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22nd March 2024

RE: COMMENTS SUBMITTED ON THE INTEGRATED RESOURCES PLAN (IRP) 2023

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PART A

This submission is made by Southern African Faith Communities' Environment Institute (SAFCEI) in response to a call for public comments in regard to the publication of the Integrated Resource Plan 2023 (IRP) on 4 January 2024.

SAFCEI is a registered non-profit organisation that was established by multi-faith environmental and social justice advocates to, among other things, confront environmental and socio-economic injustices, and to support and encourage faith leaders and their communities in Southern Africa to take action on eco-justice, sustainable living and climate change issues. SAFCEI includes an Energy and Climate Justice Programme that focuses on climate change and energy.

EXECUTIVE SUMMARY

The IRP process has become superfluous as a result of the gazetting on April 28 of President Cyril Ramaphosa's decision to bring Section 6 of the National Energy Act[1] into operation, effective April 1, 2024, following legal proceedings launched by SAFCEI and the Green Connection in January 2023 to review government's failure or refusal to bring Section 6 into operation. The IRP 2023 should therefore be withdrawn with immediate effect as it has become a resource wasting exercise.

In the event that it is not withdrawn, the following submissions are made:

The IRP 2023 proposals for long term nuclear are policy provisions that must comply with section 195 of the Constitution, section 4 of the Public Administration Act and the objects of the Electricity Regulation Act. These provisions include requirements of cost effectiveness and transparency in decision making. The proposals for nuclear do not meet these requirements and will therefore be irrelevant considerations in future energy planning.

[1] Act 34 of 2008

South Africa currently has a constrained and unstable grid and it is doubtful that it would be able to support such a large new nuclear build programme. This issue should have been considered in the IRP 2023.
The IRP 2023 is untransparent, making proposals for massive new nuclear expenditure that cannot be critiqued by the public due to the absence of critical information.

As policy the IRP fails to comply with basic constitutional and legislative requirements for public administration and its proposals regarding proposed Horizon 2 nuclear programme should be withdrawn.

LEGISLATIVE CONTEXT.

South African legislation requires electricity planning to be sustainable, efficient and cost effective. Policy proposals regarding future nuclear procurement contained in the IRP 2023 do not meet these requirements and therefore violate section 195 of the Constitution, the Public Administration Act and the Electricity Regulation Act.

Under Horizon 2 Pathway 3 of the IRP 2024, it is proposed that that 4000 MW of nuclear electricity generation be built by 2040 and up to 14 500MW built by 2050. (see Annexure C of the IRP 2024.)[2]

The Electricity Regulation Act (ER Act)[3] was enacted to establish a national regulatory framework for the electricity supply industry.[4] One aspect of this framework is the integrated resource plan which it defines as: *"a resource plan established by the national sphere of government to give effect to national policy;"*[5]

The ER Act empowers the Minister of Energy under section 35(4) to make regulations regarding *inter alia* new generation capacity, and types of energy from which electricity must be generated. In 2011 under this section the Minister promulgated Electricity Regulations on New Generation Capacity[6] which make provision for the promulgation of an Integrated Resource Plan.[7] The IRP 2023 is promulgated under section 4(1) of these regulations.

[2] Item 8 of the IRP 2019 which is not in a section 34 determination.
[3] Act 4 of 2006
[4] Id Preamble
[5] Id section 1 definitions
[6] Published in Government Notice R399 in Government Gazette 34262, dated 4 May 2011 and amended by Government Notice R1366 in Government Gazette 40401 dated 4 November 2016
[7] Regulation 4

Although the IRP 2023 presents long term policy options including previously unheard-of levels of nuclear power, the regulations themselves state that they do not apply to nuclear power.[8] Scenarios related to nuclear power that appear in the IRP 2023 under Horizon 2 are therefore not governed by the provisions of these regulations. They are general statements of policy, and as part of public administration they must meet the requirement of promoting efficient, economic and effective use of resources set out in the Constitution, and Public Administration Act as well promote the objects of the Electricity Regulation Act given its regulatory role over the electricity supply industry. This must also be achieved in a transparent manner.[9] The relevant provisions of these statutes are as follows:

The objects of the ER Act are *inter alia* to achieve efficient and sustainable electricity supply, and it follows that policies for new generation procurement announced under the IRP 2023 must comply with these same goals:

> (2) Objects of Act
> The objects of this Act are to –
> (a) achieve the efficient, effective, sustainable and orderly development and operation of electricity supply infrastructure in South Africa;
> (b) ensure that the interests and needs of present and future electricity customers and end users are safeguarded and met, having regard to the governance, efficiency, effectiveness and long-term sustainability of the electricity supply industry within the broader context of economic energy regulation in the Republic;
> (c) facilitate investment in the electricity supply industry;
> (d) facilitate universal access to electricity.

These objects also fall broadly under general obligations of government administration set out in Section 195 of the Constitution and the Public Administration Act[10], and therefore govern the making of policy by the public administration. Section 195 states:

> "195. (1) Public administration must be governed by the democratic values and principles enshrined in the Constitution, including the following principles:

[8] Regulation 2 of the 2006 regulations and regulation 3 of the 2011 regulations
These Regulations apply to the procurement of new generation capacity, by organs of state, including -
(a) new generation capacity derived from renewable energy sources and co-generation;
(b) base load, mid-merit load and peak load new generation capacity; and
(c) cross border projects,
but excluding new generation capacity derived from nuclear power technology
[9] Constitution section 195(1)(g) and Public Administration Act section 4(g)
[10] 11 of 2014. 'Public administration' is defined in s1 as meaning *inter alia* 'the public service', and 'the public service' is in turned defined as meaning *inter alia* 'national departments' such as the DMRE.

(b) Efficient, economic and effective use of resources must be promoted;

(c) Public administration must be development-oriented;

(e) People's needs must be responded to and the public must be encouraged to participate in policy making;

(f) Public administration must be accountable

(g) Transparency must be fostered by providing the public with timely, accessible and accurate information."

The Public Administration Act seeks to implement these constitutional obligations and the values set out in section 195(1) of the Constitution are repeated in section 4 of this act.

"(4) Each institution must—

(a) promote and maintain a high standard of professional ethics;

(b) promote efficient, economic and effective use of resources;

(c) be development oriented;

(d) provide such services impartially, fairly, equitably and without bias;

(e) respond to people's needs and encourage public participation in policymaking;

(f) be accountable to the public;

(g) foster transparency by providing the public with timely, accessible and accurate information;

(h) ensure good human resource management and career development practices to maximise human potential;"

Efficient effective and economic use of resources

As will be clear from the submissions that follow, the proposals for future nuclear options announced in Horizon 2 of the IRP 2023 violate core values of the Constitution and Public Administration Act governing public administration, as well as the objects of the ER Act as they do not promote efficient, economic and effective use of resources and are based on inconsistent or inadequate information. As such they inconsistent with our constitutional value system and legal regime for electricity governance and will have no legal purchase. They will constitute irrelevant considerations in any future energy planning, such as the making of section 34 determinations for future power generation under the Electricity Regulation Act.

The nuclear proposals are also not presented to the public in a transparent manner with disclosure of sufficient information to enable meaningful public participation, a further core constitutional value.

Public participation in any policy making process must include disclosure of sufficient information to enable informed public participation. It has long been recognised that a fair decision-making process requires (among other things) that a person '*must be put in possession of such information as will render his [or her] right to make representations a real, and not an illusory one*'.[11] Hoexter points out that there is '*a crucial link between the amount and type of information disclosed to an affected person and the quality of his or her opportunity to make representations*'.[12]

Pathway 3 in Horizon 2 as it pertains to nuclear power generation is therefore fatally flawed as a policy and should be removed from the IRP 2023.

ANALYSIS OF THE IRP 2023 PROPOSALS TO BUILD NUCLEAR POWER PLANTS

The IRP 2023 is fatally flawed in that it:

(i) fails to achieve its stated goals;
(ii) cannot promote efficient and cost-effective energy planning;
(iii) is not transparent and fails to supply the public with sufficient information to enable public participation.

