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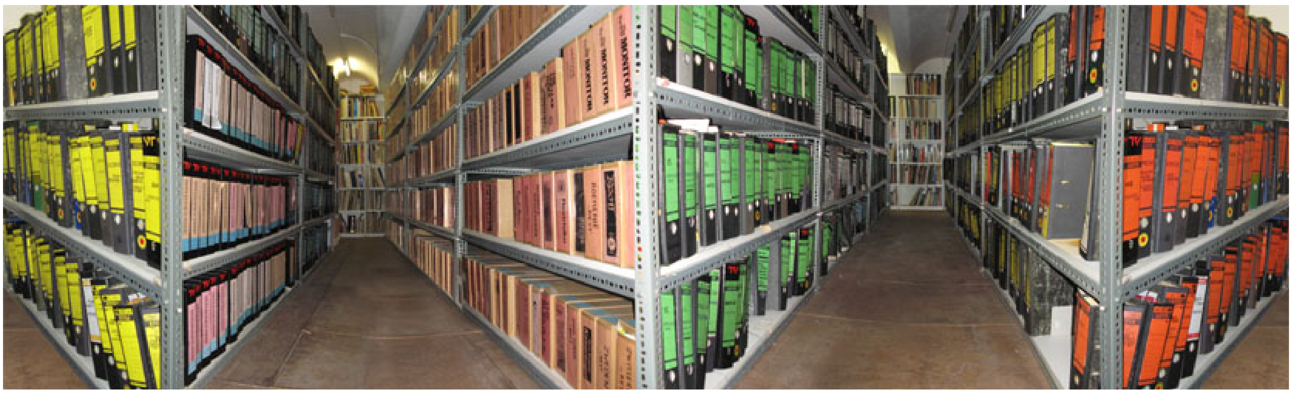

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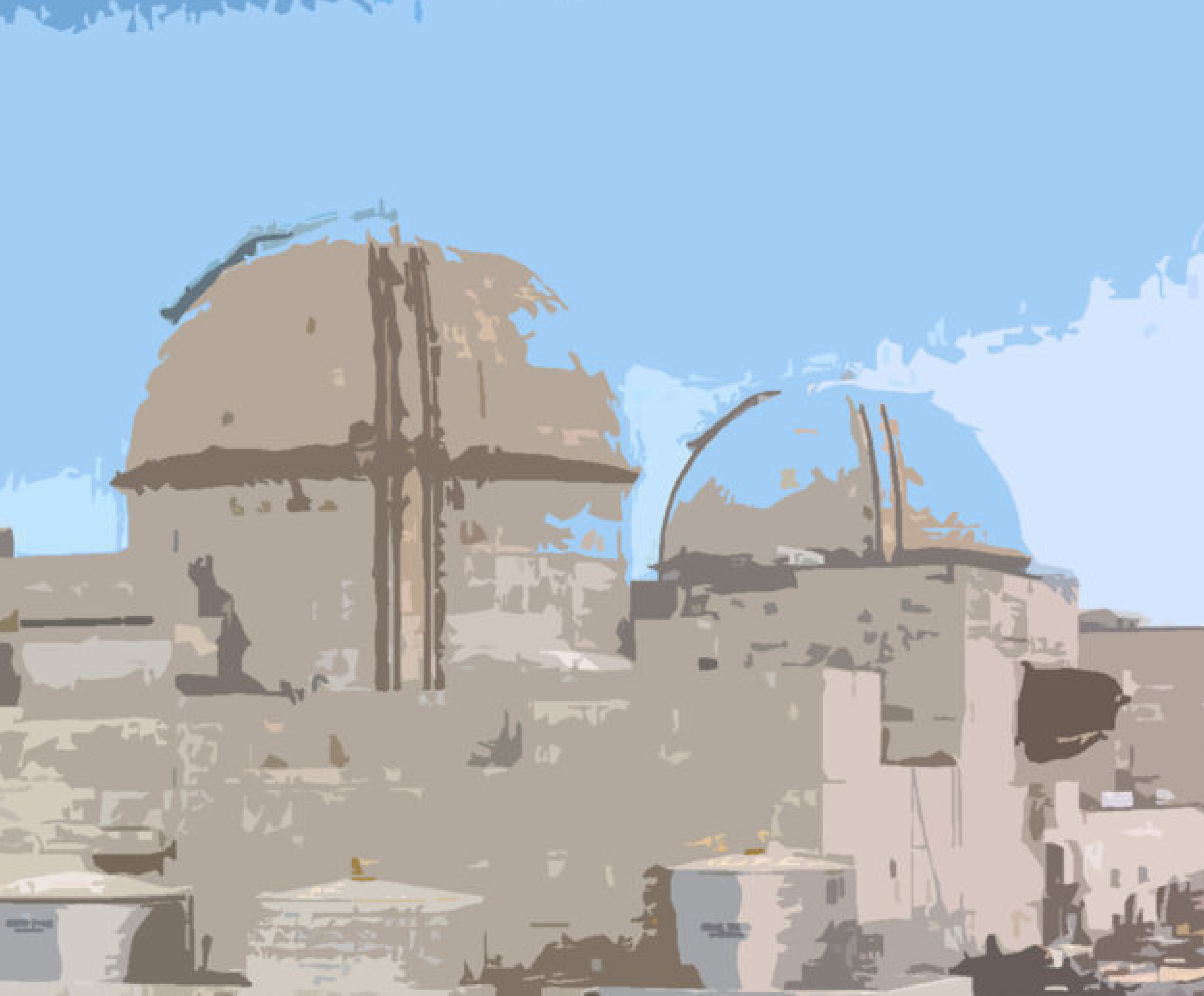
Gulf Nuclear Ambition:
New Reactors in United Arab Emirates

Dr Paul Dorfman



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Contents

1. Introduction

Four nuclear reactors are under construction in the Dhafra Region of Abu Dhabi, United Arab Emirates (UAE). The nuclear power plant is named Barakah – Arabic for *Divine Blessing*.

The Barakah nuclear plant is being built by the South Korean reactor supplier Korea Electric Power Corporation (KEPCO) and the Emirates Nuclear Energy Corporation (ENEC), in a consortium with Korea Hydro & Nuclear Power (KHNP), Hyundai Engineering & Construction, Samsung C&T, and Doosan Heavy Industries & Construction, with the UAE's Federal Authority for Nuclear Regulation providing regulation.[1] The South Korean government has a majority financial holding in KEPCO/KHNPC, and has provided loan guarantees for the Barakah project.

Yet less than a decade after Barakah broke ground, the UAE contract remains South Korea's one and only export order – with KEPCO and its subsidiary KHNP unable to replicate the Abu Dhabi contract elsewhere, despite major initiatives in Lithuania, Turkey, Vietnam and the UK.[2] Meanwhile, the Emirates are building the world's largest concentrated solar power plant, capable of generating 700 megawatts. During daylight, solar will provide electricity costing a fraction of nuclear, at night the UAE will exploit concentrated solar power, deploying stored solar heat to generate electricity.[3] So why have the Emirates invested in 4 new nuclear reactors, will their operation further destabilise the volatile Gulf region, and what are the key safety, security, and environmental risks?

