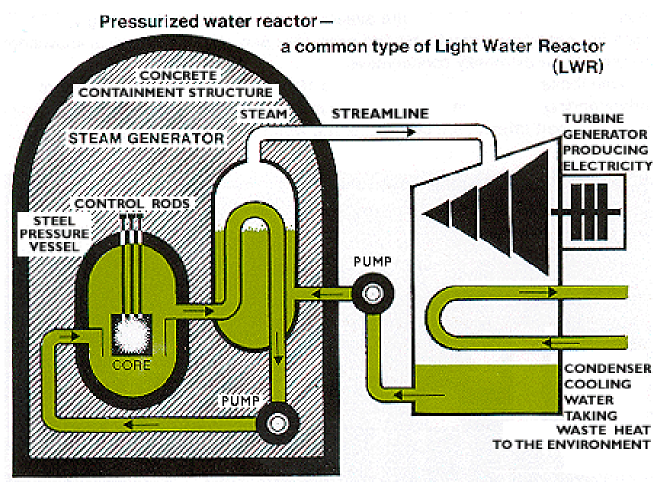
The Small reactor option for Jamaica

The first thing I want to make clear is that I am not wedded to any particular energy source. An energy system costs big money and requires long term commitments. But that said, we need cheaper energy NOW. As long ago as 1985, a UNDP/World Bank report on Jamaica stated that: “Imported oil continues to be the main energy source in the energy balance (89% of supply in 1983) while at the same time adding substantially to the country's mounting external debt. Substitution of oil by indigenous energy resources has been minimal and even if proven reserves of peat, hydropower and bagasse were developed to their optimum capacity, only a minor contribution to future energy supplies can be expected”.in 2012 so far not much has changed. Oil costs are rising, some pundits talk about 160 US$ per barrel, the equipment is older and opportunity costs are frightening. One encouraging sign is the important decision to add 380 (MW) of LNG and there is a tender out for the supply of a regasification plant for LNG.

There is also the possibility of petcoke but I was asked to speak on nuclear energy so I assume that the general situation is well known and/or the information is readily available.

Background on Nuclear



In nuclear plants the reactor replaces the furnace to generate the steam that turns the turbines that turn the dynamos. Prior to the Japanese earthquake a year ago, there were 441 operating reactors in 31 countries generating sixteen percent of global electricity production, for France the figure is a high 74 per cent of total supply. This electricity generation by nuclear power, reduced potential CO_2 emissions by 2.4 billion tonnes annually.

Expansion of nuclear energy

Because of Fukushima, Belgium, Italy, Germany, Switzerland Peru have declared their phase out or avoidance of nuclear energy. This affects 26 reactors but an enormous expansion of global energy usage is still expected over the next few decades as world economies expand and living standards in the emerging countries improve. The greatest nuclear boom will be in Asia, mostly in China and India, with Brazil at the forefront in Latin America.

Sixty one reactors are being built worldwide; 156 are projected and 343 are under official consideration. If achieved the number of functioning reactors would double from the present 437. Incidentally the US has recently issued licenses for 2 new AP1000 reactors, the first in 22 years, and has extended the operational licenses of more than 50 of their older reactors from forty to sixty years with the likelihood of more to come. They have upgraded and uprated numerous existing reactors which now have capacity factors above 90%**. But** the projected demand for electricity is so high that nuclear energy is not likely to exceed 20% of the burgeoning market, and coal will probably continue to be the major fuel for a long time despite its environment hazards.

In this, remember that the Japanese reactors though very old, worked as designed during the earthquake and that the following tsunami was far greater than the design expectations. The lessons from Japan have been well learned.

