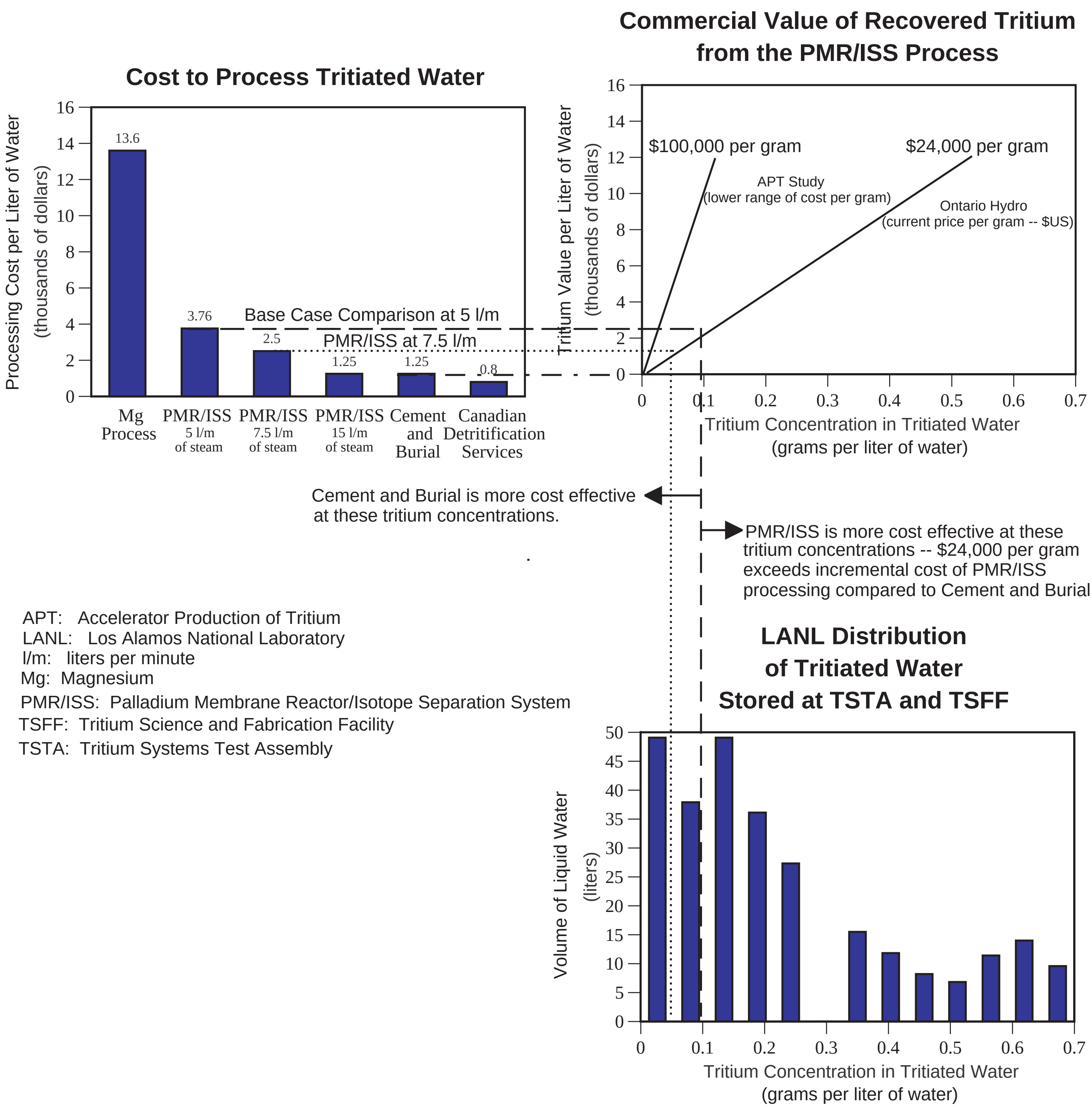

Figure 3 **Recovered tritium cost/price concentration tradeoffs.**

There are too many options and choices inherent in this analysis to detail all of the results, but the idea should be fairly clear.

5. Summary and Conclusions

The unit costs for each technology are summarized in Table 1. Firm information about the Mound water options indicates fairly unambiguously that Canadian detritification services are the lowest cost technology to handle this U.S. tritified waste water.

The PMR/ISS system is the best U.S. solution to total pollution prevention because it recovers all of the tritium without generating any new secondary waste streams. The Magnesium system is not competitive on either pollution prevention or cost bases. The Burial option is currently the lowest cost U.S. technology but does nothing to help with pollution prevention. The PMR/ISS system has the potential to be the least costly technological choice (ignoring the Canadian solution) if sufficiently high operating throughputs can be achieved. The PMR/ISS throughputs needed to beat the simple Burial option are about three times the conservative engineering design specifications, but may be achievable upon further research and development. PMR/ISS system costs are mainly driven by operating costs incorporating the expected plan to continue to operate with laboratory type schedules/personnel rather than moving toward a production environment. PMR/ISS costs could probably be lowered substantially by operating environment changes tailored to meet production needs.

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