(i) The IRP fails to achieve its stated goals

The stated purpose of the IRP 2023 is to '*ensure security of electricity supply while balancing supply and demand while considering the environmental and total cost of supply*.'[13]
However, in regard to nuclear power it is unable to cost this option without further studies. Accordingly, the IRP 2023 cannot promote its own aims, and fails as a policy. This is evident from the following extracts:

IRP 2023 Annexure D, page 46

[11] Heatherdale Farms v Deputy Minister of Agriculture 1980 (3) SA 476 (T) (486F-G)
[12] Hoexter (2nd edition, 2018), Administrative Law in South Africa, at p371, referring to by the Constitutional Court in Bengwenyama Minerals v Genorah Resources 2011 (4) SA 113 (CC) paras 69-74.
[13] IRP 2024 page 10

"Due to the magnitude of their total system cost differences, the renewable and nuclear, the delayed shutdown; and repowering warrant further techno-economic studies to ascertain their cost structures."

And

IRP 2023 SEIAS Final Assessment.

This document under heading 2.7 asks the report to identify areas where additional research would improve understanding of the costs, benefit and/or of the legislation Page 26. The response given in point iii is as follows:

"Detailed analysis of other clean energy supply options (Coal, Hydro, Nuclear and others) including their associated costs and economic benefits."

The IRP 2023 is thus unable to provide any useful analysis of future costs of nuclear power. The results of the modelling referred to in the report are unclear, and the best pathway cannot be determined. Discrepancies between the EPRI study and the DMRE spreadsheet (see below for more detail) in addition to this stated need for further study result in reasonable conclusions about the Nuclear Pathway being incapable of being drawn. This state of uncertainty regarding costs results in the IRP 2023 being unable to achieve the goals it sets which are *'to ensure security of electricity supply necessary by balancing supply and demand while considering the environmental and total cost of supply.'*[14]

(ii) The IRP 2023 cannot promote cost effective and efficient use of resources

Following on the above, since the IRP has insufficient information as to the cost of Horizon 2 Pathway 3 nuclear build proposals, it cannot promote cost effective and efficient use of resources, thus violating the requirements for public administration in terms of the Constitution, Public Administration Act and the objects of the Electricity Regulation Act.

The information on which the IRP 2023 purports to model the overnight costs of future large nuclear power plants is contained in the reports of the EPRI[15] (the EPRI report) and spreadsheets provided by the DMRE (DMRE data) - disclosed to the public by the DMRE after publication of the IRP 2023. These two reports are out of date in several

[14] IRP 2023 paragraph 1.2 page 10

[15] Supply-Side Cost and Performance Data for Eskom Integrated Resource Planning 2020–2021 Update, Electric Power Research Institute (EPRI)

material respects and give unsubstantiated and inconsistent information on the cost of future nuclear power. They cannot serve to guide policy decisions, especially over such astronomical future expenditures.

In addition, the IRP 2023 makes no reference to challenges regarding grid stability and whether the South African grid can support such a large nuclear build programme.

Finally, the Electricity demand projections of the IRP 2023 are unjustifiably high.

For these reasons the IRP 2023 modelling for future nuclear build costs cannot promote cost effective and efficient use of resources and should be withdrawn.

Detailed discussion

Historic experience with predicting cost of nuclear power

We annex to this submission the expert report of Professor S Thomas which discusses experiences throughout the world in the last 20 years with building or attempting to build new generation III nuclear power plants, as well as experiences with developing small nuclear reactors. **Most ended in bankruptcy**.

He concludes that the mean value of the four projects for EPRs and AP1000s where costs are known, it is about $12,000/kW or R230,000/kW in 2024 money. This figure is at least 100% higher than the figure given in the EPRI report[16] and about 300% higher than data given in the DMRE new tech assumptions,[17] the latter being used to model pathway 3 of the IRP 2023. No explanation is given for this massive discrepancy in costs.

Professor Thomas' conclusions are included below for ease of reference:

> "Conclusions
> Nuclear programmes are often based on exaggerated claims made by promoters of the project. The programme is costed on as the basis of what the expected cost of the 'next' reactor will be. The assumption is that we will have learned from mistakes and the 'next' project will go to plan and to time and cost. Such forecasts have invariably hopelessly underestimated the cost: mistakes are repeated and new mistakes made. A much more reliable indicator is the cost of the 'previous' project, perhaps with some addition as the trend in the real cost of nuclear power plants has been upwards throughout the history of the nuclear industry. If we take

[16] Figures given on page 183 of the EPRI report are R122 976 (1x 1600MW Areva) and R117524 (1x1117MW AP 1000) , for translating into $6471 and $6185 at a dollar rand exchange rate of R19 to the dollar.
[17] New Techno Report slide gives the total overnight cost in R/KW in April 2023 as "PWR-CP" as R67 28 and "PWR – AP" as R78 700.

the mean value of the four projects for EPRs and AP1000s where costs are known, it is about $12,000/kW or R230,000/kW in 2024 money.

It must be stressed the information given here on nuclear projects in the past two decades is not a selection of the worst performing projects, it represents ***all*** the projects. All the nuclear projects in countries where reliable information is available have gone very badly wrong. Government policies launching new nuclear programmes are invariably based on an assumption that in this country these mistakes would be avoided. If countries with long and extensive nuclear histories such as USA, France, UK, and Finland have not been able to avoid appalling performance, what basis is there for a less experienced country to assume they will do far better?

Forecasts of reactor costs made by reactor vendors, governments and utilities ahead of an investment decision are essentially worthless. For example, in the UK government White Paper of 2008 that launched the most recent UK nuclear programme, the government assumed a reactor such as the EPR would cost £2bn.[18] The latest cost estimate for Hinkley is about £22bn with only a small amount of the difference accounted for by inflation. The follow-on project, Sizewell C, also for two EPRs, was recently estimated as taking £3.5bn just to get to a final investment decision.

For the past 50 years, when governments have launched nuclear power programmes, they have sometimes acknowledged past issues. However, they have claimed that a combination of new designs that will overcome safety and economic issues with past designs, learning from past experience and errors, standardisation of designs, cutting administrative red-tape, streamlining planning and regulatory processes and series ordering. These rather general prescriptions seemed credible in the past, but their promises have never been realised. Even in France, which series ordered 58 reactors in a 15-year period in the 1970s and 1980s, real costs significantly rose over time.[19]

Around 2000, there was propaganda from the nuclear industry about a 'Nuclear Renaissance' driven by new reactor designs such as EPR, AP1000 and APR1400, so-called Gen III+, which could be built in 3-4 years and would cost $1000/kW. The outcome is that real costs are far higher than in the past, and cost and time overruns are the largest they have ever been, about 10 times the claimed cost and a construction time of 10-18 years.

There is a great deal of publicity about Small Modular Reactors with claims they will solve the problems of past technologies, being cheaper, quicker and easier to build, will have improved safety and will be easier to site. These claims are based on some highly dubious assumptions. At best, SMR designs are perhaps a decade behind large reactor designs in development terms and relying on them as any more than a long-term possibility would be reckless.

Ambitious nuclear programmes are seldom realised failing because of high cost. The problem is therefore not so much that large numbers of hopelessly uneconomic reactors will be built, it is the 'opportunity cost' of wasting a decade or more on an option bound to fail at the expense of options that are financially more attractive, much less prone to failure and much quicker to implement. The alternative, of renewables and improved energy efficiency, would require a very different electricity transmission and distribution system. A nuclear dominated system would require long transmission lines form remote nuclear power sites to centres of demand. A renewables dominated system would depend much more on a strengthened distribution system with the transmission system more for back-up.