Environmental and Health impacts

Nuclear reactors, unlike fossil fuel plants, are free of emissions of CO_2, nitrogen oxides, sulphur dioxide, particulate matter, and mercury and other heavy metals which contribute to premature death, and chronic bronchitis and asthma. In the US the health damage for coal-fired plant emissions is estimated as 63 billion US dollars per year . The US National Research Council estimates that hidden health and environmental costs of energy production and consumption in the US could exceed $120 billion per year. Like nuclear, wind, solar and hydro have very small such external costs and they have no waste disposal problem but they do have the disadvantage of dilution and intermittency.

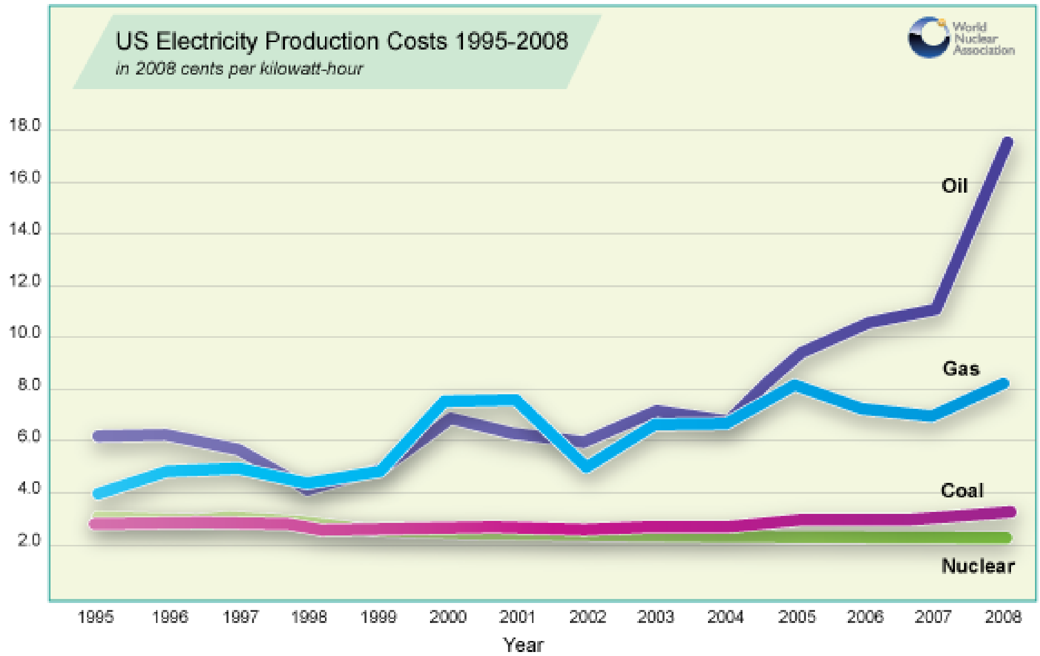
Availability of nuclear fuel

Uranium projections are robust and many countries are seeking new uranium sources. and fast neutron reactors will burn U238 which is much more available than U235. Also thorium-based systems are likely to be developed since there are very large resources of thorium which can be converted to fissile uranium 233.

Costs of electricity produced

The cost of base line nuclear electricity is presently the lowest of any fuel but is similar to that of coal. If the price of gas increases and/or a carbon tax is imposed, the gap there will widen but if fracking lives up to its promise, the large amounts of gas seeking markets might well make gas the cheapest fuel for a long time, unless there is a carbon tax or CO_2 or carbon capture removal cost.

The cost of nuclear generated electricity is not very dependent on the fuel price. Doubling this would increase the price by some 5% com-pared with, for example, 75% for a similar increase in the cost of natural gas.



Production Costs = Operations & Maintenance + Fuel. Production costs do not include indirect costs or capital.

Source: *Ventyx Velocity Suite, via NEI*

The lessons of the accidents have been well learned and safety measures have greatly improved; the radiation exposures from an operating nuclear plant are essentially background. The disposal of nuclear wastes, and nuclear weapons proliferation remain of general concern, but the nuclear industry is one of the world's safest and numerous countries, even the petroleum rich, are seriously considering nuclear power for electricity generation.

