# DEVELOPMENT OF PUBLIC ACCEPTANCE AND MARKET SUCCESS WITH VERY SMALL NUCLEAR POWER REACTORS (VSR)

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## ABSTRACT

This paper presents a case for public acceptance of **very small nuclear reactors (VSR)** as a socially welcomed, locally produced source of energy. It is argued that the subconscious associations and emotional responses that the public makes with size and appearance will often outweigh technical or economic advantages as the determining factor in their ultimate acceptance or rejection of a new power plant. The unique technical features of VSR effectively refute the three most commonly cited reasons for opposing nuclear power: cost, safety, and waste management. VSR also address the demands of environmentalists for small-scale, clean distributed energy production.

## 1. Our perception of size

### 1.1 Background

The technical, economic and environmental feasibility of using nuclear energy to generate electricity has been established for half a century, yet we live in a world where fossil fuel generated electricity continues to dominate despite its diminishing supplies, increasing expense, environmental degradation, and uncertain security of supply. Nuclear energy has been seen as a pariah, to be tolerated only when no other option exists. The principal reason for this is a serious misunderstanding of nuclear science, technology, and the biological effects of ionizing radiation, all of which have given rise to a widely held public fear and mistrust of all things nuclear. The effectiveness of this fear in restraining the expanded use of nuclear energy is difficult to overstate and is worthy of some review before discussing a possible solution to this dilemma.

### 1.2 The problem with big

As corporate size and power increased during the 1960s and 70s, some citizens became increasingly concerned as they watched or felt large companies flex their corporate muscles when dealing with governments, communities, or groups they deemed not compatible with their corporate interests. Aggressively and persuasively urged on by well-organized activist groups, a decidedly negative public perception gradually crystallized around the notion of “Big”. It was not just “Big” corporations, but “Big Agriculture”, “Big Government”, “Big Oil”, and in fact, anything “Big”. “Big” had become synonymous with powerful, centralized, corrupt, bullying, dishonest, polluting, and self-interested. Companies came to be publicly reviled simply for their “Bigness” and all the negative connotations associated with it.

*"Bigness, however, continues to cause ever-bigger problems for both people and the environment."* [1]

From living rooms to courtrooms to the media, "Big" became the pejorative label of choice when attacking large organizations or technologies. Even "softer", more "people-friendly" organizations have failed to escape the disparaging implications of size. Scarcely a day goes by when we don't hear stories in the news about "Big Medicine", "Big Education", or the "Big Drug Companies". Even the huge and graceful wind turbines, often portrayed as the most eco-friendly symbol of power generation, are increasingly being labeled as "Big Wind" by rural community groups, and organized cottagers.


Figure 1

As E. F. Schumacher, the influential economist and patriarch of the small-scale environmental movement, states in his seminal work **Small Is Beautiful: Economics As If People Mattered**

> *"Ever bigger machines, entailing ever bigger concentrations of economic power and exerting ever greater violence against the environment, do not represent progress: they are a denial of wisdom"* [2]

Of course, the corollary to this perception is, that "Small" is much better. "Small" is of the people and therefore closer to the people. "Small" is less powerful, less corrupt and more genuine. "Small" is perceived as "softer", more environmentally friendly, a better citizen of the community, and certainly less threatening than "Big".

*"Amid the global madness for bigness, the small-is-beautiful alternative offers promise and hope."* [1]

"Small", and to a lesser extent terms such as "local", "family", "community" etc., are routinely invoked as a softening prefix to describe any group, technology or enterprise that its communicators wish to imbue with the implication or aura of simplicity, desirability, non-threatening stature, or even moral superiority. We frequently hear of the importance and virtue of ***small*** business, the ***family*** farm, or ***local, independent*** producers. It is a theme that resonates well with the value people hold about their own independence and hard work, as well as the sense of vulnerability they feel in our interdependent and complicated modern society. The value and desirability of "small" is a perception that remains deeply entrenched in public attitudes today. In short, the public tolerates “Big” when they have to for practical and economic reasons, but psychologically, “Small” is where their heart is. More and more our increasingly well-educated public is demanding that advanced technology be employed to give us the advantages of “Big”, but with the more comfortable and less threatening scale of “Small”.