2. APR1400 Reactor

The Korean nuclear corporation KEPCO's APR1400 pressurised water reactor began development in 1992, and the basic design was established in 1999. The reactor core is made for an operating cycle of 18 months with a discharge burnup as high as 60,000 MWD/MTU – with the uranium rods staying in the reactor longer and burned at a much higher temperature than in conventional reactors. The core consists of 241 fuel assemblies built up by fuel rods containing uranium dioxide fuel with an average enrichment of 2.6 w/o in a 16x16 array, and up to 30% of the APR1400 core can be loaded with mixed oxide (MOX) fuel with minor modifications. Each fuel assembly consists of 236 fuel rods.[4,5]

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1. NS Energy (2019) : *Barakah Nuclear Power Plant*, Abu Dhabi, NS Energy https://www.nsenergybusiness.com/projects/barakah-nuclear-power-plant-abu-dhabi/
2. Chaffee P. (2019) : *Newbuild Report*, Nuclear Intelligence Weekly (NIW), August 30 2019.
3. Masdar Institute/IRENA (2015) : *Renewable Energy Prospects: United Arab Emirates*, REmap 2030 analysis. IRENA, Abu Dhabi. https://www.irena.org/remap
4. Han-Gon Kim : *The Design Characteristics of Advanced Power Reactor 1400*, IAEA-CN-164-3S09: https://pub.iaea.org/MTCD/Publications/PDF/P1500_CD_Web/htm/pdf/topic3/3S09_Hangon%20Kim.pdf
5. Kok K.D. (2017): *Nuclear Engineering Handbook*, CRC Press, Taylor and Francis, New York, Oxford. 6. Nucleonics Week (2010) : *No core catcher, double containment for UAE reactors, South Koreans say*, April 22, 2010.

3. Reactor Safety

KEPCO's winning bid for the construction of the UAE reactors was spectacularly low, about 30% lower than the next cheapest bid. Nuclear reactor design has evolved, but since Korea Hydro & Nuclear Power (KHNP) – a subsidiary of KEPCO – realised that the cost of key improved safety design features would make the APR1400 less competitive, they chose not to include them. Having done so, KEPCO was able to dramatically undercut its competition for the UAE bid, with the Chief Executive of the French nuclear corporation Areva, Anne Lauvergeon, comparing the Korean reactor to *a car without airbags and seat belts*.[6]

The Emirates have published extensively in support of their view that they have made a conscientious and systematic effort to implement fully the obligations of the International Atomic Energy Agency (IAEA) Convention on Nuclear Safety Treaty.[7] Yet KEPCO acknowledge their Barakah reactor design doesn't contain, arguably essential, features such as either additional reactor containment or a 'core-catcher' – both of which are design features normally expected in all new nuclear reactors in Europe. The decision not to include additional defence in the Barakah reactor containment building is important, since this is a feature designed to defend against significant radiation pollution release in the event of an accidental or deliberate large airplane crash, or military attack.[8] Particularly worrying is the lack of a core-catcher which, in the event of a failure of the emergency reactor core cooling system, would catch the core if it breached the reactor pressure vessel. For these and other reasons, the reactors being constructed at Barakah do not meet the criteria for more advanced Generation III+ nuclear plant.[9]

4. Reactor Containment

Christer Viktorsson, director general of the UAE's Federal Authority for Nuclear Regulation has admitted that cracks in the reactor containment building for No. 3 reactor were first

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6. Nucleonics Week (2010) : *No core catcher, double containment for UAE reactors*, South Koreans say, April 22, 2010.

7. Govt. of the United Arab Emirates (UAE) (2016) : *UAE National Report*, For the 7th Review Meeting of the Convention on Nuclear Safety, Prepared by the Government of the United Arab Emirates in fulfilment of Article 5 of the Convention on Nuclear Safety for submittal to the 7th Review Meeting of Contracting Parties: https://www.iaea.org/sites/default/files/uae_nr-7th-rm.pdf

8. On balance, the likelihood is that a commercial-sized airliner crashing onto the Barakah single shell primary containment may prove likely to result in at least localised through-rupture, if not catastrophically collapse part or much of the containment shell.

9. Generation III+ designs offer significant improvements in safety over Generation III reactor designs. Gen III+ reactors comprise all new reactors under construction in the EU and the US. The Gen III+ APR1400 reactor design features improved safety and a core damage frequency an order of magnitude lower than that calculated for the UAE APR1400 design.

discovered at Barakah in 2017. In October 2018, Abu Dhabi's Emirates Nuclear Energy Corporation (ENEC) publicly acknowledged concrete cracking in the containment buildings of two of the four reactors at Barakah. ENEC's reluctance to reveal any details speaks volumes about the transparency of the Barakah new-build.[10] Subsequent examination was conducted on the containment buildings for the Nos. 1, 2, and 4 reactors, and cracks were found in all of them.[11]

Although these sets of cracks are now undergoing repair, it's not a simple problem. A similar issue was detected in Unit 4 of the Hanbit Nuclear Power Plant in Yeonggwang, South Jeolla Province, South Korea – pointing to an underlying quality control issue which imply future safety concerns.[12] South Korea's low rate of nuclear power output over the past two years has been due to the repair of cracks and corroded plates resulting from poor construction in the past, with similar issues likely at Barakah.

5. Pilot Operated Safety Relief Valve

The reactor's Pilot Operated Safety Relief Valve is designed to protect the pressurizer against overpressure – but in the APR1400, when the valve is opened, cooling water has leaked during start-up. This fault in key equipment in the first operating APR1400, and in other APR1400s under construction in both South Korea and the UAE, casts a spotlight on the ability of the Korean nuclear corporation to maintain quality standards, and on the relative capacity of the Emirates to provide adequate nuclear regulation.[13] Given the importance of nuclear safety, these giant valves should normally be redesigned and replaced ahead of reactor operation at Barakah – but they have not.