But it was generally accepted that the standard nuclear power plants were too large and too costly for Jamaica. That has changed considerably with the advent of small power reactors of capacity say up to 100-300MW, and even much smaller.

Small modular reactors (SMRs)

These are not at all new and have long been used for submarines, air craft carriers and ice breakers. The SLOWPOKE which has been at Mona for over 20 years is an example of a very small reactor and AECL was once considering a slightly larder model for city heating. What is newer is the view that there is a large market for small power reactors that:

- Are cheaper to construct and run
- Are factory built allowing standardisation, and transported to site
- Have long lifetimes and are simple to operate.
- Are modular so that upfront costs are minimised thus controlling interest payments; and actual demand and capacity can be closely matched over time
- Are fail-safe (emergency shut downs would not require additional operator action)

- Have a reduced site boundary and emergency planning zone (EPZ) allowing them to be installed virtually anywhere.
- provide for waste handling by the supplier
- Waste heat maybe used for industrial development
- most SMRs are returned to the factory for dismantling or refueling at the end of their service lives.

These properties can make SRMs attractive to countries that don't require a full-scale plant.

Some SMRs are very small, and are even suggested for heating large apartment buildings. In some models the building size for the nuclear island is so reduced that it is placed underground which improves safety and security. The smaller size would also allow the use of seismic isolators if thought necessary, significantly reducing the probability of earthquake damage.

Safety

Since they are smaller and use less fuel, SRMs are easier to cool effectively. This greatly reduces the likelihood of a catastrophic accident or meltdown in the first place but also some cooling systems rely on natural convection rather than on electric pumps, and not on operator action. If there is a problem that requires operator action, the time demand is hours or days rather than the hours or minutes of a conventional reactor.

The SMR designs that use gas, liquid metal or salts as coolants, operate at a much lower pressure than water cooled reactors reduce the hazards of that a cracked pipe or a damaged seal can cause blow out of radioactive gases. With low-pressure coolants, this is less likely to occur and there is less stress on the containment vessel. Some SMRs are small enough for installation below ground which is cheaper and faster than to construct a reactor building and make the reactors easier to secure and install in a much smaller footprint.

Some modular reactors are based on conventional pressurized water reactors and burn somewhat enriched uranium, others use less conventional fuels. Some, for example, can generate power from what is now regarded as "waste", burning depleted uranium and waste from conventional reactors. U-238 is much more abundant in nature than U-235, and thorium is much more abundant than uranium. The combination of improved uranium use and thorium reactors could provide energy for thousands of years. Thorium has the added bonus of being useless for making weapons.

Modular reactors can be set up in batteries providing as much power as an area needs. And if one unit needs to be taken off line for repairs or replacement, it needn't interfere with the operation of the others. The idea of paying off the capital in tranches when additional capacity is as actually needed is also attractive.

Examples of SRMs

There are now more than 60 small reactor designs with more under development. Some are mentioned in the Table 1 .

Table 1. Some selected small reactors at an advanced stage of development

TOSHIBA- 4S	10-50 MWe	Toshiba, Japan
CAREM	27 MWe	CNEA & INVAP, Argentina
HYPERION	30 MWe	Hyperion Power Generation, USA
KLT-40	35 MWe	OKBM, Russia
MRX	30-100 MWe	JAERI, Japan
IRIS-100	100 MWe	Westinghouse-led, international
SMART	100 MWe	KAERI, S. Korea
NP-300	100-300 MWe	Technicatome (Areva), France
mPower	125-750MWe	Babcock & Wilcox, USA
PBMR	165 MWe	Eskom, South Africa, et al
FUJI	100 MWe	ITHMSO, Japan-Russia-USA
NuScale	45 MWe	NuScale Power Inc.,USA

WNA (26 Nov 2009)

There is wide range of designs. Russia has a programme for barge mounted nuclear power plants for their remote territories. One current project utilizes two barge mounted reactors to provide electricity to Pevek in Northern Siberia. Such sources operated by or under the supervision of the vendor, seem less attractive than the small reactors of advanced design but may be worth keeping on the list for consideration.