> *“Climate change confronts us with the opportunity to think and design the kind of energy we want in the future and to me, it’s clear it should be a network of small scale, diverse sources”* David Suzuki [3]

### 1.3 The Power Generation Angle

Many large hydroelectric and fossil fueled power plants were built or ordered in the 1950s and early 1960s when “Big” was still okay with the public. Gradually, however, activist groups, and later the general public, with their heightened sense of environmental awareness and corporate skepticism, demanded to have a say in the location and technology of new electric power plants. Led by well-organized special interest and activist groups, they demanded to have their voices heard and heeded. To the surprise of many a corporate leader who had grown accustomed to holding sway with decision makers, some large projects were denied, halted in construction, or prematurely decommissioned. The cost in both dollars and weakened infrastructure was enormous.

## 2. The Visual Factor

In the world of science and engineering, fact and reason rule the day, but when it comes to form, fashion, and basic appeal, humans are first and foremost visual beings; just ask any marketer. Images instantly convey size, scale, shades of meaning and subtle information that words and numbers simply cannot match. With little or no intellectual input, images cause us to form strongly held opinions that are often inaccurate or incomplete. However, beyond mere information, the most significant effect of images is that they are capable of conjuring powerful, visceral emotional responses; for example, the baby seal or the collapsing World Trade Centre.

Figure 2

Figure 3

Images are such powerful persuaders because we believe that we "*know*" them to be true; after all, "*seeing is believing*". There is no more damning evidence than *"the video tape"* and even the most rational and disciplined judge has to struggle to not have his judgment overwhelmed by graphic *visual* evidence introduced during trials. Professional communicators tell us with authority that the vast majority of the verbal message is actually delivered by facial expression, body language and other non-verbal communication. Certainly, an effective contemporary example of visual communication is the award winning picture, *An Inconvenient Truth*. The film makes a masterful use of emotive imagery to inform and persuade the audience. It has been enormously successful because it has imparted to its audience a sense of understanding and the perception of an informed position of an extremely complex subject (climate change) without demanding a high level of technical understanding from its viewers. The audience now perceives that they "***know***" about climate change and its threat to the planet, because they have ***seen*** it. It is impossible to over-rate the visual effect on human perception and decision-making.


Figure 4


Figure 5

To much of the public, the images of energy production technology are no less affecting, and they measurably influence their judgment in such matters. In simplistic terms, much of the public has the following perception of various energy technologies:

| Technology | Mental/Visual Image | Emotional Response |
|---|---|---|
| Wind turbines | Simple, clean, graceful | Good |
| Solar panels | Small, simple, clean, quiet | Good |
| Hydro | Powerful, natural, clean | Good |
| Natural gas | Big, complicated, clean | Neutral |
| Coal | Big, complicated, dirty | Bad |
| Nuclear | Big, complicated, dangerous | Bad |

When the public is forced to deal with complex issues that can directly affect their lives, images and visual appearance will often trump science, technical information, and abstract data. It requires an objective, rational and disciplined mind to ignore the emotional responses that images may invoke.

## 3. The public voices their concerns

Most people have little or no understanding of the workings of the many technologies that they use so extensively in their everyday lives. Yet perhaps because they are competent with the ***use*** of these technologies they feel qualified, compelled and even obligated to offer strong opinions on policy decisions regarding the adoption or expanded use of new or existing technologies. In a democracy, politicians who ignore strongly voiced public sentiment do so at their peril, and consequently we have seen an increasingly large number of important public policy decisions based not on the best science and engineering available, but rather, on a public's perception, however misguided, of what they believe to be the best technology to employ. This is particularly true in power generation. For activist and advocacy groups: "***Renewable***, ***Simple***, ***Small*** and ***Distributed"*** is their mantra

> *"Many opportunities exist in our communities for the local, small scale application of renewable technologies."*
> Sierra Club Energy Resources Policy 2006 [4]

## 4. The technology choice conundrum

The performance, safety, and cost effectiveness of large nuclear generating plants is self evident and unsurpassed. However, to many members of the public, nuclear reactors are big, mysterious and complicated monsters that stir a subliminal uneasiness. Their mental image is one of huge containment domes, "smoke" issuing from enormous cooling towers, and pressure gauges straining in the red.