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[18] https://assets.publishing.service.gov.uk/media/5a7490ace5274a44083b7b15/7296.pdf

[19] https://thehill.com/blogs/congress-blog/energy-a-environment/70994-frances-nuclear-miracle-is-more-fantasy-that-fact/

EPRI and DMRE figures

a) The figures contained in the EPRI report are out of date and therefore irrelevant.
b) The figures for overnight costs of nuclear power generation in the EPRI report and DMRE data are inconsistent. They are percentages apart. There is no explanation given for the difference in these figures or the source of the DMRE data.
c) The figures contained in the EPRI and DMRE documentation regarding small nuclear reactors is out of date, and the conclusions therefore irrelevant.

a) *The figures contained in the EPRI report are out of date and therefore irrelevant*;

The EPRI report is a study that is confined to considering the Areva 1600 and AP1000 reactors to estimate overnight costs for large reactors. The Areva 1600 EPR costs estimates presented in the EPRI report are based upon the U.S. EPR design.[20] However this reactor is still seeking US regulatory approval.[21] There is therefore no up to date information on the cost of building and running this reactor available for modelling in South Africa.

b) The figures for overnight costs of nuclear power generation in the EPRI report and DMRE data are inconsistent. They are percentages apart. There is no explanation given for the difference in these figures or the source of the DMRE data.

<u>Discrepancies between EPRI and DMRE New Tech Assumptions</u>

Comment: the data used by DMRE on overnight costs of nuclear power in the New Tech Assumptions is not the same as the data presented in the EPRI report. This means that the EPRI report was not used to model nuclear costs in Pathway 3 and the EPRI report is therefore largely irrelevant regarding the cost of nuclear power. The following are the differences between the EPRI report and New Tech Assumptions provided by the DMRE on the rated capacity MW net.

Firstly, the plant ratings are not the same:

- EPSI: 1600 MW for U.S. EPR

[20] EPR report Page 101
[21] https://www.nrc.gov/reactors/new-reactors/large-lwr/design-cert/epr/review-schedule.html; Construction of the first is slated for 2027 with completion between 2035 and 2037. The EPRI study gives build times for the U.S. EPR, page 183: 6 years.

- DMRE: 1500 MW for a PWR-CP.

Comment: The New Tech Assumptions provided by the DMRE do not describe what the source of these figures are, and there is no explanation of methodology for reaching the costings as there is in the EPRI report. The term PWR-CP is not explained. The New Tech assumptions report is therefore untransparent and fails to provide the public with sufficient information to enable it to review the IRP's nuclear costing. Public participation in the development of one of the most significant public expenditures ever conceived is rendered meaningless.

- EPRI: 1117 MW for AP1000
- DMRE: 1250 MW for PWR-AP. Again, there is no information on the source of the costs relating to this technology, whether it is in operation or not.

Comment: The total overnight cost figures for EPRI study and the New Tech Assumptions referred to in the bullet points above do not even come close to each other. DMRE's costs are between 54.7% and 66.9% cheaper than those of the EPRI. Therefore, whatever DMRE's source/study/etc for the costing is, it is not the EPRI study. The EPRI study is once again irrelevant to the IRP 2023. The source is not disclosed rendering the process of public participation meaningless.

c) *The figures contained in the EPRI and DMRE documentation regarding small nuclear reactors is out of date, and the conclusions therefore irrelevant.*

The EPRI study as it relates to small modular reactors is also out of date. The report relied on the approved reactor Utah Associated Municipal Power Systems project.[22] Figures used are those of a UTAH reactor which has since been abandoned after costs rose considerably. The estimated costs of the project rose to $4.2 billion in 2018, then $6.1 billion in 2020, and finally $9.3 billion in 2023, after it was scaled down to 462 MW in 2021. In the end, the costs were clearly too high for UAMPS members to bear.

The change in rating from 720 MW to 462 MW in an attempt to bring down the costs is not referred to in the EPRI report, nor the fact that the project was abandoned. The DMRE spreadsheet also refers to the figure of 720 MW. Both documents are therefore

[22] See page 96 of the EPRI study which states:
"SMRs are another technology garnering interest for their potential to provide safe, scalable, dispatchable, and carbon-free energy. The U.S. NRC defines an SMR as any LWR producing under 300 MWe. This report focuses on the SMR design developed by NuScale Power, LLC, which has developed the first and only SMR technology to gain design certification approval by the NRC."

out of date and in any event since the plant has not been proceeded with it cannot form the basis of modelling of preferred pathways under Horizon 2 of the IRP 2024.[23] Media reports observed that "*the financial challenges and cost trends witnessed in that case will afflict any SMR project"*[24]

The report of Professor Steve Thomas contains an analysis of the cost of electricity generated by small modular reactors currently:

> "No modern design SMR is operating, only three prototype SMRs are under construction (China, Russia, India). No current design has completed a full safety review by an experienced & credible regulator. Until this is done, it will not be known if the design is licensable or what the costs would be. No design of SMR is commercially available to order yet."

It follows that the IRP 2023 should exclude reference to small modular reactors on the basis of this electricity generation source and its costs a currently purely speculative.

Electricity demand projections of the IRP 2023 are unjustifiably high.

The model used in the IRP 2023[25] assumes GDP will climb to 3.2% in 2030, 3.8% in 2040, 3.8% in 2050. This is unrealistically high given that currently GDP growth contracted to South African real gross domestic product (GDP) contracted by 0,2% in the third quarter (July–September) of 2023.[1]stands at 0.9%, and Treasury is optimistically predicting 1.6% for 2024 and 2025. Investec for example estimates that GDP might reach 2% by 2027. The IRP arguably assumes demand that might well be too high for realistic planning.

Conclusion

With both the EPR (U.S. or EPR2) and the SMR-NS, the EPRI study is out of date and therefore so is the IRP, provided the EPRI figures were put into the model. However, it appears that in any event these figures were not used for modelling and instead the unsubstantiated figures from the DMRE spreadsheet were used for modelling. There is no explanation for why these figures should be so much lower than the EPRI figures which in turn are around 50% lower than the experience internationally for building generation lll reactors as per the report of Professor Steve Thomas.

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[23] https://www.utilitydive.com/news/nuscale-uamps-project-small-modular-reactor-ramanasmr-/705717/
[24] id
[25] IRP 2023 page 14

(iii) The IRP 2023 is not transparent and fails to supply the public with sufficient information to enable participation

As stated above the EPRI report and DMRE table of new tech assumptions provided to the public to enable comment are out of date, inconsistent and in the case of the DMRE data lack crucial information on nuclear costs which would enable public review. This is problematic in that these costs differ so substantially from the overnight costs estimated by the expert Professor Thomas based on international experience.

The information supplied by the DMRE in the new tech assumptions report was used for modelling but since its source, methodology and other critically relevant information was not disclosed to the public, insufficient information has been disclosed to enable meaningful public participation.

The presentation of information on the long term nuclear programme in the IRP 2023 is an exercise in obfuscation. The main body of the IRP 2023 report does not refer to the scale of the future nuclear programme. This is to be found in Annexure C, but the main report does not link its proposals specifically to this annexure.

It follows that the public is not put in a position to meaningfully participate in the IRP 2023 process as a result.

GRID STABILITY AND NUCLEAR POWER

The IRP 2023 makes no reference to challenges regarding grid stability and whether the South African grid can support such a large nuclear build programme.

> A power network for a system reliant on a small number of very large nuclear power plants would look totally different to one designed for a large number of renewable sources. Hence if the grid is built for large scale nuclear power generation and then the reactors cannot built, the money on the system will have been wasted and the system will be ill-suited to renewables entailing further cost.
>
> (Professor S Thomas)

Furthermore the suitability of a constrained grid subject to repeated loadshedding with the risk of grid collapse should have been considered in the IRP 2023, in order to ensure to ensure that the interests and needs of present and future electricity customers and end users are safeguarded and met, having regard to the governance, efficiency, effectiveness and long-term sustainability of the electricity supply industry within the broader context of economic energy regulation in the Republic, as well as their safety.

