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Submission to the South Australian Nuclear Fuel Cycle Royal Commission

Terrestrial Energy

The Integrated Molten Salt Reactor from Terrestrial Energy is a revolutionary nuclear reactor design. Through the deployment of sealed, integrated reactor cores running on liquid salt fuels, the IMSR achieves step change improvements in safety and commercial viability. These characteristics will make IMSR a competitive provider of reliable clean energy in Australia's National Electricity Market.

Terrestrial Energy

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INTRODUCTION

Terrestrial Energy Inc is a private Canadian Company that is developing its proprietary nuclear technology, called Integral Molten Salt Reactor (IMSR) technology, for global commercial deployment within the next ten years. IMSR technology is small modular advanced nuclear technology that is based on proven technology, and can revolutionize nuclear safety, waste, proliferation and cost-competitiveness. Terrestrial Energy's IMSR can provide carbon-free heat and power to global industry at a cost that is competitive with coal and natural gas.

The Company has filed patent applications in 59 countries as part of a program to secure the intellectual property associated with the IMSR design.

The Company consists of a team of credentialed scientists and businessmen – over thirty directors, officers, managers, advisors and consultants. During Phase I of its four-phase business plan, the Company assembled a technical team, a management team and a corporate governance infrastructure. The Company's technical team consists of employees and consultants, with each member secured under contract and recruited for their specific technical expertise. The Company has a board of directors numbering five, a management team of seven, an International Advisory Board of ten, and a team of external technical consultant experts. Together this represents a team of notable capability with members demonstrably credentialed in the fields of international business, finance, environmental protection, nuclear science and engineering, nuclear regulation, the natural resource industry and the power utility industry. Two of the Company's technical team were previously from ORNL and one worked extensively on the original ORNL MSR program. The Company has strong and formal connections with ORNL and other leading nuclear laboratories globally, including the Canadian national nuclear laboratory.

We are pleased to bring this submission to the South Australian Nuclear Fuel Cycle Royal Commission. We regard Australia as a potentially ideal market for the IMSR, as well as a potential sovereign partner in the next stages of research, development and manufacturing. The submission is structured to respond to the questions raised in Issues Paper 3, with some reordering and merging of questions to present the most logical flow of information.

We look forward to the opportunity to meet with the Commission and discuss this submission in detail.

3.1 Are there suitable areas in South Australia for the establishment of a nuclear reactor for generating electricity? What is the basis for that assessment?

IMSR is suitable for deployment across South Australia. We note the issues raised in precursor to this question in Issues Paper 3.

The IMSR concept is based on small reactors cores that may be deployed as modules to create large power stations. With core sizes of 300 MWth and 600 MWth, generation from IMSR could be easily spread to balance generation across the relatively “skinny” South Australian grid. This also allows generation to be located to target specific new demand that may arise such as mining or mineral processes. The size of the units and the ability to build incrementally mitigates the risk of over-investment for South Australia for scenarios of either slow growth in new demand or replacement of incumbent generators for the purpose of decarbonisation.

Traditional build concerns for nuclear generation are not relevant to the IMSR. As previously highlighted, the largest component is the integrated core. This is to be manufactured in an assembly line manufactory setting with high levels of quality control and is then transportable by truck or rail for installation. On site construction and associated local impacts are therefore minimised. The core is replaced once every 7 years.

Operations of the IMSR are minimally invasive. The reactor development will be low rise, with below-grade reactor cores as a standard design feature.

The IMSR has no potential vectors for the release of waste to the surrounding local environment. The reactor core remains sealed for 7 years of operation plus a multi decade period of on-site cooling before removal to centralised decommissioning. Gaseous fission products are removed and contained. The operation requires the delivery of less than 12 metric tonnes of LEU fuel for the entire lifetime of the replaceable core-unit. Volumetrically, this equates to 0.6 cubic meters. Otherwise, it entails no deliveries of fuel by road, rail or pipeline, and no combustion of fuel. Operation of the IMSR will entail far less noise, waste and pollution concerns than existing fossil plants in South Australia.

On the basis of the matters raised relating to this question in Issues Paper 3, the IMSR is suited for broad deployment across South Australia.

3.2 Are there commercial reactor technologies (or emerging technologies which may be commercially available in the next two decades) that can be installed and connected to the NEM? If so, what are those technologies, and what are the characteristics that make them technically suitable? What are the characteristics of the NEM that determine the suitability of a reactor for connection?

This submission describes Terrestrial Energy's reactor design called the Integral Molten Salt Reactor (IMSR). For reasons to be discussed, this reactor is eminently suitable for connection to Australia's National Electricity Market. This initial response provides a summary of the main features of this reactor and its suitability in the National Electricity Market. More detailed discussion of key issues of safety, waste and economics are addressed in further detail in response to subsequent questions.

The IMSR is a liquid fuelled, graphite moderated, burner reactor. It has been developed from over five decades of research and development into liquid fuelled reactors. The IMSR operates with a proprietary liquid fuel salt eutectic. The IMSR design permits the use of a salt that is plentiful, cost effective and produces little tritium in operation, much of which can be captured using existing methods. This is only possible with a burner reactor as the much higher neutronic efficiency of a breeder fuel cycle, mandates the use of lithium fuel salts; these produce much higher quantities of tritium during operation. Furthermore the IMSR's 7-year fuel cycle is materially longer than that of conventional reactor systems in commercial use today and so consumes far more of its nuclear fuel. As a result the IMSR requires 1/6th the amount of uranium fuel and so delivers exceptional fuel resource efficiency on a per kWh basis.

Innovative design characteristics and decisions overcome historic challenges of both liquid-fuelled reactors and the well-understood limitations of solid-fuel reactors that make up the mature nuclear energy sector today. As a result, the IMSR offers transformative cost advantages that will enable it to compete in mature and established markets, on price alone.

The most important innovation presented by the IMSR is the integrated, replaceable reactor core, the "Core-unit". A long-standing challenge for liquid fuel reactors has been the longevity of reactor core materials. Of the greatest importance in this regard is the lifetime of the graphite moderator. The use of graphite imparts many advantages in MSR design and its performance is extensively understood. However its lifetime is directly related to the power density that is employed. Retaining an economic power-density in the design requires regular replacement of the moderator. This is challenging as the core would need to be opened, and elaborate protocols would be required to manage the handling of the irradiated graphite moderator as well as managing the release of volatile fission products. Such complex maintenance protocols with attendant regulatory burden would heavily detract from the reactor's commercial merit.

Terrestrial Energy's IMSR seeks to maximize the simplicity and advantages of the graphite-moderated MSR-Burner approach, while also offering a novel solution to the concerns listed above through a simple but major change in basic reactor design. This patent-pending solution integrates all components of the reactor core that operate on the hot salt into a permanently sealed core-unit, which would be replaced periodically at an estimated cost of $50 Million CAD for the largest IMSR600 model, which is rated at 600MWth, or approximately 291 MWe. (The fuel costs for this model are negligible.) The power output from this model is equivalent to the electrical power output of 5.25 million metric tonnes of bituminous coal, which has a value today of approximately $350 million USD. The economics of the replaceable unit are robust and justified. The IMSR has achieved a design allowing a seven-year operational life of a sealed core unit. This confers several economic advantages:

- Allowing far higher and more economically viable power densities
- Allowing assembly-line style manufacturing of the cores, permitting the highest levels of quality control and the lowest levels of site-to-site variation
- Allowing centralised return and decommissioning of cores, potentially paired with fuel recycling

With replaceable core-units and the ability to refurbish other components, such as steam generators or turbines, a many decades-long plant lifetime is possible. The overall advantages of this "sealed *and* swapped" approach include easier regulatory compliance, reduced R&D, and operational lifetime confidence.

