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BALANCING RISK AND REWARD: A BRIEF LITERATURE REVIEW PERTAINING TO THE IDEAL DESIGN OF RADIOLOGICAL PROTECTION MEASURES IN RELATION TO THE POSSIBLE SITING OF A COMBINED POWER AND DESALINATION NUCLEAR REACTOR IN MALTA.

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1 Introduction

In the Maltese Energy Policy,

"...nuclear power generation is not considered a feasible option."

-A proposal for an energy policy for Malta 2009

Presumably the rationale for the above statement is twofold. Firstly, financial , such a presumption is solidly rooted in the reality that the limited amount of nuclear generating station's that have come online in the past twenty or so years , in the west at least, have done so at enormous cost. Secondly the perceived risk associated with a nuclear generating station is large, both form a safety and investment point of view. These factors are inescapably intertwined.

This writing off of nuclear power for Malta, though seemingly reasonable, is entirely premature. It is certainly true that Malta is a small island and nuclear power generation is generally considered an expensive niche technology, but this perception is largely due to extraneous considerations with very little foundation and certainly not due to the limitations of current nuclear technology. Indeed, even in regard to legacy systems only a small number of, mostly Soviet built systems, are / were of any real concern. As such this paper will briefly examine what would constitute the ideal design of radiological protection measures which would allow for the protection of the public as well as create a situation where private capital, as well as the general public, could potentially derive a benefit from the construction and operation of a nuclear power and desalination facility.

2 MANAGING RISK: RADIATION

It is the opinion of this paper that, one single, often misunderstood word, radiation, is the primary root cause of nuclear public perception and by extension, economic issues.

The logical course to follow is to ask what exactly radiation is as it applies to nuclear power generation.

"Radiation; Physics
The emission of energy as electromagnetic waves or as moving subatomic particles, especially high-energy particles which cause ionization."
-google definition

In relation to health effects the correct handling and limiting exposure to substances emitting ionizing radiation is a must, other less high energy emitters should also be treated with care but are not as challenging [T. Henriksen et al, 2013]. However this is not to say such substances are inherently dangerous, far from it, they possess properties that are immensely useful to health care, industry and agriculture [IAEA, 2014]. It is the manner and magnitude of exposure that under certain circumstances can cause harm [T. Henriksen et al, 2013].

How this relates to nuclear safety is largely dependent on what sort of model one refers to in relation to approximating the harm potential of material that has been released.

The most common and possibly inappropriate model, when applied to public health and radiation, is what is "called linear no threshold" or LNT. It is a model which presumes harm occurs from the very slightest exposure to radiation and that consequently there is no safe dose of radiation, this model is well intentioned, erring towards what is presumed to be an abundance of caution. The reasons to question the validity of applying the LNT model in relation to radiological protection are twofold.

Firstly the LNT approach does not explicitly take into account wide variations in natural background radiation, for example, 0.2 mSv per year in Honolulu to 0.7 mSv per year in Colorado Springs [HPS, 2010]. Secondly when applied to radiation protection, the LNT model may be inappropriate due to a process known as hormesis [M. Cuttler, 2014] [T. Henriksen, 2013]. Hormesis is the process by which an organism responds positively to a small amount of a stressor , in this context a small dose of radiation , this exposure may stimulates a repair response which has, on balance a positive effect [M. Cuttler , 2014] [T. Henriksen , 2013]

The necessity of having a properly understood model for roughly estimating potential health effects cannot be over stated, this is regardless of whether nuclear generation is pursued.

With the focus of this paper being Malta, it would appear necessary to place particular emphasis on examining material relating to populations and areas proximal to an uncontrolled release of radiation and radioactive material. This emphasis is undertaken due to the small size of the Maltese islands and though not a perfect approach, could be of some benefit in assessing the localized risk brought about by the occurrence of such a mishap in Malta.

To roughly achieve this, a brief look at the after effects of Hiroshima and Nagasaki bombings will be taken. Though not strictly an uncontrolled release, as both cities were bombed and bombs by their very nature, are explicitly designed to go bang.

That said the radiation exposure, albeit mostly radiation rather than deposited radioactive material, and general destruction endured by the populations of both cities was far in excess of any credible civilian nuclear power plant accident. Thus providing a reasonable point of departure to reality check any concerns regarding the effects of a serious civilian accident.

In regard to the Life Span Study (LSS) undertaken on the survivors of Hiroshima and Nagasaki, there were definitely negative consequences endured by individuals unfortunate enough to have been exposed to high levels of radiation. However these negative consequences, though individually tragic, are, when viewed in a wider sense, manageable. Certainly when viewed against the expected outcomes for activities as mundane as improperly managed diabetes or a sedentary lifestyle. As an illustration of this in 2003 the last full year of the lifelong studies and almost sixty years after exposure, 80% of those who were under 20 at the time of exposure were still alive as were 42% of the total study cohort [K. Ozasa, et al 2012].