Grid stability

The issue of grid stability is recognized internationally as an issue of critical importance in planning for nuclear power generation. As stated by the International Atomic Energy Association (IAEA) in its guidelines for the design of electrical power systems for nuclear power plants regarding grid stability, the electrical grid should provide stable off-site power and the trip of a nuclear power plant main generator should not jeopardise the stability of the grid: [26] IAEA guidelines on nuclear safety and grid reliability state that when considering siting a new nuclear power plant the reliability of the off-site power will have to be calculated.[27]

The addition of 14500 MW of new nuclear power to the South African grid is a significant development which the grid might not be capable of supporting. South Africa already faces an uncertain future as regards its constrained grid. Sustained loadshedding and grid instability is internationally recognized as having the potential to impact on nuclear safety, and therefore potentially impacts on the viability of any proposal to add significant new nuclear power generation to the grid - as with the proposed nuclear build programme in Pathway 3 of Horizon 2 and given the significant increase in renewable energy in this pathway. Grid stability should therefore have been mentioned in the IRP 2023 as a consideration relevant to the interests of current and future consumers, and the efficient use of resources. However, it appears not to have been considered. SAFCEI has made extensive submissions in regard to this issue in comment on the application to extend the life of the KNPS dated 16 March 2023 and some of these are repeated below. [28]

The following quote from the US Nuclear Regulatory Commission, explains why off site backup by means of a stable grid is critical to nuclear safety. On site backup, which is

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[26]GRID STABILITY AND RELIABILITY

6.45. The electrical grid should provide stable off-site power; that is, it should be capable of withstanding load variations without exceeding the specified voltage limits and frequency limits.

6.46. The grid should have enough running inertia to make certain that the loss of a large power generating unit, the trip of the nuclear power plant main generator or busbar faults in the grid do not jeopardize the stability of the grid.

6.47. The degree to which the grid can maintain an uninterrupted power supply to the nuclear power plant with sufficient capacity (i.e. voltage and frequency) is a measure of the reliability of the grid. (emphasis added)

IAEA Publication Design of Electrical Power Systems for Nuclear Power Plants - Specific Safety Guide No. SSG-34 2016 https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1673web-53477409.pdf

[27] IAEA Nuclear Energy Series No. NG-T-3.8,2012, Electric Grid Reliability and Interface with Nuclear Power Plants - available at https://www-pub.iaea.org/MTCD/publications/PDF/Pub1542_web.pdf

[28]

usually limited to emergency generators and their diesel stocks, is really only used as a last resort. In the event of a nuclear trip event it is advisable to have a stable grid that provides this off site backup:

> WHY DOES NRC CARE ABOUT GRID STABILITY? Nuclear power reactors must be cooled continuously, even when shut down. The numerous pumps and valves in the reactor cooling systems therefore must have access to electrical power at all times, even if the normal power supply from the grid is degraded or completely lost. As a regulator, we want to minimize the time a nuclear power plant is subjected to a complete loss of offsite power, otherwise known as Station Blackout. Even though plants are designed with emergency diesel generators to supply power to pumps and valves that keep the reactor cool when normal power is lost, we do not like to challenge those diesel generators any more than is absolutely necessary.[29]

Published journal articles support this view with details:

> The electrical grid is the preferred power source for safe start up, operation and normal or emergency shutdown of the NPP, in addition to the necessity of the adequate capacity for exporting the produced power from the NPP (IAEA N, 2012). Hence, loss of offsite power (LOOP), (i.e. loss of power from the grid) is defined as the "simultaneous loss of electrical power to all safety-related buses that causes emergency power generators to start and supply power to them" (Eide et al., 2005a). LOOP stands out as the most dominant contributor to the core damage frequency of NPPs (Mohsendokht et al., 2018).[30]
>
> The availability of alternating current power via the electrical grid is essential for safe operation and accident recovery of nuclear power plants (NPP). Loss of offsite power (LOOP), as an initiating event, contributes more than 26 percent to the core damage frequency (CDF) of generation II reactors. The LOOP event dramatically affects plant operations because it influences the mitigation responses by placing demands on the onsite power systems.[31]

South Africa currently operates a constrained grid with very little surplus capacity,[32] and unplanned outages can result in electricity demand exceeding available supply as it

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[29] https://www.nrc.gov/docs/ML0620/ML062050519.pdf

[30] Assessment of the grid-related loss of offsite power to the nuclear power plants in the presence of wind farms Sh Kamyab [a], A. Ramezani [b], M. Nematollahi [a], P. Henneaux [c], P.E. Labeau [c] https://www.sciencedirect.com/science/article/abs/pii/S0149197022003821

[31] Reducing the loss of offsite power contribution in the core damage frequency of a VVER-1000 reactor by extending the house load operation period, January 2018 Annals of Nuclear Energy 116:303-313DOI:10.1016/j.anucene.2018.01.030Massoud Mohsendokht, Kamal Hadad, Masoud Jabary https://www.researchgate.net/publication/324295283_Reducing_the_loss_of_offsite_power_contribution_in_the_core_damage_frequency_of_a_VVER-1000_reactor_by_extending_the_house_load_operation_period

[32] Affidavit of Andre Marinus de Ruyter: IN THE HIGH COURT OF SOUTH AFRICA GAUTENG DIVISION, PRETORIA CASE NUMBER: 2023/005779 In the matter between:

does not currently have the requisite reserves to rely on in order sustain supply. In these circumstances Eskom has resorted to load shedding.

Grid stability and reliability is thus a key requirement in ensuring safety of nuclear power stations and the current and potential future state of grid stability in South Africa should have been referred to in the IRP 2023, against international best practice, to determine whether it is viable to consider building 14500 MW of nuclear power generation in the not too distant future over a period of 20 years.

The failure to mention and assess these safety issues is a fatal flaw in the IRP 2023.

CONCLUSION

For reasons set out above SAFCEI submits that the IRP 2023 should be withdrawn, and if not the references to nuclear power in Horizon 2 should be removed from the IRP 2023.

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Part B: Annex, below, is an Expert Report by Professor Steve Thomas.

UNITED DEMOCRATIC MOVEMENT AND 18 OTHERS Applicants and ESKOM HOLDINGS SOC LIMITED AND 7 OTHERS Respondents, paragraph 58.

PART B: Annex

Annex
Nuclear power plant costs & reactor options for South Africa
Professor Stephen Thomas
March 2024

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1. Introduction

There is a huge range in the published reactor cost estimates and if appropriate estimates are to be used, it is important to identify what type of estimate it is and how reliable the data is as an indicator of future reactor costs.

In this Annex, we look at: the analytical issues involved in estimating future nuclear power plant costs; the different bases for estimating reactor costs; the large reactor options available to South Africa; the option of Small Modular Reactors

2. Analytical Issues

Construction costs are typically quoted as the cost, excluding finance charges, during the construction phase, so-called overnight costs. For comparison between reactors of different outputs, the cost is often quoted in coast per unit of capacity, for example, $/kW. So, a 1500MW reactor costing $15bn would be quoted as $10,000/kW. In this analysis we convert costs to $ (2024) for ease of comparison.

While the overnight cost is useful for analytical purposes for identifying trends, the finance costs are significant and could be of the same order as the overnight cost so the cost paid by consumers could be double the overnight cost. The finance charges will depend on the interest rate, the credit-worthiness of the customer and the construction time. If construction is delayed, the finance costs will be much higher.

Construction is generally assumed to start when the first structural concrete is poured. It is likely to take several years, up to four, from Final Investment Decision (when firm contracts are signed) to this point, to allow equipment to be ordered, the site to be prepared and the workforce mobilised. Completion of construction is taken as when the plant enters commercial operation. This occurs when the plant has passed all its commissioning tests and the operation of the plant is handed over from the reactor vendor to the customer, generally the electric utility. The testing phase, from first criticality to commercial operation typically takes at least 6 months and sometimes significantly more if construction or design errors are identified in testing. For example, the Finnish Olkiluoto 3 reactor took 18 months from reactor criticality to commercial operation

There are difficulties in making comparisons between reactors costs for several reasons. Costs are quoted in a particular currency and as exchange rates can vary significantly, this can distort comparisons. There is also the issue of inflation and costs quoted in currency of a particular year have to be escalated or reduced using the general inflation rate to make them comparable with costs from another plant calculated in a different year. As an approximation, we will assume inflation in the countries examined is 3% per annum, although in UK and South Africa, inflation in the past few years has been significantly higher. For exchange rates, we assume the rates that applied in mid-March 2024: $1=€0.92, $1=£1.27, £1=€1.17 and $1=R19.

This means there is inevitably some uncertainty in comparisons and not too much should be read into relatively small differences in cost. There is also uncertainty about how reliable data from some countries are. In Europe and North America, accounting law means the quoted costs have to be accurate. However, in some countries, e.g., Russia, China and Korea, there is a close connection between the reactor vendor and the local utility, the companies are nationally-owned and there is a policy priority to win export orders for the company. In these circumstance, there will be a strong incentive to understate the actual costs.