6. Nuclear Quality Control

Construction in Korea of the first two units of the APR1400 design was first delayed due to the discovery of large-scale falsification of quality control documents for more than 2000 nuclear components.[14] In 2012, Korean Hydro and Nuclear Power (KHNP), a subsidiary of KEPCO, began investigations into illegal activity among the South Korean nuclear corporation's parts

10. Cooke S. and Klaus O. (2018) : *Newbuild : Has Barakah Lost it's magic ?* Nuclear Intelligence Weekly.
11. Ha-yan C. (2018) : *KEPCO undergoes repairs for cracks in nuclear reactor containment buildings in UAE* Oct.17, 2018, Hankyoreh. http://www.hani.co.kr/arti/english_edition/e_business/866228.html
12. Ha-yan C. (2018) : *Cracks found in containment building of UAE nuclear power plant built by S. Korean companies*, Hankioreh, Dec.17, 2018 http://english.hani.co.kr/arti/english_edition/e_international/874728.html
13. Cooke S. (2019): *Safety: Shared POSRV Nightmares for KHNP and Enec*, Nuclear Intelligence Weekly.
14. Kwon K.J. (2012) : *South Korea shuts down 2 nuclear reactors after parts scandal*, CNN World: https://edition.cnn.com/2012/11/05/world/asia/south-korea-nuclear-reactors/

suppliers, later evolving into a formal criminal investigation. Prosecutors discovered that thousands of parts had been installed in South Korean nuclear reactors, backed up with forged safety documents.[15] By 2014, the KHNP inquiry had escalated into a far-reaching investigation of corruption, collusion, and forgery. 68 people were sentenced, and the courts dispensed a cumulative 253 years of jail time. Guilty parties included KHNP president Kim Jong-shin, a KEPCO life-time employee, and President Lee Myung-bak's close aide Park Young-joon. Perhaps this may help to explain why South Korea is dismantling its nuclear industry, shutting down older reactors and scrapping plans for new ones, with state energy companies being shifted toward renewables.[16] It's important to note that several faulty parts were also installed in the UAE plant, and Neilson-Sewell, the Canadian advisor to Barakah, stated that *the Emirates had lost complete faith in the Korean supply chain*.[17]

7. Construction Time-Line

When construction started, the first Barakah reactor was expected to come online in 2017, then delayed until 2018. In 2018 ENEC estimated that Unit 1 will only come online in late 2019 or early 2020.[18] Whilst no reason has been given for ENEC's latest postponement, it seems reasonable to suggest that sets of safety and quality-control related construction issues, the lack of experienced nuclear workers, and shortage of trained staff may have substantially contributed to this construction over-run.[19]

These problems have been compounded by a deepening feud between Korea Hydro & Nuclear Power (KHNP) and ENEC – following the former's unilateral decision to replace its workforce – with ENEC's CEO Mohamed Al Hammadi sending a letter to KEPCO CEO Kim Jong-kap, noting *the severity and the critical risk of a unilateral decision taken by KHNP to withdraw critical expert resources away from Barakah*.[20] Here, it's important to stress the key role of normal functional technical dialogue between nuclear regulators and operators[21] in contrast to the quality assurance, staffing and related safety issues that obtain at Barakah.

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15. Ju-min Park (2013) : *South Korea charges 100 with corruption over nuclear scandal*, Reuters World News: https://www.reuters.com/article/us-korea-nuclear/south-korea-charges-100-with-corruption-over-nuclear-scandal-idUSBRE99905O20131010
16. Kim M.S. (2019) : *How greed and corruption blew up South Korea's nuclear industry*, MIT Technology Review, April 22, 2019. https://www.technologyreview.com/s/613325/how-greed-and-corruption-blew-up-south-koreas-nuclear-industry/
17. Kim M.S. (2019) (ibid.)
18. Nuclear Engineering International (2018) : *More delays for UAE's Barakah project*, NEI, 6 July 2018: https://www.neimagazine.com/news/newsmore-delays-for-uaes-barakah-project-6233083
19. Cooke K. (2019) : *Spectre of Chernobyl hangs over Middle East's nuclear ambitions*, Middle East Eye, Mar 22, 2019. https://www.middleeasteye.net/opinion/spectre-chernobyl-hangs-over-middle-easts-nuclear-ambitions
20. Hyun-woo, N. (2019) : *'Nuclear feud' deepens between Korea*, UAE, Biz & Tech, Apr 3, 2019 : http://www.koreatimes.co.kr/www/tech/2019/04/693_266552.html
21. Rolina G. (2017) : *Human and Organizational Factors in Nuclear Safety*, CRC Press, Taylor and Francis, New York/Oxford.

8. Nuclear Proliferation

The Gulf region faces unique challenges and perceived opportunities when it comes to nuclear power. The tense geopolitical environment makes nuclear power an even more controversial issue in the region than elsewhere. Gulf states are concerned that neighbours might use their civilian nuclear programs for military ends.[22,23] It's not that nuclear military interests are sole drivers of support for civil nuclear power, but dual-use technology may comprise a significant complementary factor.[24]

There are a large range of safety and security concerns that should be taken into consideration in curtailing the potential for a Gulf nuclear arms race.[25] Unless enrichment of uranium and reprocessing technologies are effectively regulated against diversion of civil materials for military purposes, the reality is that new nuclear power plants can provide the cover to develop and make nuclear weapons.[26] Whether that capability is turned into actual weapons depends largely on political inclination,[27] and Saudi officials have made it clear on more than one occasion that there is another reason for their interest in nuclear energy technology which was not captured by the royal decree on the Saudi nuclear program – the relationship of the civil program to nuclear weapons.[28]

In 2017, the Saudi Kingdom sent a Request for Information to international suppliers to build two nuclear power plants, and a parallel set of agreements has been signed for the Korean KAERI design Small Modular Reactor (SMR). An important motivation for the Kingdom's interest in SMRs may be allied to the consequent high level of nuclear technology and

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22. Nakhle C. (2016) : *Nuclear Energy's Future in the Middle East and North Africa*, Carnegie Middle East Centre : https://carnegie-mec.org/2016/01/28/nuclear-energy-s-future-in-middle-east-and-north-africa-pub-62562
23. Egozi A. (2019) : *Israel Meets with UAE, Declares it's Joining Persian Gulf Coalition*, Breaking Defence : https://breakingdefense.com/2019/08/israel-meets-with-uae-declares-its-joining-persian-gulf-coalition/
24. Stirling A and Johnson P (2018) : *Interdependencies Between Civil and Military Nuclear Infrastructures*, SPRU Working Paper Series, 2018-13, SPRU - Science Policy Research Unit, University of Sussex Business School : http://www.sussex.ac.uk/spru/newsandevents/2018/findings/nuclear_infrastructures
25. Mason R. and Bahgat G. (2019) : *Civil Nuclear Energy in the Middle East: Demand, Parity, and Risk*, The Arab Gulf States Institute in Washington, April 11, 2019 : https://agsiw.org/wp-content/uploads/2019/04/Mason_Bahgat_Civil-Nuclear_ONLINE-1.pdf
26. Diesendorf M., Broinowski R. (2019) : *Is the push for nuclear power a covert push for nuclear weapons?*, Renew Economy : https://reneweconomy.com.au/is-the-push-for-nuclear-power-a-covert-push-for-nuclear-weapons-95422/
27. Law B. (2018) : *Saudi Arabia and the high-stakes nuclear game*, Middle East Eye. https://www.middleeasteye.net/opinion/saudi-arabia-and-high-stakes-nuclear-game
28. Murphy A., Ramana M.V. (2019) : *The Trump administration is eager to sell nuclear reactors to Saudi Arabia. But why?* April 16, 2019, Bulletin of Atomic Scientists : https://thebulletin.org/2019/04/the-trump-administration-is-eager-to-sell-nuclear-reactors-to-saudi-arabia-but-why/

knowledge transfer into Saudi Arabia.[29] This should be set in the context of the announcement, that Saudi may plan to enrich uranium in the future to fuel its proposed nuclear power programme – with Saudi's energy minister openly noting that enrichment opens up the possibility of military proliferation.[30] Although Saudi's statement was apparently the first public remark by an official expressing a move towards enrichment, it's hardly news to US government officials negotiating the Nuclear Co-operation Agreement. As a former high-level US State Department official noted: *I have not heard them say out loud 'We want to pursue enrichment to have a nuclear weapons option,' but I think it's fairly clear that is on their minds*.[31]