Argentina is developing their CAREM-25 which is a modular 100 MWt /27 MWe pressurized water reactor with integral steam generators designed for use as an electricity generator (27 MWe or up to 100 MWe), as a research reactor or for water desalination (with 8 MWe in cogeneration configuration). CAREM has its entire primary coolant system within the reactor pressure vessel, self-pressurised and relying entirely on convection. The fuel is standard 3.4% enriched PWR fuel, with burnable poison, and is refuelled annually. It is a mature design which could be deployed within a decade. It is also a prototype for a larger reactor sized 100MWe or 300MWE. The estimated cost is about US$200 million. It will require an operational staff of 189-200 people: 80 professionals with university degrees, 100 technicians and 70 workers (Bisauta, 2009).

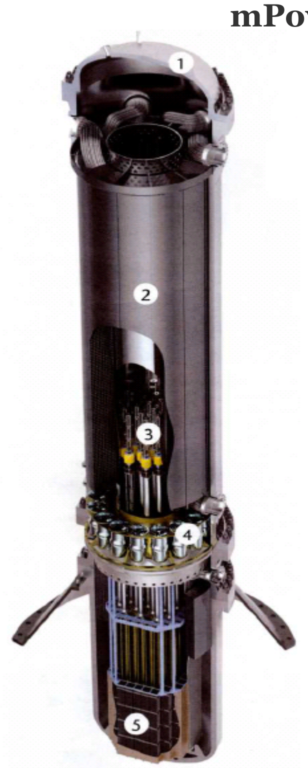
Examples of modular reactors

Light water reactors

A modular light-water reactor is a scaled-down version of the conventional item. They use water as coolant and neutron moderator. There are already many decades of decades of experience with light-water SMRs through submarines air craft carriers and other ships. Our SLOWPOKE is a light water reactor.

Most types of conventional reactors, have the steam generator outside the reactor vessel. With light-water SMRs, the steam generator can be placed inside the vessel. This not only makes the reactor more compact and self-contained, but it also makes it much safer. One common problem in reactors is radioactive water leaking as it travels from the reactor to the steam generator. With the steam generator inside the reactor vessel, it's the much safer situation of only non-radioactive water/steam going into and out of the reactor vessel.

mPower



mPower integral nuclear steam supply system:
1. Upper vessel head, which contains steam bubble that acts as pressuriser
2. Steam generator
3. Control rod drives
4. Internal primary loop reactor coolant pumps
5. Core

Babcock and Wilcox has designed a small Generation III +reactor, the mPower, based on US Navy reactor designs, which would be installed within three years of order.. mPower is a scalable, modular, passively safe, advanced light water reactor (ALR) with a unit output of 125 MWe. The reactor lifetime is rated at 60 years and used fuel is stored in a spent fuel pool within the containment B&W also offers the steam generating plant. The nuclear plant consists of a cylindrical pressure vessel 23m by 4.5m (75ft by 15 ft) that contains all the components of the nuclear steam supply, system core (standard fuel enriched to 5%, control rod assemblies, primary loop pumps, steam generator and pressurize. It would be installed underground.

It is designed to be factory built, rail-shipped and installed below ground. Like the Westinghouse SMR, the mPower uses a passive cooling system and the steam generator is integral with the reactor. The mPower needs refueling every four years by a replacement of the entire core by a new one which inserted like a cartridge.

The reactor has a 60-year service life and is designed to store its spent fuel on site for the duration.

Licensing

Because the mPower design contains no unproven technology, B&W believes the reactor can be certified, manufactured and operational within today's existing U.S. regulatory environment. There market plan is to begin construction in 2015 and begin providing electricity to customers in 2018. Assuming that Jamaica would wish to benefit from about five years of operation of an industrial unit, the reactor could be ordered in

2023 and would probably be generating electricity in 2026. B&W estimates that the costs will be within 10% of US$ 3,500/kW.