3. Reactor cost estimates

There are several possible sources of cost estimates for nuclear power plants including:

- Estimates given by reactor vendors and nuclear trade bodies for new designs.
- Estimates given by international agencies such as the IAEA and the NEA.
- Contract prices; and
- Outturn costs.

The record of all of these as predictors of costs for new power plants is poor except for actual outturn costs. Estimates by reactor vendors are no more than promotional material to stimulate the market. Around 2000, reactor vendors were claiming their new designs could be built for $1000/kW. The outturn costs for these designs were an order of magnitude more. Nevertheless, these estimates achieved their aim and countries such as the USA and the UK launched (unsuccessful) nuclear programmes based on these claims.

International agencies such as IAEA and NEA are not unbiased, they have in their mission statements the promotion of nuclear power and their estimates, often uncritically taken from reactor vendors and member state governments, have to be seen in that light. They have also been worthless as predictors of nuclear power plant costs.

It might be expected that contract prices would be more reliable. However, nuclear power plants are built by many contractors: the reactor vendor designs the reactor and supplies or procures the reactor equipment; other suppliers supply the 'balance of plant' (the non-nuclear part) such as the turbine generator; architect engineers design the overall plant integrating the reactor into the balance of plant; an engineering company oversees construction; and civil, mechanical and electrical engineering companies carry out the work. No single company would be willing to be at the mercy of the performance of all these interdependent companies, so, essentially, nuclear power plants are built on a 'cost-plus' basis - whatever it costs, the customer pays. In the past two decades, this outturn cost has been much more than the contract price. For example, the Flamanville 3 plant in France was expected to cost €3.2bn and the latest estimate, about a year ahead of completion is €13.2bn. The Hinkley Point C plant was contracted at £18bn but the latest cost estimate is £31-35bn with 6-7 years of construction remaining. All these estimates are 'overnight'[33] costs, excluding finance charges as these cannot be controlled by contractors. Finance charges depend on the interest rate charged and on the length of the construction process.

It might be expected that a fixed price contract[34] would provide some protection for customers against cost escalation during construction. However, the record of the small number of such contracts for reactor vendors is very poor and genuinely fixed price contracts are unlikely to be on offer as the represent to large a risk for a supplier. In the mid-60s, the nuclear industry persuaded reluctant US utilities to choose nuclear by offering turnkey contracts for 12 projects.[35] The US vendors had to try control all the elements of construction, a task they were ill-equipped to do, lost large amounts of money on them and has never offered them since.

The next example was the Olkiluoto 3 contract of 2003 offered by the French company, Areva NP, for €3bn for a 1600MW EPR. The completed plant cost in excess of €10bn and losses on this contract

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[33] So-called because they assume the plant was built 'overnight' and therefore incurred no finance charges.

[34] Sometimes known as 'turnkey' as the customer just has to turn the key at the gate of the plant when it is finished.

[35] ***Light Water: How the Nuclear Dream Dissolved. By Irvin C. Bupp and Jean-Claude Derian. (New York: Basic Books, 1978***

contributed to the financial collapse of Areva in 2016. The plant should have been completed in 2009 but was only completed in 2023 and the customer had to pay the finance charges for these extra 14 years.

Westinghouse was forced under threat of legal action, to offer fixed price contracts for two US projects (Vogtle and Summer, both for two AP1000 reactors) in 2015 for projects that had started construction two years before because construction had gone so badly wrong. Westinghouse's completion cost estimate quickly proved a gross underestimate, it declared losses of about $6bn on these contracts and was forced to file for Chapter 17 bankruptcy protection in 2017.

4. Large reactor options

There is limited experience with modern designs of the type that could be bought by South Africa, and it is uniformly very poor. Worldwide, there are five active suppliers of nuclear power plants currently: Framatome, Westinghouse, KEPCO (Korea), Rosatom (Russia) and China. Of these it is assumed that Rosatom is politically unacceptable, and it can be excluded, China might be an option, but other countries such as UK, Poland and Czech Republic have chosen to exclude China because of security concerns.

4.1. Framatome

Framatome was previously known Areva NP, a division of the Areva group, but Areva collapsed financially in 2016. Areva NP was rescued by the French government and taken over by the French national electric utility, EDF, and it reverted to its previous name, Framatome, the supplier of the Koeberg reactors. Its current design is the European Pressurised water Reactor (EPR) a 1600MW PWR. It has won six orders for this design, one for Finland, one for France, two for China and two for the UK.[36]

4.1.1. Finland

The final investment decision to buy an EPR (Olkiluoto 3) was taken in 2003 with construction starting in 2005 when completion was expected for 2009. The plant was declared commercial in May 2023 after 18 months of testing. The plant was bought under a fixed price contract for €3bn where the vendor, Areva NP guarantees the price paid by the customer with it taking on any cost overruns, but not any additional finance costs. When the construction started to go wrong, Areva claimed it was not their fault and that it should not be liable for all the cost overruns. A lengthy dispute ensued taking nearly a decade to resolve, in 2018. At that time, completion of the plant was expected in 2019, four years earlier than actual completion. The cost on which the settlement was based excluding finance was in excess of €10bn.[37] Additional costs in the period 2019-2023 and inflation will mean the final figure in today's money could easily be in excess of €13bn, €7900/kW or $8600/kW.

The losses made by Areva NP on the fixed price contract were a significant factor in Areva's financial collapse.

4.1.2. France

The final investment decision to buy the Flamanville 3 EPR was taken by EDF in 2005 with construction starting in 2007 when completion was expected in 2012 at a cost of €3.2bn. By March 2024, the plant was not yet complete and a recent target to start loading fuel in March 2024 will not be met so commercial operation is unlikely before 2025. EDF's most recent cost estimate was €13.2bn

[36] An expression of intent was made by India to buy six EPRs (Jaitapur) in 2009 but while EDF still mentions this project, no contracts have been signed and it seems unlikely the project will go ahead.

[37] Nuclear Intelligence Weekly 'End In Sight After Settlement on €11.4 billion-Plus OL3' March 16, 2018, pp 4-5

(2015 money).[38] There will be additional costs after start-up because the reactor vessel lid did not meet specification and will have to be replaced. In 2024 money, the cost based on the current estimate would be about $17.2bn or $18.7bn, $11,300/kW.

4.1.3. China

China signed contracts to buy two EPRs (Taishan site) in 2007. Construction started in 2009/10 and took nine years. Costs are not known but are thought be about 60% over-budget. Unit 1 was off-line for a year in 2021 and again for nearly a year in 2023 due to design issues that do not appear to have been fully resolved yet.

4.1.4. UK

The UK signed contracts to build two EPRs at Hinkley Point C in 2016, although site work had started in 2013. Construction started in 2018/19 when completion was expected in 2025 at a cost of £18bn (2015 money). The most recent estimates forecast completion forecast completion in 2029-32 at a cost of £31-35bn (2015 money). In current money, this equates to £40.5-45.6bn or $51.4-57.9bn or $15,600-17,500/kW. With at least 5-7 years of construction left, it would be against all experience with the EPR if further significant cost increases did not occur.

4.1.5. Is the EPR an option?

What is noticeable about EPR construction is that, despite claims that learning will reduce costs, real costs have risen substantially with each successive project. The forecast cost of Hinkley Point C is about double the cost of Olkiluoto and about 50% more than Flamanville[39] despite the project appearing not to have gone so badly as its predecessors. If there is learning, it has increased, not decreased the cost of an EPR.

There is a plan to build two more EPRs in the UK at the Sizewell site but no final investment decision has been taken. France effectively abandoned the EPR as an option for France in 2010 when a report commissioned by the French government and headed by a former President of EDF, Francois Roussely, into the problems at Olkiluoto and Flamanville reported:[40]

> "The complexity of the EPR comes from design choices, notably of the power level, containment, core catcher and redundancy of systems. It is certainly a handicap for its construction, and its cost. These elements can partly explain the difficulties encountered in Finland or Flamanville.' He recommended: 'The EPR should therefore be further optimised based on feedback from reactors under construction and past achievements. This optimisation would be led jointly by EDF and Areva, in conjunction with ASN, with a view to make the detailed design as safe [as the current design]."