At the end of its seven-year run, the operational IMSR Core-unit would be shut down and coolant lines would be connected to a new IMSR Core-unit in an adjacent containment silo. The spent IMSR Core unit can remain in place for the next seven years, and at any later point, fuel salt can be removed for reuse, recycle, or conversion to waste form.

This manufacturing and design philosophy represents a departure from traditional forms of nuclear energy that are based around achieving long lifetimes to minimise amortized capex per year and demonstrate economic viability. By accepting and embracing the possibilities of replaceable low-cost cores, IMSR delivers an entirely different value proposition than the traditional, solid fuel light-water reactor industry. Therefore from an economic perspective, the IMSR is highly suitable for Australia's National Electricity Market. The economic performance of the IMSR is discussed further in response to questions 3.15 and 3.16

The IMSR uses a molten salt liquid fuel mixture made up of the fuel salt (uranium fluoride) and the salt coolant (carrier salt). This provides the foundation for an enhanced safety profile in this reactor, which achieves "walk-away" safety. From a safety perspective, and from the point of view of securing public confidence, the IMSR is highly suitable for Australia's National Electricity Market. Safety related details are discussed further in relation to question 3.9 and 3.13.

Terrestrial Energy may develop an 80 megawatt thermal (MWth) (32.5 MWe) unit first and target off-grid markets. South Australia and Australia has many remote settlements and mineral resource operations demanding reliable electricity supplies. The IMSR80 will be strong competitor in these markets.

The larger IMSR units will be 300 MWth (141 MWe) and 600 MWth (291 MWe). This size range is ideal for the displacement of fossil fuel generators from the National Electricity Market. The IMSR300 and IMSR600 could be connected within South Australia with no network enhancements, as it is well within the modelled limit of 450 MWe[1] . Therefore from the perspective of the size of the units, there are few barriers to the inclusion of IMSR in the National Electricity Market.

If paired with suitable fuel recycling facilities, the IMSR burner can deliver near-complete elimination of long lived transuranic wastes. Waste and decommissioning issues are discussed further in response to question 3.12.

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[1] (Electranet 2012)

3.3 Are there commercial reactor technologies (or emerging technologies which may be commercially available in the next two decades) that can be installed and connected in an off-grid setting? If so, what are those technologies, and what are the characteristics that make them technically suitable? What are the characteristics of any particular off-grid setting that determine the suitability of a reactor for connection?

Yes. As per the response to question 3.2, the first priority for the IMSR is the 80 MWth unit targeting off-grid settings. This has been pursued with the remote settlements of Canada in mind, and such remote circumstances are wholly applicable to the South Australian setting.

3.4 What are the conditions that would be necessary for new nuclear generation capacity to be viable in the NEM? Would there be a need, for example, for new infrastructure such as transmission lines to be constructed, or changes to how the generator is scheduled or paid? How do those conditions differ between the NEM and an off-grid setting, and why?

Answers to these questions depend on the type of nuclear power plant under consideration. Establishing traditional, large, solid fuel nuclear plants might require substantial changes in Australian pricing policy and network infrastructure.

The IMSR business model is predicated on short life core, not long life, and the core replacement is low in cost. This does not demand the long-term security of price of large, solid fuel generators with cores designed for 60-year lives and very-high upfront capital investment. IMSR would require no special policy to enable financing due to the vastly improved business model provided by short-life cores and assembly-line manufacturing that diminishes requirements for up-front capital and improves early rates of financial return.

Thanks to the small generating units, no new infrastructure is likely to be required for connection.

South Australia's high and potentially growing stock of wind generating units may necessitate additional transmission in order to also take full advantage of the highly reliable, low cost, pollution-free power from the IMSR which can be exported during overnight low demand to displace brown and black coal generation in other NEM jurisdictions including Victoria and New South Wales.

IMSR would require no special treatment in the NEM for dispatch. It would compete directly on price of electricity supplied. Forecast pricing and high capacity factor suggest IMSR would succeed in displacing existing incumbent fossil generators from the NEM on a wholly competitive basis. Any policy geared toward accelerated transition to clean energy sources, be it carbon pricing or mandated targets such as, for example, a technology-neutral clean energy target, would hasten and aid this market transition. Further discussion of the economic performance of IMSR is provided in response to question 3.15 and 3.16.

Changes in key policies including the EPBC Act (1999) and the ARPANS Act (1998) are prerequisites for serious efforts to bring the benefits of the IMSR technology to Australia.

3.6 What are the specific models and case studies that demonstrate the best practice for the establishment and operation of new facilities for the generation of electricity from nuclear fuels? What are the less successful examples? Where have they been implemented in practice? What relevant lessons can be drawn from them if such facilities were established in South Australia?

While best-practice examples of existing technology can be identified, the IMSR has been designed to overcome the many inherent disadvantages of the mature nuclear industry, particularly in matters of cost, time to construct and deploy, and scalability.

As such, there are few relevant case studies, globally, providing insight into the specific advantages offered by the IMSR.

One relevant generalisation is that achieving the highest possible level of recognition of design approvals from other regulators in mature nuclear markets is a crucial step in quickly establishing facilities for nuclear generated electricity.

3.7 What place is there in the generation market, if any, for electricity generated from nuclear fuels to play in the medium or long term? Why? What is the basis for that prediction including the relevant demand scenarios?

We note the discussion preceding this question in Issues Paper 3 pertaining to the National Electricity spot market, moderating demand and existing excess capacity.

Scenarios of strongly growing demand are necessary for investment in conventional nuclear *where the costs of the new nuclear generation substantially exceeds the existing average costs of generation*.

However the IMSR will deliver electricity at a cost that is wholly competitive in the existing Australian market; not only with other newly constructed generators, but with existing market average prices.

Therefore, even in a “worst case” investment scenario of sustained low growth in demand, generation from IMSR technology will compete. Its introduction to the National Electricity Market would bring with it the advantage of highly reliable generation infrastructure with no emissions of greenhouse gas.

While demand has moderated in the National Electricity Market, this is unlikely to remain the case in the long term. Australia is maintaining strong population growth through immigration. Population is currently forecast to double by approximately 2050[2]. Scenarios of flat or declining demand under such conditions could be achieved only under policies of extreme energy conservation. Such scenarios would be challenged by new sources of demand such as transport electrification. It would therefore be prudent for South Australia and the whole National Electricity Market to plan for an eventual resumption in demand growth.

While South Australia has led Australia in the uptake of renewable technologies, it remains connected to the NEM and is a net-importer of electricity[3]. This is one of the most greenhouse gas-intensive electricity supply systems in the world. Signs of more robust international action on tackling climate change continue to grow[4]. From a risk-management perspective, Australia must plan the deployment of reliable sources of zero-carbon generation to complement the growing stock of variable renewable generators. Otherwise Australia risks a potential sudden downgrade in terms-of-trade in the future due to the greenhouse gas intensity of domestic production.

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[2] Syed (2012)
[3] Heard, Bradshaw and Brook (2015)
[4] The White House (2014)

It is therefore imperative that South Australia and the National Electricity Market develop and prepare options to meet demand growth that are both non-variable and zero-carbon[5]. The IMSR is a transformative nuclear technology that would meet this need.

Finally, in the event of any scenarios of demand growth, the small and flexible unit size of the IMSR is ideally suited to South Australia. It may serve either as incremental addition to overall supply, or as a tailored supply solution to a new demand source such as mining, mineral processing or manufacturing. The latter offers the potential to revolutionise the development of remotely located mineral deposits.