9. Enrichment

Although the UAE has agreed to implement fully the obligations of the IAEA Convention on Nuclear Safety in developing their programme for the peaceful uses of nuclear energy,[32] there remains the possibility that the Emirates may also decide to pursue advanced nuclear fuel cycle capabilities, leading to further risk of military proliferation. One issue will be the fate of separated plutonium, and whether overseas reprocessing will encourage the UAE to use plutonium-based fuels at Barakah. These fresh plutonium-bearing mixed oxide (MOX) fuels, pose a more serious proliferation risk than spent fuel or low enriched uranium fuels,[33] and up to 30% of the Barakah APR1400 reactor cores can be loaded with MOX fuel with minor modifications.

Here it's worth noting that ENEC has just renewed its Memorandum of Understanding on nuclear fuel cycle management, with Techsnabexport (Tenex), a subsidiary of the Russian state nuclear corporation, ROSATOM. The World Nuclear Association have confirmed that

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29. Ramana M.V., Ahmad A. and Salameh R. (2019) : *Localising Nuclear Capacity ? Saudi Arabia and Small Modular reactors*, Energy Policy and Security Program, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut : http://www.aub.edu.lb/ifi/Documents/publications/working_papers/2018-2019/20190708_localising_nuclear_capacity_KSA.pdf

30. El Gamal R., Cornwall A. (2019) : *Saudi Arabia flags plan to enrich uranium as U.S. seeks nuclear pact*, Reuters, Business News. https://www.reuters.com/article/us-energy-wec-saudi-nuclearpower/saudi-arabia-wants-to-enrich-uranium-for-nuclear-power-minister-idUSKCN1VU168

31. Nuclear Intelligence Weekly (2019) : *Perry to Meet Saudi's New Energy Minister on Monday*, Vol. 13, No. 37 : https://www.energyintel.com : September 13, 2019.

32. Govt. of the United Arab Emirates (UAE) (2016) : *UAE National Report*, For the 7th Review Meeting of the Convention on Nuclear Safety, Prepared by the Government of the United Arab Emirates in fulfilment of Article 5 of the Convention on Nuclear Safety for submittal to the 7th Review Meeting of Contracting Parties: https://www.iaea.org/sites/default/files/uae_nr-7th-rm.pdf

33. Technical Review Middle East (2019) : *ENEC and TENEX renew MoU for nuclear fuel cycle solutions*, Technical Review Middle East, 12 Sept 2019: http://www.technicalreviewmiddleeast.com/business-a-management/business-a-management/enec-and-tenex-renew-mou-for-nuclear-fuel-cycle-solutions

Tenex will also provide 50% of Barakah's enrichment capability, worth some $500 million,[34] indicating or further facilitating the emergence of a potential back-channel for the Emirates to obtain advanced nuclear fuel cycle technologies.[35]

Because of the risk of nuclear proliferation in the Middle East, it seems reasonable to suggest that nuclear suppliers should commit not to supply the UAE enrichment or reprocessing capabilities. Correspondingly, it may prove wise for intelligence capabilities to monitor any UAE efforts to draw back on its commitment not to acquire advanced fuel cycle capabilities, and look for signs as to whether the Emirates may be carrying out research on weaponisation. Further, although the UAE is a signatory of the Non Proliferation Treaty, and has ratified IAEA Safeguards Agreements, the Institute for National Security Studies suggests that there remains a risk that the Emirates could share its knowledge with other countries that are not bound to a non-proliferation regime, including Turkey and Jordan.[36]

10. Nuclear Security

In case of accidents and incidents, and in order to function at any level, nuclear power needs stability and co-operation between neighbouring states.[37] However, as recent military strikes against Saudi oil refineries infer,[38,39] the Gulf region is one of the world's most volatile.[40,41,42] In the case of the UAE, nuclear safety revolves around the broader issue of security, especially since some armed groups may view UAE military operations as a reason to target nuclear

34. World Nuclear Association (WNA) (2019): *Nuclear Power in the United Arab Emirates*, WNA, 12 June 2019: https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx

35. Burkhard S., Wenig E., Albright D., and Stricker A. (2017) : *Nuclear Infrastructure and Proliferation Risks of the United Arab Emirates, Turkey, and Egypt*, Institute for Science and International Security : https://isis-online.org/uploads/isis-reports/documents/Middle_East_Proliferation_Assessments_25Aug2017_Final.pdf

36. Guzansky Y. (2018) : *Nuclear Development in the Arabian Peninsula: The United Arab Emirates – A Harbinger of Things to Come?* Institute for National Security Studies : https://www.inss.org.il/publication/nuclear-development-arabian-peninsula-united-arab-emirates-harbinger-things-come/

37. Volders B., Sauer T. (2017): *Nuclear Terrorism: Countering the Threat*, Routledge Global Security Studies, Routledge, London and New York.

38. Financial Times (2019) : *The Saudi oil attack*, FT Collection: https://www.ft.com/content/2665799e-dad2-11e9-8f9b-77216ebe1f17

39. McLeary P. (2019) : *NATO's not ready for Saudi-style drone attacks; It's a serious problem*, Air Warfare, Land Warfare, Breaking Defence: https://breakingdefense.com/2019/09/natos-not-ready-for-saudi-style-drone-attacks-its-a-serious-problem/

40. Associated Press, The Guardian (2019) : *Major Saudi Arabia oil facilities hit by Houthi drone strikes*, Sept 2019 : https://www.theguardian.com/world/2019/sep/14/major-saudi-arabia-oil-facilities-hit-by-drone-strikes

41. Shane D., Kerr S. (2019) : *'State actor' was behind attacks on oil tankers, UAE tells UN*, Financial Times, Middle Eastern Politics and Society : https://www.ft.com/content/017ca012-88d4-11e9-a028-86cea8523dc2

42. Binnie J. (2019) : *Yemeni rebels claim second cruise missile attack*, Military Capabilities, London - Jane's Defence Weekly : https://www.janes.com/article/89233/yemeni-rebels-claim-second-cruise-missile-attack

installations, or intercept enriched uranium fuel or waste transfers nationally or regionally.[43] Such back-draft from foreign policy and politics more generally, will increasingly dovetail with regional nuclear safety considerations.[44]

A potential nuclear terrorist attack may be one of several types. There are two main targets in a nuclear power station for a terrorist attack: the reactor itself and the ponds storing the spent fuel removed from the reactor. An attack on the reactor could cause the core to go critical or cause a loss of the coolant that removes heat from the core of the reactor.[45] Perhaps disconcertingly, Yemeni rebels have already claimed to have fired a missile at the Barakah nuclear power plant site in 2017.[46] UAE subsequently denied the claim, insisting it had an air defence system capable of dealing with any threat.[47] Yet the protection of the UAE nuclear plant with fighter aircraft or surface-to-air missiles may not be an easy task, and time available to scramble fighter aircraft or fire surface-to-air missiles may prove limited, as recent events in Saudi seem to indicate. Thus, terrorist activity in the Middle East has heightened concern about the need to better secure high-risk radioactive material,[48,49] including risk of attack, sabotage or hijack to a transporter of nuclear material.

