Waste Offsetting: The Commodification of Low-Level Radioactive Waste (LLW) – 14220

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ABSTRACT

It is recognized that one of the most significant cost drivers regarding decommissioning cost estimates is the availability of evacuation routes for low-level radioactive waste (LLW). By incorporating a "*Recycle and Reuse*" framework into decommissioning strategies rather than "*Dispose and Replace"*, the indicator for sustainability of the nuclear fuel cycle, ratio of solid radioactive waste to energy produced, can be reduced. The policy of "Waste Offsetting" is proposed as a market-based instrument that incentives the reuse of recycled LLW in the controlled nuclear industry. Should the costs for recycling LLW be less than disposal, the build-up of decommissioning funds and the "Polluter Pays" principle can establish a deposit-refund system promoting the reuse of recycled LLW in construction and operation of the next generation nuclear facilities. "*Recycle and Reuse*" will align with the preferred strategy for the long-term management of radioactive waste; to isolate and contain radionuclides from the accessible biosphere. The reuse of recycled LLW in the controlled nuclear sector has the potential to improve sustainability, safety, and economics of the nuclear industry.

INTRODUCTION

The fundamental objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burden on future generations [1]. This begs the question, what constitutes an "undue burden"? That past 40 years of international decommissioning experience has shown that the undue burdens should be interpreted to include any type of burden, including financial liabilities that have not been internalized [2]. The generation using nuclear power facilities have an obligation to assemble and to preserve the financial, technical, and scientific resources necessary for the later decommissioning of these facilities. Society should always strive to ensure that the generation that benefits from the energy production bears the greatest responsibility in managing its risk to peoples and the environment. Knowledge, competence and resources need to be preserved, developed and effectively transferred to the next generation. Recognizing these challenges, the international community is committed to collaborate on the issues associated with the long-term management of radioactive waste.

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management is an international agreement that defines the objectives for radioactive waste management. With respect to the decommissioning of nuclear facilities, two articles are of improtance [3]:

- Article 11. ii) *ensure that the generation of radioactive waste is kept to a minimum practicable*

- Article 22. ii) *adequate financial resources are available to support the safety of the facility for spent fuel and radioactive waste management during their operating lifetime and for decommissioning*

National authorities promote the internalisation of environmental costs through the use of economic instruments that take into account the “Polluter Pays” principle in bearing the costs of pollution [2]. The precision of the decommissioning cost calculations is one of the most important prerequisites for establishing adequate funds. Minimising uncertainties of this kind involves continuous development of cost estimates, using the lesson learnt from other decommissioning projects. From a governmental viewpoint, it is essential to ensure the money for the decommissioning of nuclear instillations will be available at time needed, and that no stranded liabilities are left to be financed by the tax payer rather than the electricity consumer. In summary, decommissioning cost estimates are used for three main functions [4]:

- to inform government and guide their policy for assuring that decommissioning funds will be available when needed;
- for utilities to determine funding requirements and financial liabilities;
- to serve as a basis for industrial strategy and decommissioning planning.

Perpetual storage of radioactive waste is often not viewed as a sustainable solution given that it extends the risk of external costs on to future generations and offers no solution [5]. In order to internalize costs associated with long lived radioactive waste, the international consensus among waste management experts has been that the best option that is currently available or likely to be available in the foreseeable future is disposal in underground engineered facilities:

> *A further consideration is that if geological disposal provides a good level of safety it is not necessary, or even responsible financial management, to expend further resources on the development of alternatives* [5].

A fundamental requirement for the safe production of nuclear energy is a healthy safety culture. A “Questioning Attitude” is characteristic for a healthy safety culture and it ensures the nuclear industry is always identifying and challenging such assumptions. Expressed in Everett M. Rogers’s “*Diffusion of Innovations*” [6]:

> *Every Scientific field makes certain simplifying assumptions about the complex reality that it studies. Such assumptions are built into the intellectual paradigm that guides a scientific field. Often these assumptions are not recognized, even though they affect such important matters as to what is studied and what ignored, and which research methods favours are favoured and which rejected. So when a scientist follows a theoretical paradigm, a set of intellectual blinders prevents him or her from seeing certain aspects of reality.*

At the core of any waste management program should be the 3 R’s: Reduce, Reuse, and Recycle. While the nuclear industry has experience in waste minimization and the reuse of equipment, the recycling of LLW could provide for greater efficiencies in decommissioning. In keeping with the fundamental objectives outlined within the Joint Convention, a review of international markets for decommissioning waste was undertaken.