[5] Heard, Bradshaw and Brook (2015)

What issues should be considered in a comparative analysis of the advantages and disadvantages of the generation of electricity from nuclear fuels as opposed to other sources? What are the most important issues? Why? How should they be analysed?

To gain a holistic view of the relative merits of electricity sources we recommend the Royal Commission considers:

- Whole-of-lifecycle impacts on mortality and morbidity, normalised for the quantity of electricity produced.
- Cost of generation installed ($ per kW)
- Levelised cost of electricity (LCOE, $ per kWh)
- Whole-of-lifecycle production of greenhouse gas emissions
- Capacity factor
- Variability and climate dependency
- Raw material consumption normalised for the lifespan and generating capacity of the generator
- Production and management of wastes
- Operational pollution (e.g. emissions)
- Scalability, relevant to the demands of the 21st century for clean electricity
- National fuel security
- Fuel mining impacts
- Land footprints and consumption, particularly impacts on sensitive wilderness or biodiverse areas.

Across the criteria named above, the nuclear energy sector, over a history of more than 50 years, has performed extremely well[6].

Nonetheless, inherent disadvantages in current generations of solid fuel reactors have contributed to constraining uptake of nuclear technologies. This has been the impetus behind the development of the IMSR. The IMSR will deliver step-change improvements in safety, fuel efficiency, scalability and cost while retaining the traditional advantages of nuclear energy in reliability and low-greenhouse production.

[6] These issues are reviewed for South Australian conditions in Heard and Brown (2012)

3.9 What are the lessons to be learned from accidents, such as that at Fukushima, in relation to the possible establishment of any proposed nuclear facility to generate electricity in South Australia? Have those demonstrated risks and other known safety risks associated with the operation of nuclear plants been addressed? How and by what means? What are the processes that would need to be undertaken to build confidence in the community generally, or specific communities, in the design, establishment and operation of such facilities?

The central pillar of nuclear reactor safety regardless of reactor system, is a strong independent regulatory body that mandates strict adherence to disciplined operating procedures and promotes a safety culture within the industry. However the inherent safety of reactor system remains strongly technology dependent.

The IMSR is a completely different reactor system at the most fundamental level. The IMSR's safety and commercial case is also completely different. It is a nuclear technology with a very different social and economic narrative. IMSR renders historic accident types as not merely implausible but physically impossible.

However there will be no substitute for open and informed discussion and skilful risk communication in developing consensus for the developing of nuclear generating capacity in South Australia; this process will be given a boost by the very different design attributes of the IMSR.

There are two types of nuclear accidents. The first occurs when a reactor's power spikes to damaging levels, as happened, for example, in the 1986 Chernobyl accident. This is a "criticality accident", a rare form of accident that is concurrent with a substantial degradation in safety culture and adherence to approved operating protocols. The IMSRs are inherently and extremely resistant to "criticality accidents" for a number of reasons.

Firstly, the IMSR does not need the "excess core reactivity" of a LWR. LWRs are loaded up with fuel for 18 months of operation. In contrast, MSRs can be fueled slowly and continuously.

Secondly, without any active system support, the IMSR reactor core will respond instantly to an increase in criticality and its associated rise in fuel salt temperature. The chain reaction slows and the reactor starts to shut itself down. This is due to the reactor's "negative temperature reactivity coefficient". This is term-of-art, which signifies that the reactor is self-regulating; it is stable in operation.

All reactors have such a desired negative coefficient, but the coefficients for IMSRs are far more negative.

The important negativity of this coefficient is determined by the interplay of three factors:

1. **Fuel-salt density.** A decrease in density removes fuel-salt from the core, changing the fuel-to-moderator ratio and increasing neutron leakage.

2. **Doppler broadening of resonance-absorption peaks.** Higher temperature produces broader peaks.

3. **Graphite temperature.** Higher temperature shifts the Maxwellian neutron peak to higher energy, and into (or out of) fission-resonance peaks.

These three factors must combine to yield a negative coefficient overall, and ideally all three factors separately will make negative contributions. Modelling to date confirms negative contributions from all three factors in the IMSR, yielding a highly negative coefficient value overall.

A buoyancy-driven control rod is the primary shutdown mechanism for the IMSR. It is a simple rod, slightly denser than the fuel-salt at operating temperature and held above the core by the pumped circulation of the fuel. If pumping ceases, or if the fuel-salt rises in temperature (thus expanding and decreasing in density), the control rod passively drops into the core and takes the reactor subcritical.

The control rod is backed up by a thermally activated "poison pill" that injects neutron absorbers into the fuel-salt if the temperature rises even higher; the reactor cannot then be restarted until the neutron absorbers are filtered out or chemically removed. This safety feature is not possible in solid fuelled reactor systems.

For this reason IMSR criticality accidents that may damage the reactor core or endanger the public are a physical impossibility.

The second type of nuclear power plant accident is caused by a failure to remove decay heat from the reactor core after shutdown, a "decay-heat" accident. The Three Mile Island and Fukushima accidents are examples of such an accident.

The dispersion of heat from a reactor core is the central and critical mechanism that supports the safety of any reactor system. MSR and the IMSR specifically can use liquid convective flow as method of heat dispersion; this is not possible with solid fuelled reactor systems, the fuel is a solid. These systems must rely on the permanent supply of pumped coolant to the reactor core. The failure to maintain this permanent supply was the mechanism behind the Three Mile Island and Fukushima accidents. The IMSR, employing a liquid fuel with its natural property of convention, is not reliant on a permanent supply of pumped coolant to the reactor core. This makes for an entirely different safety case for the IMSR where the failure pathways of historic decay heat reactor accidents are absent.

The IMSR has developed a patented in-situ method to provide the highest level of reliable, passive heat removal.

The IMSR Core-unit operates within a concrete containment shell lined with a 1-meter- thick layer of solid buffer salt surrounded by a water jacket. The buffer salt is a salt eutectic, chosen to achieve the target melting point. This salt remains solid while the reactor is operating within normal temperature ranges. At a temperature about 50°C above the normal operating temperature of the IMSR reactor core, the buffer salt melts, and upon melting, its thermal properties change. In addition to absorbing the latent heat of melting, once a liquid, the salt will circulate by natural convection and conduct heat away from the IMSR Core-unit. In combination, these two effects alone permit the buffer salt to dissipate heat for the first two days of decay heat without any operator intervention.

A water jacket of coiled piping around the buffer-salt liner then provides a subsequent means of decay-heat removal. It is connected to a nearby above-ground water tank, so that any steam generated within the water jacket is passively captured by condensation in the water tank, heat then being released to the surrounding atmosphere. With these two mechanisms in place, decay heat is managed for the duration necessary to secure a robust safety case. In addition, tertiary heat dissipation is provided by thermal radiation through the shielding cap.

Collectively these mechanisms permit the removal of decay heat from the IMSR reactor core. Together with criticality control, this secures the passive safety case. The reactor is “walk-away safe”. Control rods or poison pill shut the reactor down, no further intervention is necessary.

The IMSR uses liquid (or molten) fuel, thereby rendering the term “meltdown” irrelevant. The IMSR operates at atmospheric pressure, and has no potential for energetic chemical reactions, such as the hydrogen explosions seen at Fukushima. No water or steam is present in the core, or anything that could produce hydrogen, and potentially cause a secondary explosion. The IMSR operates at 1 atmosphere of pressure, and lacks any internal driving forces that can spread radioactive material. By comparison, LWRs operate at 160 atmospheres of pressure in normal conditions.