The Hyperion Power Module

This Los Alamos National Laboratory invention is marketed by Hyperion Power Generation, Inc. (HPG), who report over 100 firm orders largely from the oil and electricity industries. The Hyperion reactor is about 1.5 metres wide and 2 metres high. The shipping weight is 15-20 tons and it is expected to cost about US$30 million per unit.

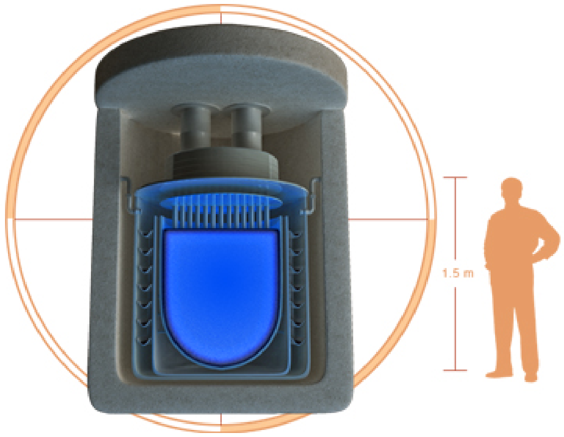
The original Hyperion Power Module (HPM) is a fascinating concept. It has a core of powdered uranium hydride (UH_3), 5% enriched in ^{235} U contained in a steel "pot". The reactor is self-regulating because of the inherent properties of uranium hydride, which serves as a combination fuel and moderator. The temperature is adjusted by the equilibrium reaction

Uranium hydride = Uranium metal +hydrogen

Above the 550^{o}C the UH_3 in the fuel dissociates decreasing moderator density and therefore reducing the core reactivity. If the temperature drops, the process is reversed and the fission rate increases.

Balancing the amount of hydrogen gas distributed between the core volume and an external hydrogen storage volume keeps the reactor stable. There are no moving parts in the reactor module which is contained within multiple gas-tight chambers to ensure absolute containment of all gases, along with other contaminants in the unlikely event that a single chamber fails. The core cannot melt-down, overheat or create any type of emergency situation. The module is never opened until it has been returned to the factory to be refuelled, approximately every five years or so, depending on usage. The containment, along with the strategy of completely burying the module underground at the operating site, protects against the natural threats, human error, or hostile tampering. It is a beautiful concept and the company claims unparalleled safety among nuclear reactors. But because it is so novel are binging a different design to market first. This has a uranium nitride core and liquid lead cooling but with the same output specifications. With an air-cooled condenser it would produce 125MWe which would be increased to 136 MWe with a water-based heat sink. It has a 5 year refuelling cycle at which the entire core is replaced at once. The refuelling operation is expected to last for about one week. Several units could be combined into a larger power station most likely of 500-750 MWe.

B&W see a group of the mPower reactors as an economical substitute for large reactors and any coal-burning plants that have to be closed on because of pollution.



Toshiba 4S (Super-safe, Small, and Simple)

Toshiba, the Central Research Institute of Electric Power Industry (CRIEPI) and Westinghouse are jointly developing a new class of micro size fast neutron reactors providing 10 MWe (scalable to about 50) for about 30 years, after which the reactor module is returned to the manufacturer for disposal or refuelling.

Description and Working Principles

Design Criteria

The Toshiba 4S reactor is a sodium cooled, fast reactor with a steel clad compact core made of a uranium/plutonium/ zirconium alloy. Combined with a compact steam turbine secondary system, it will generate 10 MW of electrical power, scalable to 50MW, for 30 years without refuelling. This is accomplished by converting the fertile material (uranium 238) in the core and by using a slowly moving reflector to compensate for fuel burn up over the core lifetime. The system is modular to allow for higher demand over time.