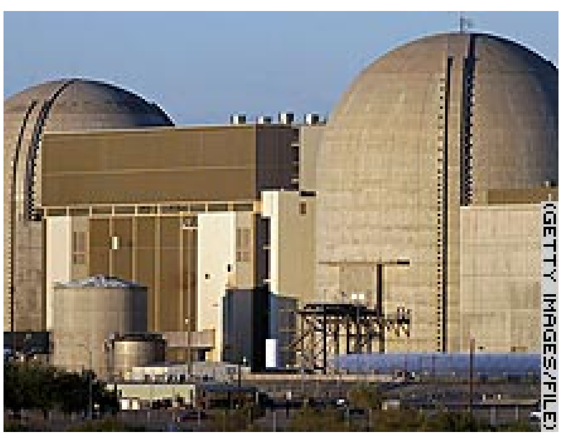


Figure 6

Figure 7

Confronted and confused by a plethora of "credible" information from both pro-nuclear advocates, but more often from anti-nuclear activists, members of the public feel caught in the middle. Unable to come to an informed decision they feel confident with, they believe that they can "play it safe", and come down on the side of *soft*, renewable energy technologies, then privately remind themselves that they must do more to conserve.

## 5. Summary

Thus far we have examined 3 critical factors in human decision making:

1. The public has a strong averse reaction to large centres of power, whether they be corporate, government, or technological. They much prefer small. Size matters.
2. Visual appearance significantly affects people's judgment and/or acceptance, particularly when the object of interest is poorly understood at an intellectual level.
3. Qualified or not, the public demands to have a say in the policy debate over visible infrastructure projects.

In this emotionally charged, passionately argued, and technologically intensive arena, is it possible for nuclear energy to be presented as a positive solution to the energy challenges we are facing? The answer is simply yes. The critical factors described above can be addressed through the development and deployment of very small nuclear reactors. In one fell swoop, these very small reactors can put much of the public's uncertainty and uneasiness to rest and provide them with the energy solutions they require and desire. Let's examine this claim further.

## 6. The small scale power generation infrastructure solution

### 6.1 Size Comparisons – Small versus Big

First, for the purpose of this discussion, let's define the very small reactor (VSR) as 10 MWe or less. Second, for the purpose of examples, let's use the 10 Megawatt thermal (MWt) "Slowpoke SES-10", and 2.4-MWt/ (600 kilowatt electric (kWe)) "Nuclear Battery" VSR as reference designs. Both designs are concepts developed by Atomic Energy of Canada Limited (AECL) and may therefore be more familiar to Canadian readers.

The following diagram shows the relative size of a typical 1000 MWe reactor, including its containment building, turbine hall, and cooling tower (when used). The containment for VSR and its turbine hall are also shown for comparison.

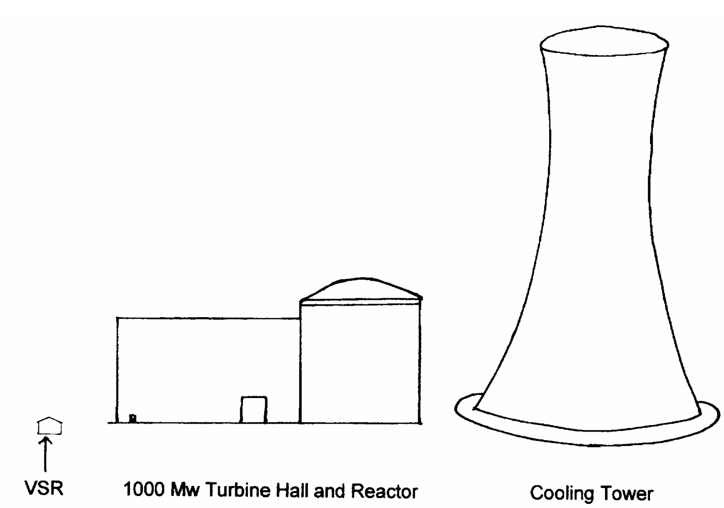


Figure 8

## 6.2 VSR design options

### 6.2.1 VSR option 1: Slowpoke-SES-10

Slowpoke SES-10 [5] is a scaled-up version of the highly successful 20-kWt Slowpoke-2 research reactor. The Slowpoke SES-10 is a 10-MWt below ground installation, pool-type reactor designed to provide large quantities of 85$^0$C water. It was designed as a reliable, low-cost district heating unit capable of heating institutional buildings, or approximately 1000 homes.