In 2022, a former CEO of EDF, Henri Proglio said: "The EPR is too complicated, almost unbuildable. We see the result today."[41]

Efforts to modify the design were started in 2010 resulting in the EPR-2 design. The French regulator has said that in principle the design might be licensable but the cost-savings have been made at the expense of safety features, for example, the replacement of a double wall containment with a single-wall containment. It remains to be seen whether the French regulator will give approval to EPR-2 without significant modifications.

France plans to build six EPR-2s with the first not complete until 2037 and EDF has said it will not try to market the design until a reactor is operating in France. In practical terms, this means the EPR-2 will

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[38] https://www.edf.fr/sites/groupe/files/2024-03/annual-results-edf-2023-presentation-2024-03-04.pdf

[39] The fact that two reactors are being built at Hinkley Point compared to only one at Olkiluoto and Flamanville should mean costs per reactor would actually be lower

[40] https://www.neimagazine.com/news/newsnei-translates-roussely-report-into-english

[41] https://www.nuclearpolicy.info/news/a-mature-design-or-junk-edf-plan-for-sizewell-c-continues-to-rely-on-controversial-epr-reactor/

not be orderable until around 2040 assuming the plans are carried through so the only Framatome option would be EPR, a design that has invariably gone horribly wrong in construction

There is also a scaled down version of the EPR, EPR1200, for export markets such as the Czech Republic and Poland. However, this is based on a scaled down version of EPR-2 so would be no less of a risk than EPR-2 until the design is proven and its costs known.

If there was a call for tenders for South Africa, it remains to be seen whether Framatome would bid and if it did, whether it would offer EPR or EPR-2. The record of the former is uniformly appalling while the latter is unproven and South Africa would be taking the risk of building an unproven design.

4.2. Westinghouse

The Westinghouse design, AP1000 (1170MW), has won eight orders, four in the USA and four in China.

4.2.1. USA

Four orders were placed for this design around 2010, two each for the Vogtle and Summer sites. Construction started in 2013/14 with completion expected in 2017/18 but by 2017, construction had gone so badly wrong in terms of time and cost that the Summer project was abandoned.[42]

Vogtle has fared little better. The first unit was declared commercial in July 2023 and the second unit went critical in February 2024. The initial expected cost of the two units was $14bn but is now expected to be in excess of $30bn.[43] This is probably mixed money but if we assume this is 2024 money, which equates to $12,800/kW.

In 2015, after the threat of legal action, Westinghouse was forced to offer a fixed price contract to complete the plant. Within a year, it was clear this was a gross underestimate and as a result, Westinghouse filed for bankruptcy. It was bought by a Canadian venture capital company, Brookfield.

4.2.2. China

Four AP1000 orders were placed in 2007 for China, Sanmen and Haiyang, with construction starting in 2009/10 and taking nine years to commercial operation. Costs are known to have overrun significantly but there is no authoritative cost data in the public domain.

4.3. Korea

The Korean design, APR1400, 1340MW, offered by a subsidiary of the state-owned electric utility, Korean Electric Power Co, has won ten orders, six for Korea and four for the UAE. The design is based on a design licensed from Westinghouse, the System 80+. Korea claims the APR1400 is its own intellectual property but Westinghouse disputes this. If KEPCO tried to bid in South Africa, there would be likely to be a dispute between Westinghouse, likely backed by the US government, and KEPCO about whether KEPCO had the right to sell the reactor.

4.3.1. Korea

Four reactors of this design are operating in Korea having taken 8-11 years of construction. Two reactors have been under construction for 6-7 years. No authoritative figures on their costs have been published. The reputation of the Korean nuclear industry was seriously damaged by the discovery in 2012 of systematic falsification of quality control documentation.

4.3.2. UAE

In 2009, UAE won an order for four APR1400s in the first time KEPCO had competed for export orders. The price was remarkably low, $20bn for the four, or about $31.2bn in 2024 money, $5.800/kW.

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[42] https://www.chooseenergy.com/news/article/failed-v-c-summer-nuclear-project-timeline/

[43] https://www.nucnet.org/news/new-us-nuclear-plant-reaches-first-criticality-commercial-operation-scheduled-for-second-quarter-2-3-2024

As this was a first, and only attempt so far by KEPCO, to win export orders, there are suspicions that the bid was far from being economic and was unrealistic. Construction started in 2012-15 with the first three reactors completed in 2021, 22, 23 with the fourth under construction still in March 2024.

4.3.3. Design issues

After the UAE tender, the CEO of Areva NP, Anne Lauvergeon, described the APR1400 as like a car without seat-belts or air-bags.[44] The basis for this statement was that the reactors lacked design features that would be essential to meet European safety standards, in particular, protection against impact by aircraft and a core-catcher. Aircraft protection arises from the 9/11/ terrorist attack and reactors in Europe and USA must be designed to withstand a large civil airline flying into it. The need for a core-catcher (or comparable system) arises from the Chernobyl disaster and it is meant to ensure that in a core melt-down, the core is retained in the core-catcher and does not contaminate the environment. KEPCO has acknowledged the need to add these systems for European markets and is modifying the design, but this has yet to be assessed by an experienced and credible safety regulator and the cost is not known, although it is clear the additional features will represent a significant addition to the cost.

4.4. China

There are three Chinese reactor vendors, CGN, CNNC and TNPG. These companies are allocated export market countries and they do not compete with each other. South Africa appears to have been allocated to TNPG in previous attempts to launch a nuclear programme. China has been attempting to export reactors for the past decade, but apart from two unrepresentative exports to Pakistan, with no success. It therefore has effectively no experience in countries outside China.

The Nuclear Power Group (TNPG) was set up to build AP1000s in China under license to Westinghouse. While there has been talk of it offering reactors for export, e.g., to Turkey, it has not won any orders. TNPG has been developing a scaled-up version of the AP1000, the CAP1400 which it has claimed was about to start construction in China for the past decade. There are reports that two reactors of this design have been under construction in China (Shidaowan Bay) since about 2018. However, these are based only on satellite images of the site and China has not confirmed to the IAEA that reactors are under construction on this site much less what design they are.[45]

TNPG claims the CAP1400 and its version of the AP1000, the CAP1000 are its intellectual property but Westinghouse disputes this. Choosing CAP1000 or CAP1400 would therefore be likely to lead to a trade dispute between USA (backing Westinghouse) and China.

China General Nuclear (CGN) and China National Nuclear Co (CNNC) have developed their own versions of essentially the same design, HPR1000, previously known as Hualong One. CNNC has built two reactors of a predecessor design in Pakistan but little is known about these reactors.

Three reactors of the HPR1000 design are in operation in China with eleven more under construction. China claims the design meets all requirements of European regulators and the CGN version did complete a thorough design review in the UK with a view to it being built at the Bradwell site. However, due to security concerns about CGN,[46] the project was effectively abandoned in 2021 well before construction started. Other countries, such as Czech Republic and Poland, have specifically excluded China from its list of potential suppliers.

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[44] Nucleonics Week 'No core catcher, double containment for UAE reactors, South Koreans say' April 22, 2010
[45] https://www.world-nuclear.org/reactor/default.aspx/SHIDAOWAN-2
[46] https://www.ft.com/content/9601ebda-bf24-11e9-b350-db00d509634e

5. Finance

In the past, obtaining finance for nuclear projects was not a problem at least for strong utilities in countries with good credit ratings. Nuclear projects have always been economically risky, but the risk fell on consumers because utilities were able to pass on whatever costs they incurred to consumers who had no choice but to pay.

Now, as utilities are exposed to competition and tougher economic regulation, nuclear projects are seen by financiers and utilities as extremely risky ventures. As a result, utilities will only consider nuclear projects if they have very full financial guarantees, usually provided by government (i.e., taxpayers). Similarly, financiers will only risk lending to nuclear projects if the debts to them are guaranteed.