Through to the year 2000, i.e. over the course of 55 years, 94 excess deaths due to leukaemia were estimated to have occurred. In regard to solid cancers 848 instances above what would normally be expected were estimated to have occurred (solid cancers being significantly more treatable than leukaemia). Both figures relate to the cohort of 44,635 LSS survivors [RERF 2015]. It also is quite necessary to point out that both Hiroshima and Nagasaki are currently thriving cities and were not abandoned or rendered uninhabitable. The lesson to be learnt is that the consequences of a release of radiation are manageable.

This pattern is further demonstrated in the continuing effects of the Chernobyl nuclear power plant accident – the largest radioactive release from a civilian nuclear accident on record [IAEA 2005].

This extensive release was due to a convergence of factors, the two most serious of which were the reactor having a positive void coefficient and it lacking an effective containment vessel. A containment vessel is more or less self-explanatory, comprehending what a positive void coefficient is sounds intimidating but in reality is quite simple; In essence when a void , or relative void forms , say water turning to steam , the rate of reaction speeds up , resulting in a difficult to control situation. This is the exact opposite to most western designs, which use water as a moderator, if the water turns to steam the reaction stops, this is in contrast to the RBMK reactor used in Chernobyl which used graphite as a moderator. Thanks to these attributes it would not be unfair to categorize the RBKM as a reactor not even a mother could love and only the soviets would build.

However despite the reactor failing and the large radiation release the physical health effects have been quite arguably largely manageable. With 28 attributable fatalities to radiation in 1986 and a roughly estimated figure of possibly 4% of the predicted 100000 lifetime cancer deaths among the 600000 or so individuals who received more significant exposure as a result of the accident [IAEA 2005]. This is in contrast to the mental health and social issues experienced by the affected populations , indeed it is the social issues experienced , particularly by the evacuees, which according to the IAEA report on the Health, Environmental and Socio-Economic Impacts of Chernobyl is arguably the most serious legacy of the accident [IAEA 2005] .

From here it would seem appropriate to look briefly at the accident that occurred at the Fukushima daiichi nuclear power plant. It is worth mentioning that accident is being used in a more loose sense than in relation to, Chernobyl, as the plant in question was stuck by the most powerful tsunami and earthquake ever recorded to hit Japan [USGS , 2011] which killed almost 16000 people [

National Police Agency of Japan , 2015] . As a result of the tsunami the Fukushima daiichi nuclear power plants ability to deal with decay heat from three shutdown reactors was compromised, resulting in their failure. However unlike in Chernobyl, the reactors in Fukushima daiichi were of a western design and were also encased in containment vessels which resulted in vastly less radioactive release, one fifth to one tenth that of Chernobyl, of which a large portion blew out to sea [UNSCEAR 2013].

However there is where the differences end's. Much like what occurred in Chernobyl, a mass evacuation was enforced by the Japanese's authorities of individuals who were previously resident within a 20km radius of the plant. The maintenance in force of large parts of this evacuation zone, despite the greatly reduced radiation levels, due to half-life decay, of the most radioactive substances, coupled with the relatively manageable levels of contamination remaining, is unfortunately resulting in a repeat of what occurred in Chernobyl, that is a hysterical fear of radiation resulting in very real human suffering in the form of, mental health issues, social isolation and the stigma of being an evacuee.

Further to this Report of the United Nations Scientific Committee on the Effects of Atomic Radiation Sixtieth session predicts that there will be no radiation attributable fatalities from the Fukushima daiichi accident [UNSCEAR 2013] The lesson to be learnt, is that a possible overreaction, even if done for what is thought to be the right reason can have serious consequences for the individuals affected. These lessons should inform those making decisions with regard to acceptable levels of radiation exposure, it would seem that a departure from LNT and towards a level that is as high as reasonably allowable would appear to be the best course of action.

3 REWARD

With the risk, or potential for risk associated with nuclear very briefly addressed. It would seem appropriate to briefly address the reward inherent in choosing the nuclear option. The primary reward gained if nuclear is done well is financial; low cost energy and predictable future costs. This by its very nature is a reward with wide societal benefits. Particularly in terms of keeping a lid on the cost of living and allowing a degree of industrial competitiveness through reasonable and predictable energy costs. Further to this keeping energy costs relatively low is likely to prove very necessary to facilitate the increase in automation that will be necessary to increase productivity with a shrinking workforce due to demographic changes.