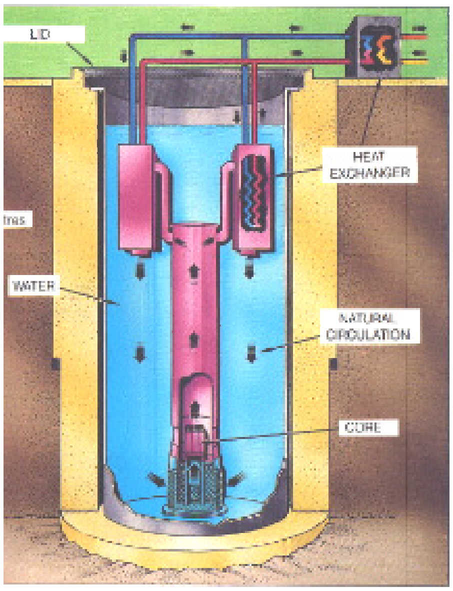


Figure 9 Slowpoke-SES-10

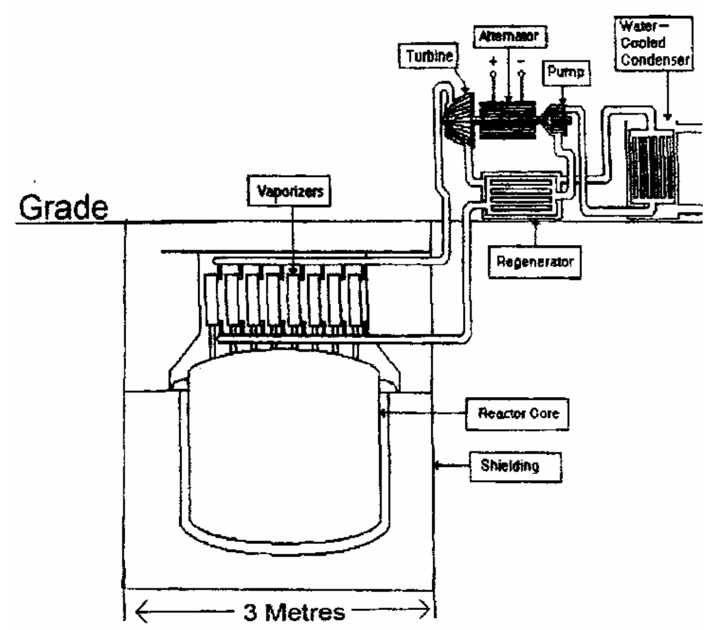


Figure 10 “Nuclear Battery”

### 6.2.2 VSR option 2: the Nuclear Battery

The Nuclear Battery [6] is a 2.4-MWt, graphite moderated reactor with an innovative heat pipe cooling system. It is also installed underground. The Nuclear Battery is designed to produce about 2 MWt of high-grade steam, or up to 600 kWe of electricity for 15 full power years before refueling. Depending on the climate, 600 kWe is enough electricity to supply 200 to 400 homes.

## 6.3 VSR common design features

Both the Slowpoke-SES-10 and the Nuclear Battery reactors employ strong negative thermal reactivity coefficients, and other passive safety features. In normal operation these VSR are intended to be operated with remote monitoring and minimal staff. Both visually and technologically, these VSR satisfy nearly all of the desires that the public seeks, consciously or unconsciously, in new electrical generation technology.

## 7. Psychological aspects of big vs. small

With visual entities that are poorly understood, size and appearance matters. By definition, VSR are very small, therefore, less intimidating and less fearsome. In addition, because VSR are designed to be installed below the surface, the visual impact above ground is miniscule. Turbine and reactor controls could be housed in a bungalow-sized building, neatly landscaped and fitting in nicely with the surrounding structures but with the VSR buried underneath it, out of sight. This is similar to the Bell Canada switching stations or electric transformer stations that are located in residential areas, but which are seldom noticed simply because they blend in so well.

**BELL CANADA SWITCHING STATION**

Figure 11

**TORONTO HYDRO TRANSFORMER STATION**

Figure 12

Consider as well, that most Canadians are unaware that 6 research reactors have been operating for decades at universities in major cities across the country. When informed of this fact the usual response is mild surprise, then a shrug. Though trite, the expression, "out of sight and out of mind" is powerfully true, and its effect should not be underestimated. You probably don't often think of the thousands of tiny dust mites that you sleep with every night!