The potential for a "*Recycle and Reuse*" framework in decommissioning is compared against "*Disposal and Replacement*" [7]. Based on findings from international decommissioning experiences, combined with environmental economic theory, a policy of "Waste Offsetting" is proposed; where the next generation of nuclear facilities have the potential to reuse recycled low-low level radioactive waste in the construction and operations to improve sustainability, safety, and economics of the nuclear fuel cycle.

SUSTAINABLE

"The prime objective is to improve sustainability of the nuclear option through better use of resources and better management of radioactive waste, together with improved economics, safety and reliability, proliferation resistance and physical protection" [8]. Further recommendations are prescribed in the IAEA`s Principles in Radioactive Waste Management. Beginning with waste minimization, these principles state that the generation of radioactive waste shall be kept to the minimum, in terms of both activity and volume, by appropriate design measures and operating and decommissioning practices. This includes the recycle and reuse of materials [1]. Recognizing that radioactive waste disposal may have adverse effects on the future availability or utilization of natural resources; incorporating recycled LLW into the construction and operation of next generation nuclear facilities minimizes these impacts. In order to reduce the long-term stewardship burden the industry needs a holistic view of the entire nuclear fuel cycle and this includes the generation of LLW.

Returning to the 3 R's, waste reduction strategies are implemented across the industry. Currently volume reduction is incentivised by requiring advanced disposal fees prescribed within the financial guarantee for decommissioning. Furthermore, as required in the International Accounting Standard 37, *Provision, Contingent Liabilities and Contingent Assets,* decommissioning provision must not include gains from the expected disposal of assets [9]. In summary, the decommissioning funds available to future generations should be sufficient to cover the costs of disposal and not account for recycling to reduce the total liability. These advance disposal fees lead to source reductions in the volumes of waste generated; however, it alone fails to incentivise recycling within the controlled nuclear industry [10]. Innovative discoveries for the potential to reduce that waste, through the creation of products with recycled content, will assist the nuclear fuel cycle in moving toward a sustainable trajectory [11].

The IAEA has defined an environmental indicator for the sustainable development of nuclear energy as the ratio of solid radioactive waste to units of energy produced [12]. The purpose of this indicator is to account for the amounts of various radioactive waste streams that arise from the nuclear fuel cycle. Emphasis should be placed on the segregation of different types of waste and materials to reduce the volume and facilitate recycling. When reactors are designed and operated with decommissioning in mind, there will be a decreasing trend with this indicator. The decommissioning of next generation facilities should generate less waste when compared with today's practices. The greatest potential for improving sustainability, as this ratio demonstrates, is incorporating recycled waste streams into new nuclear facilities to prevent the contamination of virgin materials. The next generation decommissioning waste can be offset by incorporating recycled LLW, thereby reducing the waste generated to energy produced ratio.

The “Recycle and Reuse” framework supports biomimicry, by designing industrial system to imitate nature, where one creatures waste is another’s food.

The persistence of imperfect information across various industries has contributed significantly to unsustainable production and consumption patterns. The creation of recycling opportunities is a collaborative process amongst several stakeholders as no one firm is likely to have quality information regarding the supply or demand [11]. The main factor whether to undertake a recycling strategy is the timing and availability of the materials for processing; however, the current industrial strategies to decommissioning can be subservient to national policy and regulation can differ considerably [4].

In order to determine opportunities for the recycling and reuse of LLW, decommissioning cost estimates can be used to identify potential cost drivers and how these impacts can be minimized. The decommissioning of nuclear facilities internationally has also provided invaluable lessons learned. For example, the clean-up of concrete structures represents the highest volume of material at a nuclear facility, however, as reported in a 1996 survey, less than 1% of the concrete that had radiological restrictions was designated for controlled reuse within the nuclear industry [7]. Potential improvements can also be made for the recycling of radioactive scrap metal. The disposal of radioactive scrap metal withdraws material from the world’s stocks of metals; the process required for such replacement includes mining, refining, metal smelting, casting fabrication, and the production of energy required to accomplish these activities. Recycling radioactive scrap metal would conserve natural resources and the energy requirements would likely be half that for disposal [7]. This correlates to a further reduction of the nuclear energy footprint compared with the alternative sources.