11. Nuclear Transport

A significant increase in the maritime transport of radioactive materials into and through the Arabian Gulf will occur once Barakah begins operation. Maritime transports will include uranium hexafluoride through to finished fuel rods, radioactive waste, and irradiated nuclear fuel (INF). High level waste (HLW) and INF 3 [50] cargo will travel out of the region. HLW,

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43. Dubowitz M., Sokolski H. (2019): *The ultimate Middle East missile target: Nuclear reactors*, Washington Examiner, Oct 22: https://www.washingtonexaminer.com/opinion/the-ultimate-middle-east-missile-target-nuclear-reactors

44. Mason R. and Bahgat G. (2019) : *Civil Nuclear Energy in the Middle East: Demand, Parity, and Risk*, The Arab Gulf States Institute in Washington, April 11, 2019 : https://agsiw.org/wp-content/uploads/2019/04/Mason_Bahgat_Civil-Nuclear_ONLINE-1.pdf

45. Barnaby F., Kemp J. (2007) : *Too Hot to Handle ? The Future of Civil Nuclear power*, Oxford Research Group : https://www.files.ethz.ch/isn/43709/07-07%20Too%20Hot%20to%20Handle.pdf

46. SCMP (2017) : *Missile fired at UAE nuclear power plant, say Yemen rebels*, SCMP : https://www.scmp.com/news/world/middle-east/article/2122676/yemen-rebels-claim-fire-missile-uae-nuclear-power-plant

47. Almosawa S., Erdbrink T. (2017) : *U.A.E. Denies Yemen Rebels Fired Missile at Abu Dhabi Nuclear Plant*, New York Times : https://www.nytimes.com/2017/12/03/world/middleeast/yemen-houthi-missile-abu-dhabi.html

48. United States Government Accountability Office (2019) : *Report to Congressional Committees, Combating Nuclear Terrorism, NRC Needs to Take Additional Actions to Ensure the Security of High-Risk Radioactive Material*, April, 2019.

49. Pomper M.A., and Tarini G. (2017): *Nuclear terrorism – Threat or not?* AIP Conference Proceedings 1898, 050001 (2017); https://doi.org/10.1063/1.5009230 : https://aip.scitation.org/doi/pdf/10.1063/1.5009230

50. Organised Maritime Internationale : *International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes on Board Ships*, INF Code: http://www.imo.org/fr/OurWork/Safety/Cargoes/Containers/Pages/Default.aspx

intermediate level waste, and low level waste will require storage in the Emirates – presenting major terrestrial and maritime target potential, whether directly intended or un-intentional.[51]

Incidents involving nuclear transport ships can include collision, ramming, grounding, fire and explosion, foundering, equipment and material failure, and as a result of hostile action. Such incidents can occur in ports and approaches and at sea. The very high forces during collision or ramming events may be sufficient to breach nuclear waste flask containment and, if followed by fire, the sustained temperatures involved could result in a significant airborne release of radioactivity, with the fire plume simultaneously providing an efficient dispersal mechanism by which a very significant radioactive release could be delivered directly to a human population.[52]

12. Desalination Risk

The Gulf region is one of the most water-scarce in the world. With few freshwater resources and low rainfall, many Gulf states rely on desalination, where salt is removed from seawater. The Middle East has 70% of the world's desalination plants – mostly in Saudi Arabia, the United Arab Emirates, Kuwait, and Bahrain. Saudi Arabia leads the world in the production and consumption of desalinated water, with an estimated SR91bn ($24.3bn) of expansion plans in the pipeline until 2020.[53]

The 250,000 sq km Gulf is more like a salt-water lake than a sea. It's shallow, just 35 metres deep on average, and almost entirely enclosed. The few rivers that feed the Gulf have been dammed or diverted and the region's hot and dry climate results in high rates of evaporation. With groundwater sources either exhausted or non-existent and climate change bringing higher temperatures and less rainfall, Gulf states plan to nearly double the amount of desalination by 2030.[54] Given the clear and present danger of radioactive sea-water pollution following an accident or incident at Barakah, it follows that all Gulf desalination plants (and, hence, Gulf state drinking water) would be at significantly increased risk.

Further, over recent decades there has been a distinct increase in 'red-tide' algal bloom in the Gulf. Since de-salination plants across the sea area have experienced prolonged outages due

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51. Deere-Jones T. (2019) : *Marine environmental factors and the impacts of a planned UAE NPS on the various water body sub-compartments of the Persian Gulf*, Nuclear Consulting Group Briefing Report, https://www.nuclearconsult.com/wp/wp-content/uploads/2019/09/UAE-marine-and-nuclear-TD-J-A4.pdf

52. Large J. (2007) : *Review – The Sea Transportation of Irradiated Fuel by SKB, Part II, Sea Transportation of Spent Fuel – Frequency of Accidents*, Report Ref No r3028-a1.

53. Oxford Business Group (2015) : *Saudi Arabia expands its desalination capacity*, Oxford Business Group: https://www.oxfordbusinessgroup.com/analysis/world-leader-efforts-under-way-expand-desalination-capacity

54. Leahy and Purvis (2016) : *Peak salt: is the desalination dream over for the Gulf states?* The Guardian, https://www.theguardian.com/global-development-professionals-network/2016/sep/29/peak-salt-is-the-desalination-dream-over-for-the-gulf-states

to clogging of intake filtration systems by red-tide algae biomass accumulation,[55] similar outages may be expected at Barakah.

13. Marine Ecosystem

The sub-compartments of the Arabian Gulf are widely identified as slow-flushing sea areas.[56] Whilst some Gulf surface waters have a flushing time-scale of more than 3 years, surface waters in the southern sector of the Gulf, including Kuwaiti, Saudi, Qatar and UAE sectors, have a longer flushing time of 5+ years. The highly saline and dense bottom waters of the Gulf have a flushing time of *circa* 6 years.[57] The Gulf is an unusually shallow sea area, and the UAE coastal territorial waters are some of the shallowest areas of the Gulf, with less than 20 metre depth area extending a long way seaward.[58] Thus, both normal operational radioactive discharges and pollution from accidents or incidents at Barakah would remain in the Gulf marine environment for a considerable time period.