## 8. Distributed

The 1998 ice storm and the 2003 blackout that affected Quebec and Ontario are frequently used to illustrate the fragility of the electricity grid and the vulnerability of our dependence on it. The distributed nature of VSR generation may be seen as insurance against "Big Energy" and "Big Grids" and as a proactive step against future widespread power disruption occurring again.

> *"Distributed Generation (DG) needs to become a Foundation Pillar of Ontario's Supply Mix".* Jose Etcheverry, Research and Policy Analyst, Climate Change Program, David Suzuki Foundation [7]

Grid connected or not, as stand-alone power stations, VSR provide more independence and self-sufficiency to the local users and these features are aligned with some of the key values of "alternative energy" proponents. Independence and self-sufficiency strongly correlate with a moral sense of ownership. Citizens of small, isolated communities often refer to "our power plant", which they rely upon and welcome as a vital part of their community's infrastructure.

## 9. Renewable

Although not strictly renewable in the generally accepted meaning of the word, the world's reserves of uranium and thorium are large enough that they could supply the earth's needs for tens of thousands of years. When combined with the need to refuel the Nuclear Battery only once every 17.5 years (85% capacity factor), this long-lasting alternative power source may reduce or eliminate the urge to tear apart the landscape in the quest for oil, natural gas, and coal.

Implicit in the term *Renewable* is the notion that the energy source should be clean and emissions-free. VSR emit no greenhouse gases, no nitric oxide, no sulphur dioxide, no smoke, nor soot. The total amount of waste produced is tiny, and *all* of the waste products are retained in solid form within the fuel of the sealed reactor core. To generate the same amount of electricity as a Nuclear Battery, diesel generators would consume over 19 million litres of diesel fuel and produce over 50 million kg of $CO_2$. VSR are emissions-free and environmentally friendly.

## 10. Inherent safety of VSR during operations

The two reference VSR concepts incorporate strong negative power coefficients, low power densities, convective cooling, and a passive subterranean heat sink. They have been designed to be inherently safe from the outset. An inherently safe design means that if there is a disruption to the normal operation of the reactor, the natural laws of physics will shut the reactor down to a very low power level without the aid of back-up power, cooling systems or other engineered systems. Furthermore, the TRISO fuel used in the Nuclear Battery has been designed to add several more protective layers of inherent safety. The TRISO [8] fuel is coated with carbon compounds that give it a melting point hundreds of degrees higher than the highest reactor temperature attainable, even in an extreme and highly improbable accident scenario. An accident in which the core melts is simply not possible with this fuel [9]. Furthermore, if spent TRISO fuel were introduced into the environment, as improbable as that would be, the multiple coatings on the particles act as individual containment structures, ensuring that no radionuclides escape into the environment. A multiple-layer defense-in-depth approach is used.

## 11. Proliferation safeguards

VSR are typically installed underground, resulting in an inconspicuous visual signature and a robust physical protection against a surface or airborne accident or attack. The reactors use 20% Low Enriched Uranium (LEU) fuel, well below the enrichment threshold necessary for weapons manufacture. Furthermore, because VSR are not designed for on-site refueling, the reactor core is sealed and no physical access to the fuel is possible. When the fuel in the reactor has been consumed, the entire sealed core is removed as a unit and transported to a central processing facility. A fresh core is then inserted and the reactor is returned to service. ***Unlike large-scale reactors, no fresh fuel or spent fuel is stored, even temporarily, at the reactor site***. The combination of inherent reactor safety, a below ground level installation, sealed core, TRISO fuel design, 20% LEU fuel and no on-site spent fuel storage means that VSRs have an extremely high resistance to proliferation or environmental damage.

## 12 Market appeal of VSR

### 12.1 Market appeal #1: low cost

> *"Canadian anti-nuclear activists these days tend to see the history of nuclear megaproject fiascos and the ongoing heavy subsidization of AECL as their most effective argument against more nukes."* [10]

Because of their small physical size, VSRs could be manufactured entirely in a single production facility. With the economics of an assembly line a simple, standardized design with high-volume low cost production would compete with the economies of scale inherent with very large, centralized power plants. Completed modules could be easily transported by truck to the site of final installation and little or no on-site reactor construction would be necessary. Furthermore, by virtue of their very small size, no VSR project (even ones consisting of multiple units) would involve capital requirements greater than one or two percent of a utility-scale reactor.