SAFETY

When discussing the safety of the long-term management of radioactive waste, the hazards must be addressed should be compared with the publicly perceived risk. Safe, timely and cost effective decommissioning demonstrates to the public that the nuclear fuel cycle is under control at all times and the nuclear industry knows how to remove anything that has been built. It is no secret that public attitudes toward nuclear energy are strongly influenced by concerns about waste disposal [13]. In a societal context, radioactive waste carries an important symbolic dimension: it can be associated with our uncertain destiny as the actors of technological civilization, as well as with concepts of uncleanliness and secrecy [14]:

“[Radioactive Waste] is not like other waste: to hide it out of shame creates a new form of fear, the fear of secrecy, and the fear that ‘we are not being told everything’”

Inherent to decommission activities are health, environmental, socio-economic impacts that must be considered as a part of any comprehensive justification for recycling. Overall the recycling option involves small increase in controlled risks born by radiation workers, whereas the replacement scenario has relative increases in the uncontrolled risk to the public [7]. Many aspects of the replacement process are conducted within environments that are less stringently regulated than the environment in which recycle/reuse alternative would operate. Disposal/replacement present more adverse impacts to the environment from land use, mining, and related processes [7]. Additional information on the relative risks of both management alternatives should be a determining factor in the decision making process and the formation of public opinion.

It is important that when examining the aspects of worker safety under a recycling and reuse framework that worker security is also considered. In the event that a nuclear facility represents the primary employer for a local job market, as shutdown approaches, the surrounding community may suffer job losses, a reduction in tax base, and decrease in local housing markets [15]. These factors can lead to negative worker moral can actually affect the site's safety culture and can cause an increase in accidents [15]. Early decommissioning has been proposed to maximise jobs and local income in the period after the end of productive operations [16]. Recycling and Reuse provides an alternative evacuation route for the material which could be a determining factor for whether or not the facility will enter are period of safe enclosure.

Maintaining a facility in a safe state for several decades is no easy task and, at the end of this period, radiological and technical characterization of systems, components, and buildings for preparation of decontamination and dismantlement is challenging. Although requiring greater effort in the beginning, immediate dismantlement has become the preferred strategy internationally [15]. Feedback from decommissioning projects into design and construction of new facilities is essential to improve safety for the next generation facilities. The general argument for early decommissioning is that the risks of dismantlement should borne by the present generation rather extended to subsequent generations. However the availability, or non-availability, of suitable waste repositories for decommissioning wastes has impacted the decommissioning strategy selection, and the actual timing of dismantling. In Japan for example, immediate dismantling is preferred, however, this strategy declaration was qualified by statement that should a repository not be available then reactor dismantlement will be delayed [15].

Whether adopting a "*Dispose and Replace*" or a "*Recycle and Reuse*" framework for the long-term management of radioactive waste, the safety goals of *Isolation* and *Containment* remain the same. Under "*Dispose and Replace*" , *Isolation* means the design to keep waste and its associated hazard apart from the accessible biosphere; *Containment* implies the design to avoid or minimize the release of radionuclide's from the waste form, package and disposal facility [18]. With "Recycle and Reuse", *Isolation* implies the segregation of radioactive materials from those that meet release criteria and preventing its access to the biosphere; *Containment* means preventing the release of radionuclides from the recycled waste form.

ECONOMICS

In order for the economics of the life cycle of a nuclear plant to be fully assessed, there has always been a need for a clear understanding of decommissioning costs. The number of nuclear power plants world-wide exceeds 500 units with some 400 still remaining in operation, and well over a 100 already shut down bound for dismantling in within the next few decades [15]. The size of the decommissioning industry is huge and the costs for management and disposal of radioactive waste can be a substantial part of the decommissioning financial assurances. The cost of LLW disposal is thought to be a small part of the total cost of nuclear power generation; in realty, the absolute costs for construction, operation, and long term monitoring of a repository, are by no means small [17]. The availability of evacuation routes for LLW are amongst the most significant cost driver for a decommissioning project [18].

Experience shows, that one of the most important cost elements is the management of low-level radioactive materials that arise from dismantling and need, either to be disposed of as radioactive waste in a repository, or recycled and reused. Disposal facilities would be needed for all types of radioactive waste from dismantling. In most cases such facilities are not constructed. Cost calculation regarding disposal therefore have a degree of uncertainty [2]. Currently operating waste facilities have limited capacities and are insufficient to accommodate the large volumes of wastes that will be generated from decommissioning the world's nuclear facilities. Public opposition to siting and licensing of new radioactive waste facilities makes the expansion of available waste capacity difficult and serves to increase already high disposal costs. Disposal costs are likely to continue to increase while access is likely to become more restricted [7].

Many countries have opted for early dismantling as deferred dismantling may impose undue burden on future generations. This justification for immediate dismantlement still needs to be verified because the safe enclosure period for most deferred decommissioning projects has not passed. If insufficient financial arrangements are acquired and maintained during the safe enclosure period, future generations would be burdened. During a period of safe enclosure there are costs associated with the conservation of the plant infrastructure and equipment. These costs increase in more than a linear manner in time because some maintenance and overhauls are required for operating systems in safe enclosure [20]. If there is no further nuclear energy related activity on the site, surveillance of the shutdown unit may become a significant component of the total decommissioning cost [4].