Marine radioactive discharges from Barakah nuclear power plant will include a broad cocktail of at least 60 radionuclides, with half-lives ranging from the short to the very long. Liquid discharges won't be steady-state, but will be 'pulsed' with wide fluctuations in intensity and time-scale. Many of the liquid radioactive discharges, including tritium, will be soluble – leading to risk of both radioactive transport and incorporation into mudflats in interstitial water.[59]

Since caesium-137 has a half-life of 30 years, radionuclide pollution following any accident or incident would comprise a significant pollution threat, particularly in deep sediment, as would strontium-90, which has a half-life of *circa* 28 years. Plutonium-239, due to its high density and half-life of 24,100 years, would be transported in more complex ways, persisting in deep sediment for millennia.[60]

The UAE coast is notable for fairly dense areas of both eel grass and mangrove – and coastal lagoon, eel grass and mangrove environments represent a crucial ecosystem, comprising an

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55. Michlen et al (2010) : *The catastrophic 2008-2009 red tide in the Arabian gulf region, with observations on the identification and phylogeny of the fish-killing dinoflagellate Cochlodinium polykrikoides*, Harmful Algae. 9(2): 163-172. February 2010, Harmful Algae, 9(2):163-172 · February 2010 DOI: 10.1016/j.hal.2009.08.013
56. Kämpf J., Sadrinasab M. (2005) : *The circulation of the Persian Gulf: a numerical study*. Ocean Science Discussions, European Geosciences Union, 2005, 2 (3), pp.129-164. hal-00298403
57. Deere-Jones T. (2019) : *(ibid.)*
58. Sadrinasab M. & Kampf J. (2004) : *Three Dimensional Flushing Times of the Persian Gulf*. Geophysical Research Letters (Oceans): https://doi.org/10.1029/2004GL020425
59. Deere-Jones T. (2019) : *(ibid.)*
60. Kamyab A., Azad M.T., Sadeghi M., Akhound A. (2018) : *Dispersion Simulation of Cesium-137 Released From a Hypothetical Accident at the Bushehr Nuclear Power Plant in Persian Gulf*, International journal of Coastal and Offshore Engineering, IJCOE Vol.2/No. 3/Autumn 2018 (13-17) : http://ijcoe.org/browse.php?a_code=A-10-137-3&sid=1&slc_lang=en

important nursery and juvenile area for a very large range of Gulf marine life, including those species that support human life. UAE's extensive mangrove habitats grow on and in coastal fine sediments and mudflats. Such sedimentary environments are notable for their ability to sequester a range of pollutants including radioactivity, and it's widely understood that fine sediment deposits act as a 'sink' for the concentrations of such pollutants which increase and concentrate over time.[61]

When suspended in the water column, fine clay organic particles provide material onto which radionuclides can adsorb; leading to both long-range transport through the water column, and eventual re-concentration in deposition and accretion sites distant from the discharge point. During periods of rapid deposition and incorporation, sedimentary adsorbed pollutants may also be sequestered in sedimentary deposits where – isolated from sunlight, oxygen and biological activity – they remain as an un-degraded toxic source to be released if those sediments are disturbed by storm action, tidal surge, and seismic event. Since maritime transport of sea-discharged radionuclides is well understood to extend to many hundreds of miles out from the point-source of the pollution, discharge of radioactive materials from the 4 PWRs at Barakah will inevitably lead to a human dietary dose from sea foods.[62]

Sea-to-land transfer of marine radioactivity – via coastal flooding during storm surges, super tides, and via marine sea spray and aerosols – has been shown to extend at least 10 miles inland from coast lines, and to generate both human inhalation and dietary doses.[63,64,65] Therefore any accident involving either a Fukushima type LOCA (loss-of-coolant accident) escape-to-sea of reactor coolant, cooling pond waters or emergency cooling waters; or Chernobyl type wash-out or fall-out of aerial plume material onto sea surface, presents a significant risk – with consequent impact on area-wide fisheries, tourism, and public health.[66]

14. Nuclear Risk

There are a number of distinct radiological hazards at a nuclear power station, including fission products and activated inventory of the reactor fuel and core, the irradiated fuel store, and radioactive wastes. Operational nuclear plant hazards can be broadly grouped as follows: nuclear reactors, irradiated fuel storage ponds, radioactive waste stores and

61. Deere-Jones T. (2019) : *(ibid.)*
62. Deere-Jones T. (2019) : *(ibid.)*
63. Eakins J.D. et al (1982): *Studies of Environmental Radioactivity in Cumbria Part 5 : The Magnitude and Mechanisms of Enrichment of Sea Spray with Actinides in West Cumbria*, United Kingdom Atomic Energy Agency (UKAEA), Harwell.
64. Isles C.G., et al (1991) : *Body concentration of Caesium 137 in patients from Western Isles of Scotland*. British Medical journal (BMJ): June 29: 1991.
65. Ould-Dada, Z. (2000) : *Sea to land transfer of radio nuclides. How much do we know?* Proceedings 2nd Radrem-Tesc Workshop. London: Jan 21.1999. DETR/RADREM/00.001 DETR London.
66. Deere-Jones T. (2019) : *(ibid.)*

treatment plants, irradiated fuel transportation, and new fuel delivery.[67] Consequently, the risk to people and the environment as a result of a major accident or incident is very significant. However, because accidents can be triggered by processes which a nuclear reactor is not designed to withstand, fault conditions can cascade. With its failure to plan for the cascade of unexpected 'beyond design-base' accidents,[68] the regulation of nuclear risk has proven limited.

Because of their complexity and the physical conditions during reactor operation, understanding of reactor design and operation can only be partial. Since levels of reliability required for a complex interactive and tightly coupled nuclear power plant are very great, sets of combined impacts at Barakah have the capacity to trigger serious environmental, human health, economic, institutional and political consequences.[69] Additionally, as system components and external events can interact in unanticipated ways, it is not feasible to predict all possible failure modes, particularly for beyond design-base accidents.

Key to the analysis of nuclear safety is probabilistic risk assessment (PRA). Risk in a PRA is defined as a feasible detrimental outcome of an activity or action. In a PRA, risk is characterised by two quantities: the magnitude (severity) of the possible adverse consequence, and the likelihood (probability) of occurrence of each consequence. But PRA has proven structurally limited in its ability to capture the consequences of a beyond design-based cascading nuclear accident. This means that chain-of-event fault-tree PRA models cannot account for the indirect, non-linear, and feedback relationships common for major accidents in complex nuclear engineering systems.[70]

Nuclear power plants are vulnerable to unforeseen external events or through human or engineering based fault conditions, including accidental or deliberate harm. Accidents are by nature accidental, and the cost of ignoring this common-sense axiom can prove radiologically catastrophic.[71] The reality is that a major nuclear accident is always possible and, unfortunately, far from unlikely.[72] Here, it's unsettling to reflect that, for example, all UK civil

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67. Large J. (2005) : *A Review of Offsite Emergency Planning for Nuclear Power Plant*. Report, 2005.