The basic layout is a pool-type configuration, with the pumps and intermediate heat exchanger contained inside the primary vessel. An intermediate sodium loop delivers heat from the primary system to the external steam generator for the power conversion system. The nuclear waste remains sealed within the reactor module and is returned to the manufacturer.

The reactor building houses the reactor module (lowest left), the steam generator (slightly higher and to the right of the reactor module), and other vital safety equipment. The lower part of the reactor module (containing the reactor core) is located in its own below ground silo-like reinforced concrete structure. The reactor support system provides horizontal seismic isolation for the reactor vessel, the containment guard vessel, and the steam generator. Composite rubber/steel/lead core isolation pads are used to limit horizontal seismic input to the reactor assembly, guard vessel and reactor.

The reactor module is designed to be:

- Replaceable in order to provide the capability of extending the plant life beyond 30 years.
- Capable of being installed and ready for sodium fill within 6 months after delivery to site.

- The nuclear steam supply system (NSSS) is designed to operate for 30 years. Any NSSS component not capable of meeting the 30-year design life is designed to be replaceable.

A reactor should be operational 2 to 4 years from the start of site work

Reactivity Control

To scram the reactor the brake of the fast adjustment mechanism releases and the control rod moves by gravity into the core causing the reactor to shutdown. The single control rod when inserted can maintain the core in the cold shutdown condition.

During steady state operation, the control rod is fully withdrawn and core power is controlled by movable reflectors and coolant flow through core circulation pumps. A cylindrical steel reflector shield rises from the bottom of the reactor vessel by means of an electromagnetic drive mechanism, at a rate of around 5 cm/yr to maintain the proper reaction rate by reflecting neutrons back into the core. This compensates for the reactivity loss during the 30 years burn-up.

With the liquid sodium coolant the higher steam temperatures improve the thermodynamic efficiency providing more power per unit size of machine.

Physical Size

The reactor is 1.8m by 6.1m in size. The core source is about 0.7 meters in diameter and about 2 meters tall. The actual reactor would be located in a sealed, cylindrical vault 30 m (98 ft) underground, while the building above ground would be 22 x 16 x 11 m (72 × 52.5 x 36 ft) in size. The entire system can be accommodated in less than ½ acre of land.

This nuclear section of the plant would be at the bottom of a 30 meter deep excavation inside a sealed cylinder, a location that helps to provide the driving force needed for natural circulation cooling and that provides for nuclear material security. The actual reactor would be located in a sealed, cylindrical vault 30 m (98 ft) underground, while the building above ground would be 22 x 16 x 11 m (72 × 52.5 x 36 ft) in size.

The entire system can be accommodated in less than ½ acre of land.

Safety and Security

Reactor safety is achieved by maintaining a negative temperature coefficient of reactivity (an increase in core temperature causes a decrease in core power) throughout the life of the core, and by providing sufficient natural circulation and heat removal capabilities to prevent overheating the core on shutdown since a shutdown reactor still produces heat from the decay of radioactive materials. That heat is dealt with by the natural circulation and heat removal characteristics of the installation.

The 4S reactor provides benefits in the operational capability, physical security, and public safety: important **items** that often increase cost, raise safety concerns, and pose potential security hazards. These include the elimination of: numerous mechanical pumps and valves, the need for a spent fuel pool, the reliance on high and low pressure water injection systems.

Operators

The small size and simplified systems of the 4S also reduce the manpower requirement for maintenance personnel of the non nuclear system but the details are not yet available.

No operator control is required to assure safe operation of the plant, even under abnormal events. The function of plant operators is to monitor plant operations, report abnormalities, and ensure expected plant performance during normal and emergency conditions.

The targeted date of commercialization of the 4S system is after the mid-2010s. Toshiba expects that a U.S. customer will submit a Combined Operating License application in 2012. Because 4S uses different coolant (sodium vs. water) and different fuel (metal vs. oxide) than traditional LWRs, a more protracted licensing process is very likely and will probably push potential U.S. deployment of the 4S into the second half of the next decade.