Furthermore, and of great safety importance, the fuel (uranium, thorium, plutonium, etc.), and fission products, remain locked within the liquid salt, even in the case of an extreme external event that manages to breach the many levels of containment surrounding the MSR. In even these highly unlikely scenarios, any released salt would cool and solidify, immediately causing nuclear reactions to cease. Only a few of the fission products in the molten salt are volatile and can conceivably depart.

An IMSR is therefore inherently stable and delivers safety at a small fraction of the cost of pressurised, solid fuel LWRs. The known failure modes of conventional nuclear plants, the failure modes of Three Mile Island, Chernobyl and Fukushima, have been comprehensively and successfully addressed in the IMSR design.

3.11 How might a comparison of the emission of greenhouse gases from generating electricity in South Australia from nuclear fuels as opposed to other sources be quantified, assessed or modelled? What information, including that drawn from relevant operational experience should be used in that comparative assessment? What general considerations are relevant in conducting those assessments or developing these models?

This is a mature area of academic enquiry with consistent conclusions that are accepted at the highest levels[7]. Studies indicate that, across the full lifecycle, nuclear energy is among the lowest greenhouse-gas forms of electricity production. Studies have been prepared specifically for Australian conditions and meta-review of the relevant literature has been undertaken by an Australian University[8].

The IMSR is likely to deliver even better performance in this regard than conventional nuclear thanks to:

- Lesser energy inputs for liquid fuels than traditionally fabricated solid fuel rods and large complicated fuel assemblies
- Higher efficiency in the use of mined uranium inputs by a factor of six
- Operations at atmospheric pressure, demanding lesser inputs of steel and other reinforcing materials

[7] Moomaw et al. (2011)
[8] Lenzen (2008)

3.12 What are the wastes (other than greenhouse gases) produced in generating electricity from nuclear and other fuels and technologies? What is the evidence of the impacts of those wastes on the community and the environment? Is there any accepted means by which those impacts can be compared? Have such assessments making those comparisons been undertaken, and if so, what are the results? Can those results be adapted so as to be relevant to an analysis of the generation of electricity in South Australia?

Thanks to the long fuel-cycle and very high efficiency core of the IMSR, this design achieves less outputs of waste per unit electricity than traditional nuclear generation.

Table 1 IMSR waste (indicative) versus LWR waste

Normalised to a 1 GWe-year	LWR	IMSR
Fuel (tonnes)	250	35
Plutonium waste- kg, without recycling	250	36
Plutonium waste- kg, with recycling	Approx. 50 % reduction	Virtually nil
Fission product waste, kg	1200	800
Gaseous fission product waste (m3)	39	26

The principal operational waste from the IMSR will be the spent fuel cores, being the contained fuel salt and ancillary devices.

Indicatively an IMSR80 will deliver 1.4 tonnes of waste fuel from seven years of operations.

There is the potential for the IMSR to further reduce waste both upstream and downstream of operations.

Firstly, the spent fuel salt is highly recyclable. A single-batch process after many years of use to recycle transuranic elements (in particular plutonium) would give a waste profile virtually free of transuranic wastes, which are currently viewed as “troublesome” but in fact contain enormous quantities of fission energy that can be extracted in the IMSR.

A centralised chemical fuel recycling facility[9], using processes of electrochemical separation, can remove the small quantity of fission products from the liquid fuel salt. The remaining uranium and transuranic elements can either remain in salt solution for re-use in another IMSR core, or be fabricated into solid fuel for reuse in, for example, a sodium cooled fast breeder reactor[10]. The ultimate destination would depend on operational and commercial considerations. However the important point is that with sufficient recycling capabilities only the small amount of fission products *need* be disposed of as waste. These fission products are relatively short lived (approximately 30 year half-life)[11]. As such their safe management and disposal is well-within institutional capabilities and timeframes.

Secondly the uranium and transuranic input to the fuel salt might itself be derived from existing used fuel rods from the traditional nuclear power sector. The same type of centralised recycling facility could extract usable transuranic elements, principally plutonium, from solid metal oxide fuel rods. As such the operation of the IMSR might require little or even no upstream mining for the initial fuel.

Note, these advantages are not inherent to the IMSR proposal. However the IMSR can operate synergistically with advanced recycling facilities to deliver large quantities of highly reliable electricity with the production of only tiny quantities of fission-product waste, and also alleviate the challenge of managing stockpiles of the long-lived transuranics held in used solid fuel.

The other main waste outputs of the IMSR are the reactor core vessel itself. After draining of the liquid salt, this vessel will require decontamination flushing with non-radioactive salt to reduce residual activity to a minimum. The core would then be stored for several years to allow the decay of any activated material or residual fission products. At this time, the core would likely be classified as either intermediate level waste or, more likely, low level waste. This will require disposal at an approved facility.

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[9] Such as that described in Argonne National Laboratories/ Merrick and Company (2015)
[10] Triplett, Loewen and Dooies (2010)
[11] Till and Chang (2011)

3.13 What risks for health and safety would be created by establishing facilities for the generation of electricity from nuclear fuels? What needs to be done to ensure that risks do not exceed safe levels?

The nuclear industry, to date, has achieved an outstanding operational safety record normalised for electricity production against all other energy sources for power production[12]. This has been achieved through robust engineering and regulatory responses to credible events and serious accidents. On the basis of evidence, the risk in establishing facilities of the generation of electricity from nuclear fuels will be very low.

However this safety record has come at the cost of nuclear reactors carrying a design and regulatory legacy that has increased cost and constrained deployment and has arguably failed to secure public confidence.

As previously documented, the unique design attributes of the IMSR have *eliminated* the most challenging operational safety elements of solid fuel nuclear reactors. Recapping, the IMSR:

- Operates at atmospheric pressure
- Utilises a liquid fuel, rendering the concept of "meltdown" redundant
- Passively cools for indefinite periods, rendering the reactor "walk-away safe"
- Loses criticality and shuts down automatically with temperature increase beyond normal operations
- Operates free of water in the core, eliminating the potential for production of explosive hydrogen
- Is incapable of generating sufficient mechanical or chemical energy to cause the explosive distribution of core material
- Keeps fissile material chemically locked in a liquid salt fuel, which freezes to a solid in the event of distribution by extreme external forces
- Will be based on assembly-line construction of standardised reactor cores, permitting outstanding quality control
- Uses sealed cores with long-operational life for recycling and disposal at dedicated centralised facilities. This again maximises quality control and minimises occupational exposures.

[12] (Bickel & Freiedrich 2005; Burgherr and Hirschberg (2008); Kharecha and Hansen (2013); Markandya and Wi kinson (2007))

In summary, the risk associated with the nuclear power industry is low on the basis of half a century of evidence and study. In advancing nuclear technologies, South Australia could put these matters beyond any and all credible doubt through the adoption of IMSR technology that revolutionises the safety case for nuclear-generated electricity.

3.15 What impact might the establishment of a facility to generate electricity from nuclear fuels have on the electricity market and existing generation sources? What is the evidence from other existing markets internationally in which nuclear energy is generated? Would it complement other sources and in what circumstances? What sources might it be a substitute for, and in what circumstances?

3.16 How might a comparison of the unit costs in generating electricity in South Australia from nuclear fuels as opposed to other sources be quantified, assessed or modelled? What information, including that drawn from relevant operational experience, should be used in that comparative assessment? What general considerations should be borne in mind in conducting those assessments or models?