National governments are increasingly the ones driving nuclear programme as the only entities with the financial credibility and integrity to underwrite them with taxpayer and consumer money. Investor money is seldom if ever risked begging the question why should the public take on risk that no commercial entity would go near?

In an attempt to restart its stalled nuclear power programme, the UK is hoping to utilise its Regulated Asset Base (RAB) model. Under this, consumers would pay the finance charges for the reactor during the construction phase as a surcharge on their bills long before the first kWh is generated and the price paid for the electricity produced will be whatever it takes to generate enough income to pay the plant owners (expected to be institutional investors such as pension funds and sovereign wealth funds) the income they are guaranteed to receive. So, consumers will be bearing the risk of cost and time overruns and the risk of poor reactor performance while the owners face no risks. If they did face any significant risk, an investor such as a pension fund could not justify investing.

6. Timescales and cost

Nuclear programmes are invariably based on hugely optimistic estimates of cost and timescale from a policy decision to pursue new projects to first power. All experience in the past two decades suggests that this period is of the order of 20 years. The initial phase from policy announcement includes identifying sites, establishing which technologies to pursue, and reviewing designs to ensure they meet national requirements. This takes about five or more years. The next phase is: to review the sites chosen in detail to ensure they are suitable, for example, with vulnerability to sea-level increases, water supply and seismicity; conduct some form of technology choice, for example, a call for tenders or bi-lateral negotiations; and identify financing choices. The end point of this process would be a final investment decision when binding contracts are signed and this phase might again take several years.

Once a final investment decision is taken, equipment has to be tendered and bought, a workforce mobilised and site preparation undertaken so that the site is ready for first structural concrete for the reactor, the conventional point marking start of construction. This phase is likely to take at least two years to complete. The final stage is from start of construction to commercial operation. This phase is well documented, for example, in the IAEA PRIS database.[47] Nuclear advocates frequently claim this phase should take no more than five years, but in practice, it seldom if ever is done this quickly and in the past two decades, most projects have taken 10 or more years. If we add these phases up, it can be seen that assuming less than 20 years from policy announcement to first power would be highly optimistic and against al recent experience.

In its back-up documents to legislation to allow the RAB finance mechanism, the UK government cited research it had commissioned (published in 2015) that suggested the time from final investment

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[47] https://pris.iaea.org/PRIS/home.aspx

decision to commercial operation was typically in the range 13-17 years. It also found that the outturn cost was typically 20-100% more than the estimate at the time of final investment decision.[48]

7. Small Modular Reactors

7.1. Introduction

For the past decade, there has been increasing levels of propaganda about Small Modular Reactors (SMRs). They are expected to be modular and largely factory-built so that on-site work is largely assembly of modules. It is claimed: this will make them cheaper and easier to build; they will be less prone to cost and time overruns and easier to finance; they will be safer, melt-down proof, walk-away safe and produce less waste (per kW of capacity) than large reactors; being smaller, there will be less opposition to their siting; and they will create large numbers of new jobs.

As a result of this publicity, the impression is that large numbers of SMRs are being ordered around the world. These claims are unproven or misleading or simply wrong. No modern design SMR is operating, only three prototype SMRs are under construction (China, Russia, India). No current design has completed a full safety review by an experienced & credible regulator. Until this is done, it will not be known if the design is licensable or what the costs would be. No design of SMR is commercially available to order yet.

7.2. What are SMRs

SMR covers such a wide range of sizes and technologies that the term is effectively meaningless. The International Atomic Energy Agency (IAEA) defines SMRs as reactors with an output of 30-300MW. Smaller reactors, less than 30MW are called micro-reactors but these are not relevant for grid supply and are proposed only for isolated facilities or communities without strong grid access. They are not considered further here.

SMRs can be divided into two categories:

- Smaller versions of the World's dominant reactor types: Pressurised Water Reactors (PWRs like Koeberg) & Boiling Water Reactors (BWRs), known collectively as Light Water Reactors or LWRs.
- Advanced Modular Reactors (AMRs): Technologies pursued for more than 50 years, but only built as prototypes or demonstration reactors, for example, Fast Breeder Reactors. The record of these plants is poor. There are other technologies that have been long talked about but never built (e.g., Molten Salt Reactors).

Advanced Modular Reactors are unlikely to be commercially available until after 2040 if ever. The Generation IV International Forum[49], which South Africa is a member of, was set up in 2001 to promote development of AMRs when it expected these designs to be available around 2025. Their latest estimate is that they will not be commercially available at earliest until around 2050. High Temperature Gas-Cooled Reactors (like the Pebble Bed Modular Reactor (PBMR) that South Africa pursued for more than 20 years) are often seen as the nearest to commercial deployment. However, in 2022, the UK government's assessment was:

> "BEIS [the then UK Energy Ministry] are not currently aware of any viable fully commercial proposals for HTGRs that could be deployed in time to make an impact on Net Zero by 2050."[50]

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[48] https://publications.parliament.uk/pa/bills/cbill/58-02/0174/ImpactAssessment.pdf
[49] https://www.gen-4.org/gif/jcms/c_9492/members
[50] https://assets.publishing.service.gov.uk/media/63f8c312e90e0740d2e5a745/advanced-modular-reactor-rdd-competition-phase-b-guidance.pdf

The PBMR was under development in South Africa for more than 20 years but when it was abandoned in 2010, there was still no complete design. A reactor using the same German technology was built in China. It took 11 years from construction start to commercial operation in December 2023. The reactor went critical in 2021 but was in testing for two years. It is too early to know if it will generate reliably but there are no firm orders to build more reactors of this design in China or elsewhere.

AMRs are therefore not considered further.

7.3. LWR SMRs

There are seven LWR SMR designs on which significant development work has taken place. These are:

1. Westinghouse AP300 (PWR, 300MW), announced in May 2023.
2. GE-Hitachi BWRX-300 (300MW), announced in 2019.
3. Holtec SMR-300 (300MW), announced in 2010.
4. NuScale VOYGR (77MW), under development since 2005.
5. Rolls Royce SMR, PWR 470MW, under development since 2017.
6. Framatome NuWard, PWR, twin reactors of 170MW each, under development since 2019 but still described by Framatome as 'conceptual' and first reactor not expected to be ordered before 2029.
7. CNNC (China) ACP100 PWR (100MW). Demonstration plant under construction in China since 2021.

With the exception of the NuScale design and the Chinese designs (see below) the PWR & BWR SMR designs are at least at least 300MW and the Rolls Royce design is 470MW. These designs are likely to increase in size as they are further developed to improve their economics. For example, the Holtec design was known as SMR-160 from 2010 but in 2023, after 13 years of development as a 160MW reactor, with little publicity, Holtec doubled the size of the reactor and renamed it SMR-300. The NuScale design started at 35MW and in five steps, it has increased in output to 77MW. This means the rhetoric of small reactors that can be easily sited with much less stringent siting and safety requirements is misleading. They are usually expected to be built in clusters of at least three reactors on a site making the site capacity at least 1000MW and needing as stringent requirements as a large reactor site.

The NuScale design is often seen as the frontrunner among SMRs because of the two decades of development that has gone into it and because of substantial US Federal government subsidies. However, its one solid order prospect, the *Utah Associated Municipal Power Systems* (UAMPS) collapsed in December 2023 despite being offered several billion dollars in Federal subsidies, because of continually rising expected costs. Since then, the company has downsized its staff by 28% and it is not clear whether the company will survive. The NuScale design is often claimed to have received safety approval from the US safety authorities (in 2021). However, this was for a 50MW design and by the time approval was given, this design had been abandoned and scaled up to 55MW, then 60MW and most recently (2021) to more than 50% more than the approved design to 77MW. A new review was started in 2023 and will be substantive as some design issues had not been resolved when approval was given.

Some designs claim improved safety by use of passive safety systems – in an accident, natural processes rather than engineered systems control the reactor. Some are 'integral' designs - all the major systems are contained in the reactor vessel, not just the reactor. Some reactors would be built underground and housed under water to improve their safety. The assumption that all SMRs have these features is wrong and, for example, the Rolls Royce design has none of these. While these safety features sound superficially attractive, they raise different safety issues to existing designs and until they are reviewed in detail by an experienced and competent safety authority and evaluated in practice, it will not be clear whether these really are improvements.