The most efficient diesel generators are able to extract only 4 kWh per litre of diesel fuel. In the Canadian Arctic where the unsubsidized price of diesel can exceed $2.00 per litre, this translates into 50 cents per kWh, ***just for the fuel cost.*** Using a diesel generator to generate the approximately 79 million kWh that a Nuclear Battery is designed to produce over it's lifetime, would consume nearly 20 million litres of fuel. Conversely, it is well known that fuel represents only a small fraction of the cost of nuclear generated electricity. Although precise capital, operations, and maintenance costs for VSR are not yet available, preliminary calculations suggest that over a 15 to 20 year life cycle the VSR is likely to enjoy a substantial cost advantage over diesel generation. [6] Furthermore, the 15–20 yr. refueling schedule of VSR would serve as an effective hedge against fuel price fluctuations and facilitate stable energy production costs.

### 12.2 Market appeal #2: security of supply

Grid failures, brown outs, and the threat of rolling blackouts have driven many institutions and industries to build their own independent power supplies. Costs, although taken into consideration, are usually secondary to the consequences of a power interruption. VSR are well suited for the demands of co-generated electrical power, steam, and hot water. The very long periods between refueling for VSRs would avoid the need of the huge fuel storage tanks necessary for diesel and gas turbine generation, and the associated space and safety requirements. The low, stable electricity costs that are only weakly dependent on uranium prices would protect the power generator from the vagaries of highly volatile oil and gas prices and would make costs much more predictable.

### 12.3 Market appeal #3: high flexibility

VSR can be designed to produce electricity, steam, or both in a co-generation mode. Installed in a modular fashion; generation capacity could be incrementally increased to meet rising demand by adding additional reactors. In a multiple-unit installation, individual reactors may be taken into planned outages for routine maintenance without significantly affecting overall capacity. A real example of this approach is found in the city of Bilibino in northern Russia (Siberia), where four 10-MWe reactors have been providing all of that city's electricity, space heating, and process steam, under very demanding climactic conditions, for over 30 years. [11] [12]

## 13. Markets

The low cost, security of supply, operational flexibility and small size of VSR make them suitable for a broad range of government, institutional, industrial, and domestic applications, particularly in remote locations, small island nations, or developing countries with limited transmission infrastructure. Space permits only one example to be briefly examined here.

The Canadian high arctic is the most obvious and natural early adopter of VSR technology. Increasingly expensive diesel oil fuels virtually all electricity generation and space heating requirements. Fuel subsidies consume approximately 20% of the Nunavut budget [13] drawing precious financial resources away from other Government priorities. Development of secondary industries is being impeded for want of reliable, low cost energy. Diesel is polluting, logistically problematic, and large-scale diesel storage presents a constant risk to the fragile arctic environment.

> *"There have been a significant number of fossil fuel spills in Nunavut and these appear to be increasing with time"* [14]

Arctic governments recognize their diesel economies as a significant obstacle to their future economic and social development.

> *"Nunavut must… create a viable energy system that is no longer totally dependent on fossil fuel. Simply stated, Nunavut needs to wean itself off oil"*
> *Edward Picco, Minister of Energy, Government of Nunavut.* [15]

## 14. Conclusions Public Embrace of Nuclear Energy

There are good reasons to believe that the successful deployment of small-scale VSR will help facilitate public support and welcome of nuclear energy much more quickly than that of large-scale nuclear reactors. The small size, natural passive safety features, off-site refueling, low cost and environmentally friendly nature of VSR effectively addresses most of the concerns that the public has about nuclear energy. With good performance and experience, any lingering doubts about small-scale nuclear reactors will disappear. There presently exists a favourable convergence of social, environmental, political, economic and technical factors that make **now** an opportune time for the development and widespread use of very small reactors.

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Peter Lang is a commercial airline pilot presently employed as a captain on the Boeing-777. Early in his flying career, Mr. Lang flew re-supply flights to isolated remote communities in Canada's high arctic where he experienced first hand the essential nature, and logistical difficulties encountered in keeping power plants running in a harsh and unforgiving climate. It was here that he first realized what a valuable role Very Small Reactors could play in small-scale power generation and heating applications.