There are two economic drivers that encourage investigation into the "Recycle and Reuse" of LLW. As discussed early, if the costs of the safe enclosure period cannot be internalized with the current decommissioning funds, a demand for recycled LLW materials could provide a suitable evacuation route for early dismantlement. More importantly, there is evidence that suggest it is possible to produce recycled LLW materials at a lower cost than disposal. There are a number of factors that can affect LLW disposal costs; the type and size of a repository; they can be near surface or in a geological setting, operate in different regulatory environments, and are dependent of the local labour rates. Given these differences, the NEA reported that the undiscounted costs for LLW disposal range from $1000 to $9000 per cubic metre (1995) [17]. The European Commissioned conducted a study to determine the potential for recycling and reuse of radioactive material in the controlled nuclear sector. The report analyzed various scenarios for the recycling of contaminated concrete and scrap metal that result from decommissioning activities. In summary, should disposal costs exceed \$710.00/m^3 (1999) the recycling of concrete becomes economically viable. While not as easily processed, the recycling of contaminated steel becomes justifiable when disposal costs exceed \$1800.00/m^3 (1999) [21]. The difference between the LLW disposal and recycling unit costs is an important factor when considering the adoption of a deposit-refund system.

When solid waste disposal is unpriced the private market equilibrium generates too much waste and utilizes little recycling relative to the social optimum. Producers use too much of the virgin material input in production relative to the secondary material [10]. This scenario is likely the case with early reactors that were not designed with decommissioning in mind. The nuclear industry has the opportunity to adopt recycling practices into facility designs in order to contaminate less material and reduce the generation of radioactive waste. The existence of a functioning recycling market provides incentives for design, as highly recyclable products are more valuable in the marketplace. Substituting current practices with technologies and supply chain services that minimize or even improve on earlier waste production generate opportunities for new ventures and may even improve public acceptability. Market imperfections have contributed to environmental degradation; yet, they provide significant opportunities for the creation of radical technologies and innovative business models [11].

In many nuclear facilities, concrete makes up the bulk of the material arising from dismantling. There will be a significant increase in concrete waste volume to be handled in the near future as a result of prompt decommissioning strategies [19]. The recycling of slightly contaminated concrete from the decommissioning of nuclear site has a very real prospect of producing considerable cost savings, but to achieve this further research is required. Outside of the nuclear industry there is little incentive to promote research in designing systems with recycled concrete aggregate. Recycling of conventional concrete is of marginal economic value, and depends on landfill cost, but for nuclear concrete there is a clearer economic driver. Aggregate for use in concrete could be prepared relatively easily from decommissioning using known technology and it is recommended that the further work into the feasibility of recycling for incorporation into grout be undertaken [21].

During the next 50 years dismantling and decommissioning of nuclear facilities approximately 30 million tonnes of scrap metals will be generated. Disposing of this radioactive metal inventory of will require a capacity of 5,000,000 m^3 [7]. Stainless steel, however, is a valuable material there are significant cost benefits in reusing this material in preference to disposal. Assuming a disposal cost of $5 000/$m^3$($140.00 /ft^3), this equates to an international market potential of $25 billion for the reuse of recycled radioactive scrap metal in the controlled nuclear industry.

There is an increasing trend that most new units are located on existing sites because tens to hundreds of million dollars have been invested to qualify a site for nuclear use. Should this trend continue, existing older plants may have to be demolished for new units. The reuse of existing sites for new nuclear build would mitigate the socioeconomic impacts of a facility shutdown [15]. New job opportunities for the decommissioning of redundant units, coupled with potential for recycling of the decommissioning waste streams provide continuing jobs for the local workforce. As described in the International Structure for Decommissioning Costing (ISDC), the cost for the management of decommissioning LLW is dependent upon the methods for characterization, processing, final condition, storage, transport, and disposal [22]. The reuse of recycled LLW concrete is an example where savings in characterization, storage, transportation, and disposal can be passed on to the waste receiver to improve the economic performance of the new facility.

In the following scenario, Figure 1, it is assumed that the cost of disposal is $\$5000/m^3$, while the cost to recycle the material is $\$2000/m^3$. In this example, NPP-1 has a known volume of LLW and has internalized the disposal costs over its operational period. When given the choice between disposal or recycling, the decommissioning firm will chose to recycle and record a 20% gain on the liability for each waste unit recycled. In order to increase demand for the recycled product, and in accordance with the "Polluter Pays" principle, the Recycler charges an additional $\$2000/ m^3$ and passes these revenues to the New Build firm. Recognizing the economic incentives for designing products that contain recycled LLW, the new build firm will source recycled materials when feasible; however, it must assumes the disposal liability when it receives the recycled product. To cover the future value of the disposal obligation $\$1000/m^3$ is set aside in the decommissioning fund. The remaining revenue can be used to reduce the new build construction cost.