7.4. *Scale economies/diseconomies*

At the heart of the claims for SMRs is the assertion that building reactors smaller will reduce costs per kW of capacity. The size of reactors has consistently increased since the 1960s when reactors were typically 500MW or less. The nuclear industry tried to counter poor economics by seeking intuitively plausible scale economies – a 1000MW reactor vessel weighs less and costs less than 5 x 200MW reactor vessels. Claimed savings from factory manufacture, and modularisation will have to more than counter lost scale economies.

The question that needs to be asked is whether large reactors are difficult to build because they are large or because they are complex? Why would small reactors be less complex (and therefore easier to build) than large ones unless safety features were significantly cut back?

However, being cheaper than large reactors is not enough to make nuclear power competitive. SMRs have to be cheaper than the cheapest low-carbon options if they are to make a cost-effective contribution to reducing emissions of greenhouse gases.

7.5. *Production lines and modularisation*

The rhetoric for SMRs suggests a Model T Ford image of identical equipment being made on a rolling production line like car manufacture. This is misleading, for example, the planned Rolls Royce production lines would produce only 2-4 reactors per year. Production lines are expensive to set up and inflexible. They are only cheap if fully loaded and the high cost of setting them up can be recovered over a large number of units of output. If there is not a full order book, they must be closed or mothballed. If the design needs to be changed, there will be expensive retooling costs

Rolls Royce wants to make its first reactor on a production line to prove the economics because if the first reactor is not produced on a production line, the economics of production line units will not be known. However, if production lines are set up, before the first kWh of electricity is generated, even if only two reactors are produced per year, at least another 10-12 reactors will be in various stages of manufacture. This makes opting for an SMR a huge gamble on the design being economically and technically viable. All reactors require a mix of factory work and on-site assembly. The claim for SMRs is more correctly simply that the balance is more towards off-site work than for large reactors made in the traditional way.

Note also that the Westinghouse AP1000 large reactor has many of the features of SMRs: it is said to be modular and largely factory produced; and safety systems are passive (AP stands for Advance Passive). This has not prevented all projects to build them going badly wrong with severe cost overruns and delays.

While suppliers often promise local production facilities providing local jobs, the reality is that costs will only be low if a minimum number of production facilities are set up, most likely in the vendor’s home country.

7.6. *Waste and Safety*

All things equal, a small LWR will create more waste than the same capacity of large reactors. Alison Macfarlane (former Nuclear Regulatory Commission Commissioner) calculated that SMRs will increase the volume & complexity of waste by a factor of 2-30, for example through greater neutron leakage.[51]

On safety, as argued above, it is not established whether the new safety features proposed for some SMRs will necessarily improve safety. The main issue, seldom explicitly addressed, is whether small reactor designs will be licensable without the safety features required for large reactors. If the same safety features are required, it is hard to see why SMRs would be anything but more expensive per unit of capacity than large ones.

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[51] https://www.pnas.org/doi/10.1073/pnas.2111833119

7.7. Employment

Nuclear reactors require large numbers of workers during the construction phase, typically having specific skills unlikely to be found in the local region and these workers may come from abroad. Jobs typically last only a year and this is very disruptive to the local area requiring large amount of short-term accommodation and facilities.

If SMRs are cheaper and quicker to build than large reactors, they will create less work and over a shorter period. If factories with production lines are efficient, they will require fewer workers than other methods of producing nuclear power plants. As argued above, these factories are more likely to be in the home country of the reactor vendor than in the customer's country.

An operating reactor requires few permanent staff. Operators require highly specific skills unlikely to be found among the local population.

7.8. Conclusions on SMRs

Reactor vendors always overstate how close to availability designs are. No SMR design has completed a comprehensive safety review anywhere in the world. It will be more than two years before the first review is complete and the cost more firmly established. It would be reckless to order an SMR until safety approval had been given.

Producing new reactor designs is risky, expensive and takes a long time as South Africa found with its attempt to develop the PBMR. NuScale's only serious order prospect collapsed after 20 years' work development work on the design and $1bn spent including large amounts of US public money. Traditional vendors do not have the funds to develop a new design without strong assurance of orders. Westinghouse and Framatome are emerging from bankruptcy. Scaling down existing designs is a cheaper way to produce SMR designs. For example, the Westinghouse AP300 is a scaled down AP1000 (1170MW) and the GE-Hitachi BWRX-300 is a scaled down ESBWR (Economic Simplifies Boiling Water Reactor), a design that was, despite its name, so expensive it was never offered for sale. However, given the original large designs are uneconomic, why would smaller ones be better and why would they be less complex?

Whether commercially available SMR designs will emerge is unclear but they are clearly a long time behind large designs in development and committing significant resources to them now would be a speculative and risky strategy that, given the climate emergency, countries can ill afford.

8. Conclusions

Nuclear programmes are often based on exaggerated claims made by promoters of the project. The programme is costed on as the basis of what the expected cost of the 'next' reactor will be. The assumption is that we will have learned from mistakes and the 'next' project will go to plan and to time and cost. Such forecasts have invariably hopelessly underestimated the cost: mistakes are repeated and new mistakes made. A much more reliable indicator is the cost of the 'previous' project, perhaps with some addition as the trend in the real cost of nuclear power plants has been upwards throughout the history of the nuclear industry. If we take the mean value of the four projects for EPRs and AP1000s where costs are known, it is about $12,000/kW or R230,000/kW in 2024 money.

It must be stressed the information given here on nuclear projects in the past two decades is not a selection of the worst performing projects, it represents ***all*** the projects. All the nuclear projects in countries where reliable information is available have gone very badly wrong. Government policies launching new nuclear programmes are invariably based on an assumption that in this country these mistakes would be avoided. If countries with long and extensive nuclear histories such as USA, France, UK, and Finland have not been able to avoid appalling performance, what basis is there for a less experienced country to assume they will do far better?

Forecasts of reactor costs made by reactor vendors, governments and utilities ahead of an investment decision are essentially worthless. For example, in the UK government White Paper of 2008 that launched the most recent UK nuclear programme, the government assumed a reactor such as the EPR would cost £2bn.[52] The latest cost estimate for Hinkley is about £22bn with only a small amount of the difference accounted for by inflation. The follow-on project, Sizewell C, also for two EPRs, was recently estimated as taking £3.5bn just to get to a final investment decision.

For the past 50 years, when governments have launched nuclear power programmes, they have sometimes acknowledged past issues. However, they have claimed that a combination of new designs that will overcome safety and economic issues with past designs, learning from past experience and errors, standardisation of designs, cutting administrative red-tape, streamlining planning and regulatory processes and series ordering. These rather general prescriptions seemed credible in the past, but their promises have never been realised. Even in France, which series ordered 58 reactors in a 15-year period in the 1970s and 1980s, real costs significantly rose over time.[53]

Around 2000, there was propaganda from the nuclear industry about a 'Nuclear Renaissance' driven by new reactor designs such as EPR, AP1000 and APR1400, so-called Gen III+, which could be built in 3-4 years and would cost $1000/kW. The outcome is that real costs are far higher than in the past, and cost and time overruns are the largest they have ever been, about 10 times the claimed cost and a construction time of 10-18 years.

There is a great deal of publicity about Small Modular Reactors with claims they will solve the problems of past technologies, being cheaper, quicker and easier to build, will have improved safety and will be easier to site. These claims are based on some highly dubious assumptions. At best, SMR designs are perhaps a decade behind large reactor designs in development terms and relying on them as any more than a long-term possibility would be reckless.

Ambitious nuclear programmes are seldom realised failing because of high cost. The problem is therefore not so much that large numbers of hopelessly uneconomic reactors will be built, it is the 'opportunity cost' of wasting a decade or more on an option bound to fail at the expense of options that are financially more attractive, much less prone to failure and much quicker to implement. The alternative, of renewables and improved energy efficiency, would require a very different electricity transmission and distribution system. A nuclear dominated system would require long transmission lines form remote nuclear power sites to centres of demand. A renewables dominated system would depend much more on a strengthened distribution system with the transmission system more for back-up.

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