68. Examples of beyond design-base accidents include: Three Mile Island, Chernobyl, and Fukushima.

69. Dorfman P., Fucic A., Thomas S. (2013) : *Late lessons from Chernobyl, early warnings from Fukushima*, In : *Late lessons from early warnings: science, precaution, innovation*, European Environment Agency. EEA Report No 1/2013 : https://www.eea.europa.eu/publications/late-lessons-2

70. Dorfman P. (2020) : *A Long Goodbye to the Nuclear Monument*, In : *Handbook of Managing Fossil Fuels and Energy Transitions*, Wood G., Baker, K. (Eds.), Palgrave MacMillan, forthcoming, 2020 : https://www.palgrave.com/gp/book/9783030280758

71. Stirling, A. (2011) : *Neglected Nuclear Lessons*, STEPS (Social, Technological and Environmental Pathways to Sustainability). University of Sussex: https://steps-centre.org/climate-change-and-energy/japan-neglected-nuclear-lessons/

72. Downer J. (2015) : *The unknowable ceilings of safety: Three ways that nuclear accidents escape the calculus of risk assessments*. In Taebi, B. & Roeser, S. (eds.) (2015) *The Ethics of Nuclear Energy: Risk, Justice and Democracy in the Post-Fukushima Era*. Cambridge University Press: 35-52.

nuclear infrastructure are uniquely implicated in all four 'Tier 1 Threats' identified in the UK National Security Strategy.[73]

This is important because, given Barakah is situated in a volatile region with high human activity-related hazards, there are broader concerns – and a major accident or incident at the Barakah would have significant trans-boundary consequences. In order to facilitate preparedness and emergency response planning on national and regional levels, it is imperative to assess risks from atmospheric and marine dispersion of radioactivity from potential accidents and incidents at the UEA nuclear plant.[74,75] However, to date, no detailed information has been made publicly available.

Correspondingly, in a recent letter from Qatar's foreign affairs ministry to IAEA Director General Yukiya Amano; Qatar reported that a radioactive plume from an accidental discharge from Barakah could reach its capital in five to thirteen hours, and a radiation leak would have a devastating effect on the region's water supply because of its reliance on desalination plants. Perhaps reasonably, Qatar is also concerned that *lack of any international cooperation with neighbouring states regarding disaster planning, health and safety and the protection of the environment, pose a serious threat to the stability of the region and its environment*.[76,77]

15. Nuclear Liability

The cost of major nuclear accident or incident in the Gulf would be significant. A recent cost estimate for the accident at Chernobyl, based on an extensive review of the literature, places the liability at US$700 billion.[78] Recent cost estimates for the Fukushima accident by the Japan Center for Economic Research is *circa* YEN 35 trillion – YEN 81 trillion ($315 billion and $728

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73. HMG (Her Majesty's Government) (2010) : *A Strong Britain in an Age of Uncertainty: The National Security Strategy*, Presented to Parliament by the Prime Minister, October 2010, Cm. 7953, Stationery Office, London.

74. Theodoros Christoudias T., Proestos Y., and Lelieveld J. (2014) : *Atmospheric Dispersion of Radioactivity from Nuclear Power Plant Accidents: Global Assessment and Case Study for the Eastern Mediterranean and Middle East*, Energies 2014, 7, 8338-8354; doi:10.3390/en7128338

75. Virgili N. (2019) : *Peer Review Service for Emergency Preparedness and Response Reaches 20 Year Milestone*, IAEA Department of Nuclear Safety and Security : https://www.iaea.org/newscenter/news/peer-review-service-for-emergency-preparedness-and-response-reaches-20-year-milestone

76. Al Jazeera (2019) : *Qatar: UAE nuclear plant threat to Gulf stability*, environment, 21 Mar 2019. https://www.aljazeera.com/news/2019/03/qatar-uae-nuclear-plant-threat-gulf-stability-environment-190320184348584.html

77. De Clercq, G. (2019) : *Qatar asks IAEA to intervene over 'threat' posed by UAE nuclear plant*, Reuters, Mar 20, 2019. https://www.reuters.com/article/us-qatar-emirates-nuclearpower-exclusive/exclusive-qatar-asks-iaea-to-intervene-over-threat-posed-by-uae-nuclear-plant-idUSKCN1R120L

78. Samet, J.M. and Seo, J. (2016) : *The Financial Costs of the Chernobyl Nuclear Power Plant Disaster: A Review of the Literature*. USC, 2016. https://uscglobalhealth.files.wordpress.com/2016/01/2016_chernobyl_costs_report.pdf

billion), compared with the government estimate of YEN 22 trillion.[79] Note, the current official estimate is a 58% rise from the previous one.[80] Thus, events at Chernobyl and Fukushima support the conclusion that reactor accidents prove the single largest financial risk facing the nuclear industry, far outweighing the combined effect of market, credit, and operational risks.

In Europe, the Paris and Brussels Conventions on Nuclear Third-Party Liability ensure that nuclear operators are now liable for the first €700 million of any one accident, with the national government concerned having the option to add a maximum of a further €500 million towards the nuclear corporation's liabilities. Collectively, other EU signatory states may contribute a further €300 million, potentially bringing the total available to €1,500 million for any one accident.[81]

Yet actuarial analysis estimates and costs from both Chernobyl and Fukushima accidents suggests that current EU level of cover will substantially fail to account for liability in case of major accident. Versicherungsforen Leipzig GmbH, a company that specialises in actuarial calculations, conclude that accident costs are not adequately internalised. Both the required liability (€6.09 trillion), based on an estimate of the average maximum damage and corresponding variance, and the resulting insurance premium, are significantly higher than the financial resources currently legally required in the EU. Versicherungsforen Leipzig estimated that future damage and liability insurance costs would exceed the financial resources currently required by several orders of magnitude. In this context, a nuclear disaster in the Gulf region seems uninsurable, due to a combination of methodological difficulties in estimating the probability of occurrence of damage, insufficient size of the risk pool, and the extent of potential maximum damage.[82] In the case of significant transboundary nuclear pollution, the question remains open as to whether 'victim' Gulf states would be able to take legal action against the country responsible.[83]

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79. Komori A. (2019): *Think tank puts cost to address nuke disaster up to 81 trillion yen*, Asahi Shimbun, March 10, 2019 : http://www.asahi.com/ajw/articles/AJ201903100044.html

80. Japan Times (2018) : *Estimated Cost of Fukushima Disaster Might Balloon to ¥218 Billion*, March 24, 2018. https://www.japantimes.co.jp/news/2018/03/24/national/estimated-taxpayer-cost-fukushima-nuclear-disaster-balloons-%C2%A5218-2-billion/

81. Paris Convention (2011) : *Protocols to Amend the Brussels Supplementary Convention on Nuclear Third-Party Liability*, No. 26, February, 2011.