The IMSR is, first and foremost, a commercial development. Ipso facto, this reactor development is intended be commercially competitive in free electricity markets with the ability to displace other sources of supply and capture market share.

Existing evidence and commercial assessments of nuclear electricity cost performance have little relevance to the IMSR due to the revolutionary manufacturing, deployment and operational concepts of this reactor.

IMSR cost estimates to date indicate the IMSR600 and IMSR 300 will deliver grid-connected electricity to market at US$43 and US$59 per MWh respectively on a levelised cost basis. These costs will be scrutinised and refined further in Phase II of the research and development program.

South Australian spot prices averaged AU$68 per MWh in 2013-14[13]. It can be generally asserted therefore that under these conditions the IMSR600 and IMSR300 would be heavily dispatched into the South Australian market, taking share from other dispatchable generators. Weekly spot prices from July 2012 to September 2014, and volume-weighted annual average spot prices across all National Electricity Market jurisdictions[14] suggest

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[13] Australian Energy Regulator (2014)
[14] Australian Energy Regulator (2014)

IMSR300 and IMSR600 would win consistent levels of dispatch into the market and potentially would win constant, year-long dispatch i.e. IMSR could become Australia's new baseload.

Based on price in the National Electricity Market, the IMSR would likely substitute for gas generation, followed by black coal, followed by brown coal.

Given what the IMSR price is an estimate for new plant, its ability to potentially displace established, incumbent and in some cases fully depreciated suppliers in the National Electricity Market is an excellent price outcome.

Any return to carbon pricing or furthering of technologically-inclusive clean energy policy in Australia would serve to extend this market advantage further.

We note the increasing penetration of wind energy in South Australia. Currently wind energy is subsidised into the National Electricity Market. Wind energy wins priority dispatch by virtue of low operating costs and assured revenue from the sale of certificates[15].

Introduction of the IMSR would likely have no negative impact on market penetration of wind and solar PV electricity in the National Electricity Market for the foreseeable future for three key reasons:

1. NEM-wide, penetration of wind and solar energy remains relatively low (4.4 % and 2 % of all electricity respectively[16])
2. NEM-wide, coal and gas generation remain dominant (74 % and 12 % respectively[17])
3. Pricing of IMSR will compete with baseload suppliers
4. IMSR load-following capability far exceeds that of any conventional nuclear power plant

If IMSR were added to the National Electricity Market it would firstly take market from higher-priced gas generation, then black coal generation, and finally brown coal generation. Sufficient levels of interconnection from South Australia to the National Electricity Market will ensure both wind and IMSR can dispatch low-cost clean electricity at all times. Meanwhile solar PV will continue to lower midday and early evening summer peaks in demand[18].

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[15] Heard, Bradshaw and Brook (2015)
[16] Australian Energy Regulator (2014)
[17] Australian Energy Regulator (2014)
[18] Australian Energy Market Operator Ltd. (2014)

Penetration of wind in South Australia may rise to levels where even very-low cost, clean generating IMSR would be forced to curtail dispatch. Such scenarios are distant and can be managed by good planning.

In the shorter term, the strong automatic load following capability of the IMSR, related to the strong negative temperature reactivity coefficient, makes it a good partner to assist in the efficient management of the variable output from wind generation.

CONCLUSIONS

We applaud the Government of South Australia for undertaking this structured enquiry into the potential for nuclear technologies to benefit the people of South Australia.

The IMSR represents an advantageous advanced nuclear reactor design that can deliver low cost, reliable clean energy. Engagement with this technology provides the potential for longstanding beneficial outcomes in research, development, manufacturing and clean energy for South Australia.

To conclude this submission, we wish to raise the following potential actions and outcomes for consideration by the Royal Commission:

Collaborative research partnerships

ANSTO is a world-class nuclear physics research facility. Terrestrial Energy would welcome the opportunity to expand our research at ANSTO with respect to online fuel reprocessing. The end goal of such research would be to create a next generation of IMSR-based technology that includes a centralised reprocessing facility, and as a whole, forms a closed fuel cycle -- consuming 100% of its own fuel and 100% of its own long-lived waste during the normal course of operations. Terrestrial Energy suggests that the IMSR is an excellent technology with which to pursue this goal, and this research would be world-leading in our view. Terrestrial Energy would be pleased to fund this research.

Low cost transition of the Australian electricity sector

As an end-user market, Australia is important to Terrestrial Energy. We wish to deploy the IMSR to hasten the replacement of ageing coal capacity globally by providing a scalable, low cost alternative. Australia represents a substantial market in this regard. Facilitating such a transition would seem prudent on the part of Australia as the world moves toward a more coordinated response to climate change. This cannot happen in the presence of legislation in direct antipathy to nuclear technology, even the most advanced designs. We urge the Royal Commission to consider the benefits to Australia of removing such legislative barriers.

Advanced manufacturing targeting the growth Asian energy markets

The growth energy markets for Asia are important for Terrestrial Energy, both to replace existing coal and to steer new investments away from coal. These markets are embracing nuclear technology, seeking ways to decrease coal use, and their energy demand growth is far greater over the next generation than OECD markets[19]. South Australia provides a potentially attractive base of operations for assembly-line manufacturing as a launch pad for Asian deployment of IMSR units. Such a facility will bring tremendous job opportunities to the local economy -- numbering in the thousands. Such a facility would characterize the state of the art in nuclear technology globally, and may attract other high-tech industries to the zone as well. Terrestrial Energy would like to discuss siting such a facility in South Australia.

Synergistic infrastructure development

Terrestrial Energy notes the high level of interest, globally, from advanced nuclear technology designers in South Australia's Royal Commission process. Some other advanced nuclear infrastructure, particularly centralised facilities for the recycling of nuclear fuel, would provide important and enticing synergies relating to the IMSR. The collective pull of intellectual capital toward South Australia will itself become an attractive feature of this jurisdiction. We encourage South Australia to think in terms of these potential synergies to maximise benefits to both the South Australian economy and to advanced nuclear developers

Direct Investment

Terrestrial Energy has embarked on Phase II of its research and development program for the IMSR. We would be interested to discuss the potential for South Australia to secure a financial interest in this stage of development to boost the probability of benefitting from IMSR developments in future.

[19] US Energy Information Administration (2013)

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APPENDIX A : WITNESS STATEMENT

To Whom it May Concern,

Terrestrial Energy submits that the claims made in this submission to the Royal Commission are corroborated by the submission itself and the corroborating documentation attached. Furthermore, Terrestrial Energy, will upon request provide expert witness testimony, given in the presence of the commission. Such expert testimony shall be provided by the following parties, whose Curriculum Vitum are provided as appendices to this document:

- David LeBlanc, PhD – President, Chief Technology Officer, and Co-Founder of Terrestrial Energy Inc, and inventor of the Integral Molten Salt Reactor.

- Robin Rickman – Vice President of Terrestrial Energy Inc.

Submitted,

August 1, 2015,
Vancouver, Canada

Canon Bryan,
Chief Financial Officer,
Terrestrial Energy

APPENDIX B : CV OF DAVID LEBLANC, PHD

Dr. David LeBlanc

17 Merganser Street
Ottawa ON, K1K 4T6
Canada
613 302 4775
dleblanc@terrestrialenergy.com

Education

Ph.D. Physics, 1998
University of Ottawa
Research Area: High Temperature Superconductivity and Fusion Research

M.Sc. Physics, 1993
University of Ottawa
Research Area: Flux line cutting in Superconductivity

B.Sc. Honors Physics, 1989
University of New Brunswick

Experience

President and Chief Technology Officer — Dec 2012-present
Terrestrial Energy Inc., Mississauga/Oakville ON

Founder and inventor of Terrestrial Energy's Integral Molten Salt Reactor. The accumulation of 7 years of design effort in the field of Molten Salt Reactors

President and Founder — 2008 to 2012
Ottawa Valley Research Associates Ltd.

