The Present and the Future of Nuclear Power Technology: An Opinion On Energy Policy, Competitive Concepts, Societal Safety And Acceptable Risk

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ABSTRACT

The future of nuclear technology is driven by communication rather than by rationality, which motivates the present paper. Globally there is need for nuclear reactors that produce cheap, safe, reliable, resilient and low-emissions electricity to power modern societies. The purpose of the present paper is to inform debate and provide opinions about challenges and solutions for the development of nuclear fission technology. We review the socio-political and techno-economic status of nuclear power technology that, as almost always during its history, is on an edge from which it may jump to success, or fall into the abyss of forgetfulness. In addition to cost, safety, social acceptance and political will, climate change with the need to prevent further pollution of the environment, constitutes a challenge for nuclear technology. To avoid the associated scramble for and hoarding of financial resources, and competing concepts we try to provide a framework for discussion and resolution. We look at the history of nuclear technology where high capital cost has slowed its development what has killed certain concepts is the high operation and maintenance cost. At the *interrelated* policy, fiscal level and international levels *feasible* actions are required with aggressive timelines and *specific* goals for nuclear power systems. The aim is to reduce *both* capital price and financial risk to achieve the overall goal of enhanced orders and deployment. We strongly recommend the deployment of nuclear fission for energy production everywhere in the world. The large reactors, whenever possible, should contribute to energy security, financial stability and technology development. The small reactors may contribute in areas directly impacting the reduction of pollution like naval transportation, hydrogen production and remote areas energy powering.

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1 INTRODUCTION

Nuclear technology and its deployment is inevitably linked to key government and energy policies [1-3]. Historically, high capital cost has slowed development, with long development times, larger costs and huge uncertainty for the development of any new reactor concept. Attempts to streamline technology demonstration, minimize costly needed R&D, and simplify licensing are not harmonized, and claims for new concepts and cheaper 'smaller' systems are unproven. So the simple question is how to ensure that existing and known technology is competitive given that the designs needing the least new work are those that can be swiftly ‘proven’ when new or more exotic or innovative reactors have greater financial and developmental risk

Today the status and the challenges are clear. Nuclear power did not meet the expectations of the 1960’s, as tens of thousands of reactors should have been built, while in reality there are today less than about 600. As a result the technology is declining in countries that largely contributed to its development, namely the USA and many EU countries and remains in vogue in three major countries: Russia, China and India. Meanwhile, interest is growing in emerging countries like Bielorussia, UAE, Turkey, Egypt, Bangladesh, and Vietnam and others as part of national energy policy. In addition, deployment plans are part of the development and “green” strategy of some countries,such as Finland, Czech Republic, Hungary, Argentina, Pakistan, UK, S Korea, and Japan.

There are many claims, studies and graphics-rich brochures seeking government and/or entrepreneur investment for developing designs but also underwriting the First-Of-A–Kind (FOAK) risks and costs for ‘small modular reactors’ (e.g. Google “SMR’ to view some 85M results/hits). Cost data collected for 50 different reactor types and 11 studies demonstrate a factor of two to four range in published overnight capital generating cost estimates, but that “do not consider the construction duration and financing that would be included in the total plant cost”[4]. It is indisputable that there are long development times, large costs and uncertainty in the development and construction of any new reactor concept (viz. liquid metal cooled reactors), which explain the recent attempts to streamline technology demonstration, minimize costly needed R&D and simplify licensing [5]. Then the questions become how to ensure that existing and known technology is competitive (see e.g. [6]) given that the designs needing the least new work are those that can be swiftly ‘proven’ and have to proceed effectively whereas the new or more exotic or innovative reactors that are exposed to greater financial and developmental risks.

In the current context of commercial nuclear power, the purpose of the present paper is to inform debate and provide snapshot opinions about challenges and solutions for the development of nuclear fission technology.

2 ECONOMIC FACTORS DOMINATE

2.1 The financial realities

Ideas behind adopting small reactors has led to self-evident statements considering every aspect of energy demand, use, supply, and importantly market forces [7]:

“Estimates of the role for advanced nuclear energy in this mix is highly dependent on assumptions…. The assumptions with the greatest impact on nuclear deployment were policies and technology cost” and “The economic challenge that advanced reactor developers face is daunting.”