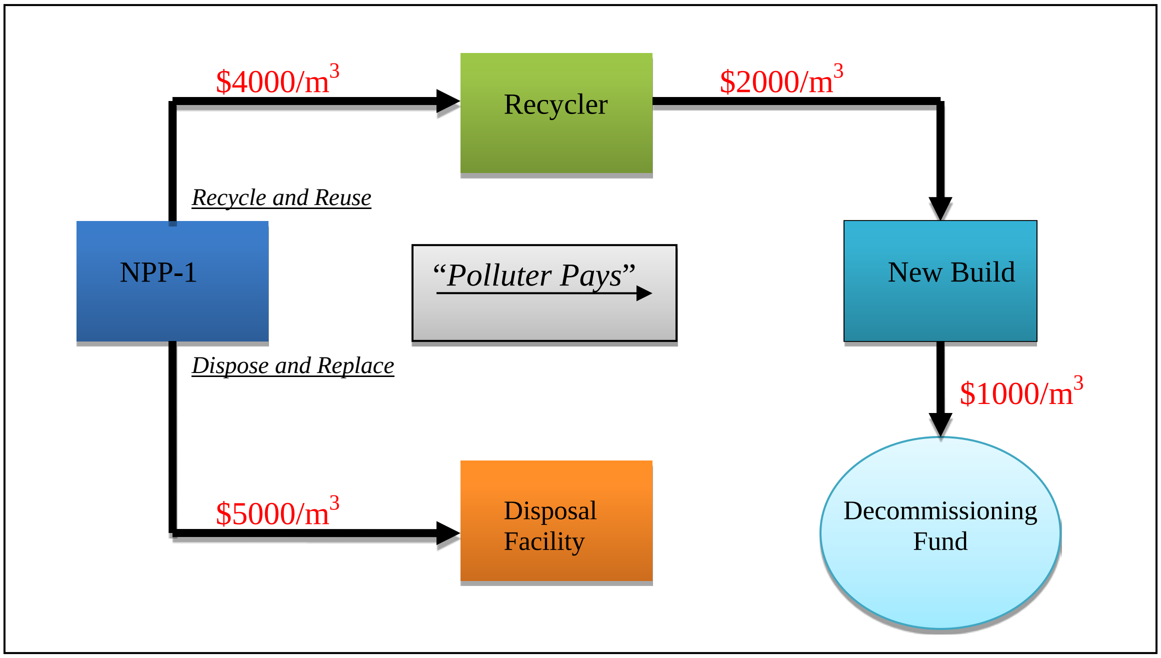

Fig. 1. Waste Offsetting: A "Polluter Pays" approach for LLW Recycling

CONCLUSION

The publicly available information on the decommissioning activities has been a valuable tool in examining the nuclear fuel cycle. The continued communication of international lessons learned will reduce information asymmetries and improve efficiencies in the decommissioning of nuclear facilities. Recognising the need for alternative evacuation routes for decommissioning wastes streams, it is recommended that the nuclear industry continue to investigate and promote the reuse of recycled LLW within the controlled nuclear sector. The fundamental safety goals for radioactive waste management, *Isolation* and *Containment*, could be achieved with a properly designed recycling infrastructure. The proposed policy of "Waste Offsetting" is a market based instrument has two intended results:

1) it facilitates the reduction of radioactive waste, moving the nuclear industry in a sustainable trajectory

2) it expands the overall pool of entrepreneurial opportunity creating job markets for the recycling of slightly contaminated material in the controlled nuclear industry

When reviewing the international experiences in decommissioning, an objective should be to identify areas where sustainability can be improved. The past 40 years of the "*Dispose and Replace*" framework has allowed for the internalization LLW disposal costs; however, in order to improve the performance of the nuclear fuel cycle alternative evacuation routes for LLW should be identified. Further research should be conducted regarding the recycling of LLW as an alternative to disposal recognizing that *"[t]he more we know how to do something, the harder it is to learn how to do it differently"* [23]. "*Recycle and Reuse*" strategies have the potential to expand the knowledge, competencies, and skills that will be transferred to the next generation. The reuse of recycled LLW in the controlled nuclear sector has the potential to improve sustainability, safety, and economics of the nuclear industry.

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