Design and consultation in the field of Molten Salt Reactors. IP portfolio development of various innovative MSR systems. 3 patents filed through OVRA.

Lab Coordinator and Lecturer — 1999 to 2011
Carleton University, Ottawa ON

Ran undergraduate labs in the Carleton Physics Department. Taught in both lab and course lectures and responsible for approximately 15 graduate teaching assistants.

Research Contractor — Mid to late 1996

Atomic Energy of Canada Limited, Sheridan Park Mississauga ON

Contracted by AECL Chief Engineer Dan Meneley to perform a comprehensive global reactor design comparison. Work resulted after numerous interactions with AECL staff on nuclear design concepts. Temporarily left Ph.d studies to complete this work.

Honors and Awards (reverse chronological order)

Long term Fellowship, Canadian Fusion Fuel Technology Program	1993-1996
Ontario Graduate Scholarship	1992

Journal Publications

Numerous publications from 1990 to 2015 in the field of superconductivity, nuclear energy and Molten Salt Reactors. Most comprehensive MSR example;

"Molten Salt Reactors: A New Beginning for and Old Idea" Nuclear Engineering and Design 240 (2010) 1644-1656

Magazine Publications

"Too Good to Leave on the Shelf" May 2010 Mechanical Engineering Magazine (ASME)

"The Integral Molten Salt Reactor" Dec 2014 Nuclear News (American Nuclear Society)

Conference Proceedings

Approximately 20 conference papers and invited talks on Molten Salt Reactor technology since 2007. Including Canadian Nuclear Society Annual Conference (3 publications), Thorium Energy Alliance (6 times), International Thorium Energy Organization (London), ICONE 2009 Brussels, Uranium 2010 Saskatoon and Molten Salts in Nuclear Technology, Mumbai India 2013.

Patents

Patent One "Molten Salt Nuclear Reactor": Provides the optimal Thorium Molten Salt Breeder Reactor design of the Two Fluid variety which solves issues which caused this promising approach to be abandoned by Oak Ridge National Labs in 1968. Original filed U.S. PTO May 9, 2008 followed by refiling with new claims Dec 2, 2011 Application Number 13/310,075. Also have entered national phases in India and Canada.

Patent Two Also termed "Molten Salt Nuclear Reactor": Provides for an optimal design of a Single Fluid Molten Salt Reactor with minimal use of solid moderator producing a hybrid spectrum core having the advantages of both thermal spectrum and hard spectrum approaches while solving engineering issues related to the faster spectrum approach. Filed internationally PCT/CA2012/050218 on 05/04/2012

Patent Three "Integral Molten Salt Reactor": Is a combination of functional and method patent relating to the optimal design of a Single Fluid, Graphite moderated Molten Salt Reactor which integrates several basic operational features into a single unit in a unique and functionally practical manner. Filed internationally Feb 6, 2013 CA2013050090 based on a U.S. Provisional Patent Application one year earlier.

APPENDIX C : CV OF ROBIN RICKMAN

Robin A. Rickman

364 Collins Road, Ellwood City, PA 16117 Phone: (724) 758-3419 Email: katzandmice713@verizon.net

Mr. Rickman is the current director of the Westinghouse Small Modular Reactor development program and has been involved in all aspects of the program including business development, marketing, engineering, and licensing since the inception of the program. Mr. Rickman, since retiring from the United States Navy's nuclear propulsion program has worked successfully in all segments of the federal and private nuclear industry in the United States. He is innovative, versatile, and a proven dynamic leader with broad experience and expertise in project, personnel, and business management functions within the highly technical and heavily-regulated nuclear industry.

Work History & Accomplishments

Westinghouse Electric Company, LLC, Cranberry Township, PA

2013 – Present – Westinghouse Nuclear Power Plants

Director, New Reactor Projects

- Responsible for the strategic and organizational planning, budgeting, cost and schedule performance management, technical and regulatory issues resolution, engineering design, licensing activities, and strategic partner identification and selection associated with the Westinghouse Small Modular Reactor (SMR) program; a program that is projected to exceed $1B over its development life.
- Directs the development and implementation of marketing strategies for the Westinghouse SMR product. Activities include brand development, identification of potential markets, creation of pricing strategies, gathering of competitive intelligence, and design of market research campaigns.
- Directs targeted marketing campaigns to position Westinghouse SMR technology for future investment and partnership opportunities both in the US and abroad.
- Directed the planning and implementation of a SMR Project Office to deliver the stated engineering and licensing milestones in accordance with technical, quality, cost and schedule requirements. Responsible for developing the Project Office Charter, Project Management Plan, Project Execution Plan, Project Quality Plan, Risk Management Plan, Configuration Management Plan and other lower tier documents and plans needed to implement the project.
- Secured cost-sharing partners to support exclusively, the Westinghouse SMR development efforts to reduce the investment spending required by Westinghouse to design and license the SMR. Responsibilities included identifying and developing potential sources of development funding or in-kind contribution support through partnerships or other collaborative relationships. Partners included Department of Defense industrial contractors, universities, US DOE national laboratories, and other industrial engineering firms.
- Directed the development of a compliant Westinghouse proposal response to a DOE cost-shared funding opportunity to receive government funding for the Westinghouse SMR design and licensing effort. Objectives included identifying and selecting appropriately qualified personnel to provide proposal support, developing the necessary organizational policies and guidance for developing the proposal, preparing a compliance matrix based on tendered requirements, and coordinating the in-process executive reviews of the proposal documentation.
- Responsible as the company's single point of contact for all matters associated with the US DOE relative to the SMR program. Primary points of contact are the DOE SMR Program Manager and the DOE-NE Procurement Office.
- Coordinated and directed all activities of the NexStart SMR Alliance to maintain support of the Westinghouse SMR program by NexStart members. Acted as the single point of contact for NexStart members to Westinghouse.
- Developed and presented financial projections for the Westinghouse SMR including investment scenarios and ROI to such an extent as to frame the case for investment to allow executive level decision-making regarding partners and incremental investment levels.

Westinghouse Electric Company, LLC, Cranberry Township, PA
2010 – 2013 – Westinghouse Corporate Center, Research and Technology
Manager, Strategic Project Development, Fuel Cycle Technology