This financial reward is achievable only if risk is appropriately addressed, intrinsic to this is the recognition that it is always possible to make any system safer. The key is to reach a point where an acceptable level of safety is reached with the overall cost remaining competitive. Fundamental to achieving this on a small scale, with limited resources, which essentially would be the challenge in the Maltese setting, is the selecting of a safe and proven reactor design to be built in a safe but cost effective manner.

In regard to selecting an inherently safe reactor design, a largely pre-manufactured, or indeed fully modular reactor would be the ideal choice. However seen as there are currently no turnkey or modular reactors on the market, or unlikely until the mid-2020's at the earliest [IAEA 2014]. An alternative approach may have to be pursued. Such an approach need not be novel; for example it is the opinion of this paper that a facility consisting of four small reactors of a little over 60MWe each would constitute a facility that could feasibly be handled by the Maltese grid.

As to the individual reactors , it would appear feasible to construct each unit as an exact replica of the final iteration of the Shipping port light water reactor as configured to accept the light water breeder reactor core [LWBR] . The LWBR was extensively run and proved to be an exceptionally efficient and long lasting configuration [DOE 1986], which would be ideal for a plant whose purpose is to provide energy as cheaply and cleanly as possible

This approach, in common with the logic behind the use of a Modular or semi modular reactor, would essentially eliminate research and development as a significant cost, allowing the sole focus of the project, to be finding efficiencies in the construction and procurement effort.

Of quite some importance in providing breathing room for the finding of efficiencies, in a project as suggested above, would be ensuring realistic specifications and realistic supervision in the application of quality control. To achieve this adopting, as far as practicable, a standard reasonably familiar to industry, such as aviation grade, may result in more companies being willing to bid for and complete work to the required standard for a lower overall cost.

4 FUNDING AND LIABILITY

The ideal design of radiological protection legislation, much like any piece of legislation, needs a certain element of being a two way street. In this regard attracting investment to fund such a project would require a balance be found, to ensure a degree of flexibility, expedience and legal certainty.

In order for a project to be completed with minimum cost to the state and by extension the taxpayer, it would seem logical for conditions to be created where by private sector investment can be enticed in. For a large infrastructure project like a nuclear power and desalination plant the primary concern would be enabling the plant to be built and operated on budget, and on time without undue legal or administrative uncertainty. The primary reason for explicitly mentioning legal and administrative uncertainty would be the situation that befell the operation of the Shoreham Nuclear Power Plant in New Jersey, where a completed plant was unable to begin production due to political difficulties with administrative issues [D.P. McCaffrey, 1991]. In current reactor licensing in the US, permission to construct and operate a reactor is granted together, in the form of a Combined construction and operation licence, a nuclear regulatory commission 10 CFR 52.103(g) , this model avoids many of the issues encountered in Shoreham and may prove useful as a reference in drafting a similar procedure.

In regard to realistic liability in the case of an accident it would seem, given the experience of the unfortunate but limited consequences of an uncontrolled release of radiation. It would appear appropriate to stipulate, in legislation, the circumstances and extent of compensation payable in the event of release of radioactive material. Such compensation should be in line with that normally payable under tort and be explicitly limited to the carrying out of remedial works. Such an approach would lead well away from the slippery slope of claimed real estate value losses.

In addition to this , given the significant investment involved and vulnerability of such an investment to persistent legal and media harassment, as illustrated by the recent campaigns for the early closure of some units in the united states , particularly Vermont Yankee [M Angwin , 2014] . It would seem necessary to stipulate some additional legal procedural protections, particularly in relation to the balance of probability in civil matters. In this regard the standard of proof for bringing an action and for the finding of fault against an entity directly involved in the safe operation of a nuclear facility should be set at a standard of beyond all reasonable doubt. In addition to this the standard of proof needed to mount a successful defence by the entity involved should be to the standard of the balance of probability. The same approach should also be explicitly provided for in instances of defamation. This is much the same benefit provided to the most vulnerable individuals in the justice system, those accused of a criminal offence. The application of similar protections to the benefit of a vulnerable facility of national importance would, in the opinion of this paper be warranted.

Such additional protections may seem stacked in favour of the entity involved, but this stacking is justifiable given the extensive history of interference, through legal systems or otherwise by third parties intent on creating a situation where generating power from nuclear fission is rendered all but impossible [D.P. McCaffrey, 1991].

5 CONCLUSION

Nuclear power is a technology with enormous potential and significantly less risk than its portrayal in the media would suggest. With appropriate legislation, good planning and careful execution this potential to provide large amounts of very affordable energy and water could be realized.

The course of action outlined above may provide a useful starting point in building a framework which could hopefully succeed in creating a situation where private capital could be recruited in the endeavour to construct and operate a facility which would result in a significant economic and environmental benefit to Malta.

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