For small reactors, the biggest attraction is and was in minimizing the financial risk exposure and faster payback, not in the unbelievable claims reported by the NAS of the 50% lower overnight capital cost [7]. Reality has turned out four times the initial promise [8,9], currently blamed on rising inflation and materials, not on possibly incorrect analyses, misleading methodology and inadequate margins.

But are smaller reactors actually smaller in size and cost as so often claimed? Despite subsidies and loans, it is challenging to build multiple units and the NuScale design combined risks of large reactor’s civil construction with lack of economy-of-scale for small reactors (>10x smaller power output per reactor), which made it impossible to execute the project, unless factory production lines are outputting hundreds of units. This was after all the basis for reducing costs for automobiles and for almost every modern domestic and electronic appliance, with the famous statement by Henry Ford that “ the customer could have any colour provided it was black.”

Such shortfalls while pronounced in the case of the NuScale design, show up in other leading vendor concepts. The BWRX-300 design still publicly advertises a cost which is unattainable since the ABWR, with smaller reactor building, while producing 4.5 times the power level and getting built at a record 40 month by leveraging expansive modularization and experience, never achieved less than $3,000/kW in Japan at the four unit Kashiwazaki-Kariwa site [10]

The biggest portions of the cost of nuclear power plants, big and small, are the same and known to everyone [7](p74). The nuclear ‘island’ equipment itself is only 10-20% of the total cost for Large Reactors whereas the majority of the cost is due to installation and construction works [11]. This means that the Nth-of-a-kind (NOAK) cost for large reactors approach the cost of their plant equipment, since most learning and cost reductions are realized through rapid project execution and streamlining of on-site construction. When deploying smaller and/or higher temperature units, nuclear island equipment and civil infrastructure constitute a larger portion of the total cost, which jeopardizes nuclear energy NOAK potential. The ‘irreducible’ or ‘fixed’ costs are largely independent of the nuclear technology so need to be addressed.

Minimal market competitiveness against natural gas and subsidized wind and solar, with unproven suggestions that new plants can somehow replace old or forced-closure coal units to retain their communities and recycle some staff [12,13] while incidentally gaining local political support. High interest payments and financing costs require some power price guarantee or purchase agreement to assure returns on investment.

2.2 What is observed

Lack of proven technological experience and insufficient depth of technical and real project completion expertise, leading to excessive optimism and unrestrained aggressive marketing with sweeping claims on costs, safety, feasibility, fuel cycles and waste reduction. Achieving high capacity factors can only be attained for nuclear technologies with significant prior experience: this has been proven over and over again, with low capacity factors achieved by fast and high temperature reactors.

Overly complex national safety cases and protracted licensing risks based on rules, guides, regulations and laws that are clearly obsolete, let alone microscopic. For instance, despite operating in Republic of Korea (ROK) and United Arab Emirates (UAE) as well as obtaining design certification for U.S. NRC, the APR1400 design for the entire EU market is drastically changed with the adoption and addition of double containment and core catcher

Whereas governments can partially bail out the high capex of a nuclear technology, through legislation, subsidies and load guarantees, the O&M (Operations and Maintenance) and fuel cost must also be kept low. High O&M costs have been historically the leading reason behind the demise of nuclear commercial shipping industry by U.S., Germany and Japan lack of penetration of non-water cooled reactors leading to 97% market share dominance by the water cooled technology low longevity of test reactor to support long leading enabling material R&D. The latter always forces “real” nuclear projects to rely on already tried and failed legacy approaches and technologies and is manifested in and by conservative engineering standards and “proven” practices.

Adopting technical solutions are commonly challenged by the realities of energy market demand projection, which is only firm in a 5-year horizon. But companies have to freeze design and spend some 10 years on licensing, after which not only the design has been adopted based on legacy concepts (as noted above) but also missed the market demand by five years let alone the extraordinary pace of digital and other technology changes. The plant computers become obsolete and spare parts difficult by the end of project completion. This vicious cycle is the reality of today, and nuclear technology R&D for new systems and components continue to be on average on a 15-20 year time frame. This sample of observations are coupled with well-known social and long-outstanding political issues:

a) public fear of radiation because of the atomic bomb and poor Science Technology Engineering and Mathematics (STEM) and Social Science (SS) education;

b) lack of internationally accepted standards or processes for licensing;

c) investor and regulatory pressures for local power companies/entities to show financial returns amid politicians' short re-election horizons;

d) continuing lack of long-term strategic international cooperation when not in the national economic and political self-interest.