- Provided direction, coordination, and oversight in representing Westinghouse business interests at the Idaho National Laboratory (INL) to identify, evaluate, and consider appropriate opportunities for joint INL and Westinghouse research and development collaborations that offered Westinghouse a high probability for commercial success while recognizing and valuing the participation of the INL.
- Managed the development of a compliant Westinghouse response to $452M US DOE funding opportunity associated with the development and licensing of small modular reactors. The response to the tendered announcement was submitted to the DOE three days ahead of schedule.
- Managed the development of an innovative nuclear fuel cycle approach to eliminate high level wastes resulting from the utilization of nuclear fuel. The program included developing a technically sound position that a Thorium-MOX fuel cycle has a reasonably proven high potential for success in transmuting actinides and potentially other isotopes. Objectives included gaining support from the US DOE and other industry bodies for such an approach.
- Managed all DOE-NE Indefinite Delivery/Indefinite Quantity (IDIQ) contract awards to include leading company level evaluation and response to each DOE Task Order RFP issued under the IDIQ contract awards such that Westinghouse proposals were submitted to the prime contractor within the required 10 day response limitation for each TO RFP.
- Managed the execution of all task orders awarded to Westinghouse under the IDIQ master contract. All Westinghouse work scope was delivered to the prime contractor on the schedule identified in each awarded task order and was accomplished within the price submitted with the associated task order proposal.
- Stimulated government funding opportunities for research and development activities and positioned Westinghouse for award of those funds through numerous discussions with the DOE via multiple technical working groups associated with advanced fuel cycle initiatives. Resulting DOE funding opportunity announcements were issued by the DOE for Advanced Reactor Materials and for Accident Tolerant Fuel development. Westinghouse was successful in securing funding for both initiatives and this effort gained Westinghouse future access to a government funding stream of $60M.
- Managed the development of Westinghouse technical responses to US DOE solicited Request for Information (RFI) tenders relative to the back-end approach to the elimination of high level waste. Responses included a concept for a Reduced Moderation Boiling Water Reactor with thorium oxide, TRU burning and full actinide recycle as the reference fuel cycle option; a second concept was a Fast Reactor based on the Toshiba/Westinghouse Advanced Recycling Reactor developed for GNEP (T-ARR), various thorium fuels, TRU burning and full actinide recycle as the reference fuel cycle option.
- Program manager of the development of a Multi-Facet Neutronic Transmutation approach to the elimination of high level wastes resulting from the utilization of used nuclear fuel. This approach was found to be in principle, achievable for both Uranium and Thorium-based fuel. Program activities included analysis of the behavior of Thorium-Based fuels and the investigation of the multiple fuel cycle option scenarios including the ultimate assessment of system sustainability and wastes generated to allow selection of candidate advanced fuel cycles to produce more environmentally-acceptable nuclear waste streams.
- Program manager of revolutionary near term back end fuel cycle technology identification, evaluation, and development efforts. Focus was on technologies aimed at improving uranium resource utilization, maximizing energy generation, minimizing waste generation, improving safety, or to complement institutional measures in limiting proliferation risk with the potential to be delivered to the marketplace within a two to five year time period. Twelve short term technologies were identified and evaluated for feasibility. Three with the greatest potential for short term success were selected for further evaluation. Of these three, Zirconium enrichment and recycling was found to be most promising. Corporate funding restrictions precluded further research of Zirconium enrichment/recycle.

Westinghouse Electric Company, LLC, Monroeville, PA
2008 – 2010 - Nuclear Services, Global Plant Engineering
Manager, Strategic Product Development, US Government Services

- Developed a comprehensive growth plan and financial business case focused on decommissioning and dismantlement of retired government facilities, nuclear waste disposal, and the management and operation of waste disposal or treatment facilities in support of the US government's goals for cleanup of the existing nuclear weapons complex. The plan described the identification of a US government services market share directly related to services that Westinghouse and strategically selected teaming partners could execute. This share was estimated at a value of $9.5B holding a potential net cash flow of ~$30M with a potential Simplified Return on Investment (SROI) greater than 500% over a five-year period.
- Positioned Westinghouse as a preferred teaming partner with a major US DOE contractor in pursuit of multiple DOE business and contracting opportunities. Specific projects included supporting bids for the $400M West Valley Demonstration Project Phase I M&O contract, a re-bid of the $2.9B Idaho Completion Project, and a potential bid valued in excess of $9.3B for a multi-year, Integrated Management Execution contract solicited by the National Nuclear Security Administration for upgrade of the existing nuclear weapons complex facilities. The DOE chose to not tender two of the three opportunities.
- Managed the formation of United Conversion Services, LLC, a joint venture between Westinghouse and Shaw. Activities included leading the development and negotiations of the JV operating agreement, the initial teaming agreement, non-disclosure agreements, identification and selection and approval of other subcontractors to the JV, selection of board members, and developing the jointly approved division of responsibilities and work scopes. The JV submitted a proposal to the U.S. DOE for a $478M cost-reimbursable, cost-plus-award-fee-type contract for the operation of two depleted uranium hexafluoride conversion facilities and the direct disposition of the DOE inventory of DUF6. The proposal was selected as one of two for best and final discussions with the DOE.
- Led the Westinghouse efforts in developing and executing a formal partnership agreement with Shaw, Areva, and URS and secured a preferred supplier position on the successful URS led bid for the $2.3B DOE Office of Civilian Radioactive Waste Management Yucca Mountain management and operations contract for design, licensing, and Probabilistic Risk Assessment services in support of the NRC review of the DOE license application for the proposed high-level nuclear waste repository. This teaming agreement positioned Westinghouse as a preferred subcontractor to provide engineering services associated with this contract for a five year period.
- Responsible for developing the market strategy for providing nuclear engineering and management services to selected opportunities within the US government services marketplace. Responsibilities included leading growth activities, defining new markets and market trends, developing new business strategies for market entry, creating and maintaining strategic business planning documents, maintaining customer and competitor market information, and identification and integration of existing engineering products and services into the strategic plan.

Westinghouse Electric Company, LLC, Monroeville, PA
2007 – 2008 - Nuclear Services, Plant Operations & Support Engineering
Manager, Component Installation Services

- Managed up to 23 direct, indirect, exempt, and subcontractor personnel. Controlled annual budget resources in excess of $3M. Actual sales during this period exceeded the forecast by 33%. The actual margin achieved in this period exceeded the forecast by 25%. Customer Satisfaction Reports improved to an average of 9.43 (10.0 scale) over this period for all customer projects. This score exceeded the company objective of 9.0.
- Product Manager of the Plant Operations and Support Engineering Component Installation Services product line which included LWR reactor vessel head replacements, moisture separator re-heater replacements, feed water heater replacements and other large balance of plant components such as station transformers. Responsible for overall product viability, including growth strategies, and for designing and sourcing innovative, competitive engineering solutions and services for these and other products.

- Provided overall management and direction to multiple installation project managers delivering concurrent complex nuclear installation and modification packages. Included were reactor vessel replacement head and head assembly upgrade projects at Comanche Peak U1, South Texas Project U1 and U2, Arkansas Nuclear One and the successful delivery of a permanent cavity seal ring installation at San Onofre U2.

Advanced Mixed Waste Treatment Project (AMWTP), Idaho Falls, ID

2005 – 2007 - Bechtel BWXT, LLC Idaho

2000 – 2005 - British Nuclear Fuels Limited, Inc.