A unit has been offered as a grant to the Alaskan village of Galena which has a population of 100,000 persons.

Barge mounted reactors

Russia has a programme for floating nuclear power plants for their remote territories and their naval vessels have supplied electricity for civilian uses. These are expected to be operated by or under the supervision of the vendor and may be worth consideration should energy demand greatly outpace our ability to develop the necessary infrastructure.

Costs and The absolute capital costs will be very much lower than that of standard larger units. Nuclear reactors seem to present an opportunity for making a significant contribution to Jamaica's electricity needs and could support other industrial development.

Earlier preliminary discussions with many private sector decision makers, and educators showed strong support for the consideration of introduction of nuclear power. Economics and timing are the key factors.The small reactors being developed have designs are validated with respect to the science and some are very interesting indeed but few if none that I know of has yet been demonstrated commercially. Jamaica would probably initially at least require that any reactors receiving detailed assessment be approved by a regulatory authority perhaps that of Canada, France, the United Kingdom or the United States.

CONCLUSION

I don't claim to know the future , so this is sheer extrapolation but nuclear has survived the cost overruns of the 80s and the Three Miles Island and Chernobyl accidents . It has leaned from them and it will survive Fukushima.

But there are challenges:

The economic advantage of nuclear energy might be weakened by successes with fracking shale gas. Especially as it is easy to argue that even with coal the global effect our size on climate change would be more cosmetic rather than practical. Another is that to global recession may bring problems in finding money.

Still with nuclear, Jamaica has to be to be thinking (and doing work) a decade ahead ahead evaluating longer term options. In this frequent reviews of the progress with the development of small reactors on a continuing basis would seem useful as would an attempt to provide a demonstration plant for a likely winner.

There would be a lot of support from the IAEA and many countries if Jamaica's interest were formalised and our interest in having assistance confirmed. The potential order of magnitude of equipment costs ia in rgw table tha follows

Approximate costs for some small reactors

Rating	Reactor	Unit size (MWe)	Capital Cost (US$)	Comment	Cost to have 125 MWE/Hyp
1	mPower	125	<625 million	<US$ 5000/ kW	
2	Hyperion	30	42 million	1,400/kw	175
3	Toshiba – 4S	10	25 million	2500/kW	312.5

Appendix

The distribution of operational nuclear fission reactors worldwide.

Country	**Percent**	**Number of Reactors**
France	78.1	59
Lithuania	72.1	1
Slovakia	55.2	5
Belgium	55.1	7
Sweden	51.8	10
Ukraine	51.1	15
Bulgaria	41.6	2

Slovenia	40.4	1
South Korea	40	20
Switzerland	39.7	5
Armenia	38.8	1
Hungary	33.8	4
Germany	32.1	17
Czech Republic	31.2	6
Japan	29.3	55
Finland	26.6	4
Spain	22.9	8
United States	19.9	104
U.K.	19.4	19
Russia	15.6	31
Canada	15	18
Romania	10.1	2
Argentina	8.2	2
South Africa	6.6	2
Mexico	5.2	2
Netherlands	3.8	1
Brazil	3	2
India	2.8	17
Pakistan	2.4	2
China	2.2	11

Conclusion

A. The current expansion strategy could result in the installation of over 400 MW of new generating capacity by 2014 using natural gas as fuel to replace aging plants and provide for growth in demand. The expansion requirement targets a further 300 MW. Jamaica continue to evaluate options of introducing nuclear technology in the longer term, and review the progress with the development of small reactors on a continuing basis.

GLOSSARY

Overnight costs. Cost without interest or real escalation during construction. They include engineer-procure-construct (EPC) costs, owners' costs and various contingencies.

Levelised cost. This is the price of electricity necessary to cover all operating expenses and taxes and provide an acceptable return to investors over the life of a power plant