2.3 What is needed

An objective assessment is needed of relative technology maturity and experience as they directly affect risks of return on investment (ROI), construction delays and production shortfalls. The impacts on cost and schedule are already well known from McNulty "learning curves" or Series for ranking and evaluating investment risks in mining and processing technology [14-16]:

Series 1: Mature, proven, fastest and best production baseline (= existing Gen-III LWRs and HWRs)

Series 2: Less production because of being a prototype and having limited field experience or testing (= new design variants of existing designs like EPR, AP1000, VVER1400 etc.)

Series 3: Even slower and less with little variability experience (= any water-cooled new SMRs or Gen-IV types…)

Series 4: The slowest and least with more complex or new processes that are pioneering, novel or unproven (= all other types of SMR like molten salt, fast reactors, gas-cooled reactors, Gen-IV, any other hypothetical SMRs)

Series 5:The "promoters curve" (= not based on any data)

The available data for major nuclear project cost and schedule increases show this technology classification and the subsequent risks are independent of reactor type and are truly internationally applicable. To offset these known impacts, there are generic approaches to reduce the risks and increase licensing/build efficiency that should be implemented:

- Decreased time scales reduce risk for licensing, site selection and review
  This requires consider adopting standardized licensing approach for aircraft ("type certification") is issued, valid internationally, so suitable target is an (internationally) agreed process that is about 24 months for a new build, rather than 60
- Lower up-front risk and initial capital investment to produce earlier ROI.
  In competitive energy markets with cheap gas for the foreseeable future the target capital cost reduction required to compete directly is a factor of four or five, and can only be achieved through radical innovations (not for China, Russia, India).
- Shorten engineering and construction times
  Requires streamlining designs for "constructability", implementing new modern materials and techniques (less rebar and concrete), and integrating modern wiring and CAD/CAE techniques into the construction schedule and processes
- Shared facilities and site infrastructure to basically promote "nuclear parks" or "energy centers"
  Provide the infrastructure and economic incentive for co-production of electricity, hydrogen, process heat, and manufactured fuels such as methanol, reducing greenhouse gas and other emissions dramatically

- Implement a new national and industrial research agenda
  Address the new national and international requirements, and re-align existing efforts, and traditional thinking.

3 CONCLUSIONS AND OPINIONS

The complexity of nuclear reactors is the market-solution, not the devil. China, Russia and India continue with Large Reactors, bypassing/dominating *(what we call)* the market..

This technology deployment is against the background history of The Bomb: disconnected from energy production, but not from international politics communication and business dealings.

The world's major populations in China and India need nuclear energy for sustainable economic expansion with minimum pollution to the environment, which explains their investment in developing domestic nuclear capability, national designs, new concepts and manufacturing facilities

Nuclear technology is not immune of accidents: (a) looking at failures of components, probabilities of severe events can be 100+ times larger than today estimates; (b) looking at industrial disasters in the last century, it is difficult to justify probability for severe accident lower than 10^{-3}/year.

Safety and the risk of accidents are uppermost in many people's minds, and feature strongly in current regulatory procedures but in regard to public communication of risks, the radiation hazard nuclear terminology/technology is beset by ICRP, Bq, Gy, R, Ci, Sv., technical names and units that confuse and do not easily inform public risk. For example, nuclear waste is an energy resource rather than a million year problem but the deep-geologic sites are for civilization-term storage to attain miniscule hazard levels but are not designed or sited to facilitate energy resource recycling of once gently-used fuel.

We strongly recommend the deployment of nuclear fission for energy production everywhere in the world. The large reactors, whenever possible, should contribute to energy security, financial stability and technology development and preferably be market driven (exceptions being Russia, China, and India). The small reactors may contribute in areas impacting the reduction of pollution, like naval transportation, hydrogen production and remote areas energy powering.

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