Operations Support Officer

- Project Manager for several nuclear facility operational startups. Projects included obtaining operational startup approval of a new $1.23B high-throughput, one of a kind, Department of Energy, Hazard Category 2, transuranic waste treatment facility plus startup of the AMWTP nuclear waste retrieval and characterization operations. Coordinated all preparations for startup and liaised on all actions between the Operations, Commissioning, Engineering, Nuclear Safety, Licensing, Criticality Control, Environmental, Maintenance, and Training organizations, the DOE, and multiple independent review teams. Operational startup authorization for all projects was achieved ahead of schedule.
- Project Manager responsible for the identification and implementation of all contract requirements into operational management procedures and instructions. The project included the ultimate development of over 1,900 implementing documents for the AMWTP including document control procedures, records management procedures, operational instructions, reports, waste certification procedures, emergency plans, and all conduct of operations procedures and instructions. Personally drafted and responsible for receiving the final DOE approval of procedures for Startup and Restart of Nuclear Facilities, Occurrence Reporting, and the Unreviewed Safety Question process.
- Project Manager for implementation of reliability centered maintenance analyses of important to safety systems. Systems included the real time radiography units, fissile mass tracking system, drum assay systems, and the box assay system. Each independent analysis required coordination of multidisciplinary work groups including engineers, operator technicians, maintenance workers, vendor representatives, safety analysts, and management personnel. The analysis results for the Real Time Radiography units supported a fundamental change in Department of Energy maintenance requirements for these units which resulted in a documented maintenance-related cost-savings of over $25M to the U.S. government.
- Compiled and evaluated facility production data using six-sigma methodologies. Project evaluations included comprehensive reports to the Department of Energy providing statistical data indicating significant process improvements had been made since awarding the AMWTP contract to Bechtel BWXT. A separate project provided a statistical-based conclusion supporting the Bechtel BWXT position that continuation of Bechtel BWXT as the contractor of choice for operating the AMWTP would be in the best interests of the Department of Energy and the State of Idaho. Bechtel BWXT was awarded the continuation of the contract.
- Led multidisciplinary teams and facilitated completion of root cause analysis of numerous incidents and process and program failures. Significant events investigated included an inadvertent shipment of transuranic waste into the State of Utah, a fire in a transuranic waste drum, multiple fork-lift and truck incidents, and severing of energized 480v underground conduits.
- Completed multiple readiness and management assessments. Team leader for the AMWTP management self-assessment in preparation for the treatment facility operational startup in 2004. Conducted readiness assessment for the AMWTP acquisition of the Transuranic Storage Area Retrieval Enclosure and the associated 65,000 cubic meters of stored transuranic waste. Conducted independent management assessments of programs to evaluate compliance with local, state, and federal requirements for AMWTP.

Idaho National Engineering Laboratory, Idaho Falls, ID
1999 – 2000 - Bechtel BWXT, LLC Idaho
Principal Technical Specialist

- Established a professional partnership with the Eastern Idaho Technical College and the INEL Training Directorate for providing workforce training programs. This partnership resulted in a $268K dollar cost avoidance savings to the U.S. Department of Energy.
- Facilitated training related to conduct of maintenance procedures and philosophies for work planners, nuclear system engineers, and nuclear facility managers. Training centered on the disciplines of maintenance and on hazard identification and mitigation.
- Directed efforts to design, develop, and deliver training and qualification programs to over 600 maintenance craft personnel. Personally responsible for all trade specific mechanical maintenance training activities at the INEL.
- Analyzed and tracked an annual department budget in excess of $300K; responsibilities included identifying sources of budget overruns, budget forecasting, and making budget adjustments through reallocation.

Braidwood Nuclear Generating Station, Braidwood, IL
1995 – 1999 - Commonwealth Edison Company
Mechanical Maintenance General Foreman

- Supervised 10 management and 101 union workers assigned to a nuclear generating station. Controlled annual budget resources in excess of $11M.
- Project manager for various nuclear and utility projects including a first ever nuclear utility, on-line ultrasonic inspection and subsequent repair of a Component Cooling Water Heat Exchanger. This job was conducted during a first time ever dual unit LCOAR involving removing a Component Cooling Water Heat Exchanger from service during on-line operations at a U.S. nuclear utility. The project was completed under budget and in less than 50% of the allotted time.
- Developed complex project schedules including comprehensive requirements for complex work windows including the determination of accurate project milestones and detailed sub-tasks for each major job in the project; developed work windows for major equipment to ensure compliance with the Probabilistic Risk Analysis for conducting on-line work at a nuclear facility.
- Experienced in all aspects of nuclear mechanical maintenance activities including non-routine activities such as hot-tapping and installing line stops in pressurized piping systems, leak stopping by sealant injection, and installing freeze seals for component isolation.
- Managed the planning and estimating of maintenance work orders. Work order preparation was completed using the Indus Passport Electronic Work Management System. Work planning included determining technical requirements, writing detailed work instructions, ordering and reserving required parts, and interfacing with engineering and craft supervisors to ensure the work was planned and scheduled accurately.
- Communicated on a daily basis with engineers, supervisors, craft and regulatory inspectors to resolve technical issues such that maintenance work could be performed accurately, timely, and in a safe, efficient and cost effective manner without compromising on-line operational commitments.

Electric Boat Shipbuilding, Groton, CT
1994 – 1995 - General Dynamics Corporation
Senior Mechanical Systems Engineering Assistant

- Provided engineering evaluation and resolution to various technical issues associated with mechanical reactor, steam plant, and related support systems.
- Developed technical repair and maintenance procedures for various mechanical systems and components associated with nuclear reactors and steam plant equipment.

- Reviewed and provided technical feedback on proposed design revisions to piping system diagrams and construction drawings. Responsibilities included ensuring each revision met all regulatory and technical requirements.

United States Navy, Groton, CT
1974 – 1994 - Department of Defense
Senior Chief Petty Officer - Engineering Department Enlisted Advisor

- Supervised the safe operation and maintenance of nuclear reactor plants and associated steam plant systems as both Engineering Watch Supervisor and Engineering Officer of the Watch. Supervised the overhaul and subsequent post-overhaul testing of mechanical systems associated with reactor and steam plant equipment onboard multiple fast attack submarines.
- Supervised inspection and testing of all nuclear systems on a new construction 688(I) class submarine including hot and cold pre-operational testing, core load, post-core load hot and cold operational testing, initial criticality, ascension to power, and power range testing.
- Coordinated an integrated maintenance and modernization-planning program in support of submarine extended operating cycles for 11 nuclear attack submarines. Responsibilities included prioritizing, planning, and scheduling of all maintenance actions for accomplishment, reporting completion rates and maintaining legal records.
- Directed the daily maintenance and repair of reactor, steam plant, and associated auxiliary support systems on four different classes of nuclear powered submarines.
- Management positions held in the U.S. Navy included Assistant Nuclear Power Engineering Officer of a Submarine Squadron Staff, Engineering Department Enlisted Advisor, and Training Coordinator at a Naval Prototype Training Unit.

Affiliations, Industrial Boards, and Civic Work

2014	Assistant Scout Master, Troop 457, Boy Scouts of America (current)
2013	Member, Nuclear Energy Institute Small Modular Reactor Working Group (current)
2012	Member, Industrial Advisory Board, University of Missouri Small Modular Reactor Research and Education Consortium (current)
2012	Director, NexStart Small Modular Reactor Alliance (current)
2011	Member, Nuclear Energy Institute Used Fuel Recycling Working Group
2010	Cub Master, Pack 452, Boy Scouts of America
2005	President of the Greater Clark County Idaho Chamber of Commerce
2000	Member, Board of Advisors, Eastern Idaho Technical College Center for New Directions

Professional Qualifications

Motorola University 6 Sigma Greenbelt
Aladon Certified Reliability Centered Maintenance Analysis Facilitator
Ken Blanchard Companies Certified Situational Leadership II Training Facilitator
Ken Blanchard Companies Certified Situational Team Leadership Training Facilitator
10CFR830, Unreviewed Safety Question Preparer, Reviewer, and Approver
Radiological Worker II and 40-Hour Hazwoper (Hazardous Waste Operator)
DOE Systematic Approach to Training and DOE Classroom Instructor

Formal Education

University of Phoenix, *Phoenix, AZ*	BS, Business Management	2007
Three Rivers College, *Norwich, CT*	Nuclear Technologies	1994
University of New Haven, *New Haven, CT*	General Studies	1991
Naval Nuclear Power School, *Mare Island, CA*	Naval Nuclear Technology	1976
Mapleton High School, *Mapleton, OR*		1974

TERRESTRIAL ENERGY

APPENDIX D : CONFIDENTIAL BUSINESS PLAN OF TERRESTRIAL ENERGY