82. Günther, B., Karau, T., Kastner, E.M. and Warmuth, W. (2011) : *Calculating a Risk-appropriate Insurance 924 Premium to Cover Third-party Liability Risks that Result from Operation of 925 Nuclear Power Plants*, Versicherungsforen Leipzig GmbH. 927 Leipzig, 1 April 2011.

83. Piguet F-P., Pierreii E., Knüsli C., Deriaz B., Wildi W., Giuliani G. (2019) : *Modeling of a Major Accident in Five Nuclear Power Plants From 365 Meteorological Situations in Western Europe and Analysis of the Potential Impacts on Populations, Soils and Affected Countries* : https://www.institutbiosphere.ch/wa_files/EUNUPRI-2019v01.pdf

16. Radioactive Waste

The four APR1400 nuclear reactors at Barakah will use a 'high burn-up' fuel regime – where the uranium rods stay in the reactor longer and are burned at a much higher temperature than in conventional reactors. But since the waste from the reactors will be significantly more radioactive than conventional spent fuel, this means that each cubic metre of high burn-up spent fuel will be significantly more toxic and generate significantly more heat than conventional spent nuclear fuel. Safety will depend on the effective and continuous removal of the significant thermal power of high burn-up spent fuel, requiring additional pumps, back-up electricity supplies and back-up water supplies: all systems vulnerable to mechanical failure or deliberate disruption. Also densely packed high burn-up spent fuel will need additional neutron absorbers, and greater radiation shielding during encapsulation and storage.[84]

UAE's plans for nuclear waste management are still 'emergent', involving the development of a national programme whilst exploring regional options, and continuing to work on a longer-term strategy.[85] In practice, spent nuclear fuel will build up on-site at Barakah, stored in reactor ponds for up to 20 years, or transferred to dry storage.[86]

High-level nuclear waste will remain very toxic for many hundreds of thousands of years, and the permanent disposal of nuclear waste remains a profound and, as yet, unresolved problem. Although there are plans for geological deep disposal for nuclear waste, and construction of geological disposal facilities are underway in Sweden and Finland, deep disposal remains unproven and no country has yet established permanent facilities for the disposal of high-level or intermediate-level radioactive waste, which continues to accumulate in temporary storage.[87,88]

17. Climate Change

The International Panel on Climate Change have just reported that extreme sea level events that used to occur once a century will strike every year on many coasts by 2050, whether

84. Alavarez A. (2016) : *The Downside of High Burnup Fuel, Nuclear Intelligence Weekly*, Vol. 10, No. 28.

85. Nasr J. and Ahmad A (2019) : *Middle East Nuclear Energy Monitor: Country Perspectives 2018*, Issam Fares Institute for Public Policy and International Affairs (IFI), Energy Policy and Security Program.

86. World Nuclear Association (WNA) (2019): *Nuclear Power in the United Arab Emirates*, WNA, 12 June 2019: https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx

87. Nakhle C. (2016) : *Nuclear Energy's Future in the Middle East and North Africa*, Carnegie Middle East Centre : https://carnegie-mec.org/2016/01/28/nuclear-energy-s-future-in-middle-east-and-north-africa-pub-62562

88. Heinrich-Böll-Stiftung (2019) : *World Nuclear Waste Report: Final disposal of nuclear waste confronts governments with incalculable technical, logistical, and financial risks*, Heinrich-Böll-Stiftung : https://worldnuclearwastereport.org

climate heating emissions are curbed or not.[89] This means that coastal nuclear power plant, such as Barakah, are increasingly vulnerable to sea-level rise, storm surge, tidal ingress, flooding of reactor and spent fuel stores, and nuclear islanding,[90] which, under many climate change scenarios, may well happen quicker than planned for.[91,92]

Perhaps alarmingly, the UK Institute of Mechanical Engineers (IME) point out that coastal reactors, together with radioactive waste stores including spent fuel, may need to be relocated.[93] In this sense, adapting coastal nuclear power, such as Barakah, to climate change may well entail significantly increased expense for decommissioning and radioactive waste storage.[94]

The low-lying nature of the UAE coastal zone emphasises the vulnerability of Barakah to climate change induced sea-level rise. Here, it's important to reflect that assessments of climate change sea level rise, storm surge, flooding, sea water temperature rise, thermal expansion, and increasing salinity in the Gulf proximal to Barakah are, as yet, conspicuous by their absence.[95]

The Gulf and, more specifically, the coastal waters of the UAE already have high sea surface and bottom water temperatures and the trend appears ever upwards. UAE waters are even more susceptible, due to shallow draft and slow flushing times. Gulf marine system exhibits severe oceanographic conditions – notably, the world's highest sea temperature with seasonal maxima between 34°C – 36°C, along with abnormal seasonal fluctuations of about 20°C, and hypersaline seawater. Thus, despite the installation of large heat exchangers and condensers, future global heating induced temperature regimes may contribute to increasingly reduced reactor cooling at Barakah.[96]

18. Nuclear Lock-in

The case for nuclear power in the Middle East has never been strong, and because Gulf state electricity systems are relatively small, significant nuclear electricity grid input risks overload

89. International Panel on Climate Change (IPCC) (2019) : *Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)*, IPCC, 25 Sept 2019 : https://www.ipcc.ch/report/srocc/
90. Vidal J. (2018) : *What are coastal nuclear plants doing to arrest climate change?* Ensia, https://ensia.com/features/coastal-nuclear/
91. Nerem R.S., Beckley B.D., Fasullo J.T., Hamlington B.D,. Masters D., and Mitchum G.T. (2018) : *Climate-change–driven accelerated sea-level rise detected in the altimeter era*, PNAS, 2018 115 (9) 2022-2025.
92. Kulp S.A., Straus B.H (2019) : *New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding*, Nature Communications, volume 10, Article number: 4844 (2019) : https://www.nature.com/articles/s41467-019-12808-z
93. IME (Institution of Mechanical Engineers) (2009) : *Climate Change: Adapting to the inevitable*, Institution of Mechanical Engineers, Westminster, London : https://www.imeche.org/policy-and-press/reports/detail/climate-change-adapting-to-the-inevitable
94. Kopytko N. and Perkins J. (2011) : *Climate change, nuclear power, and the adaptation-mitigation dilemma*, Energy Policy, Elsevier, vol. 39(1), pages 318-333, January.
95. Deere-Jones T. (2019) : *(Ibid.)*
96. Deere-Jones T. (2019) : *(ibid.)*

and blackouts – particularly troubling for the nuclear reactors at Barakah whose safe operation depends on a secure external electricity supply.

More importantly, market investment in nuclear power plant has proven to be uneconomic – this holds for all plausible ranges of investment costs, weighted average cost of capital, and wholesale electricity prices – with new nuclear only going ahead with very significant government subsidy. Nuclear investment generates significant financial losses, with the weighted average net present value around minus €4.8 billion. Even in the best-case scenario, the net present value of nuclear comprises *circa* minus €1.5 billion – including conservative assumptions with high electricity prices, low capital costs, and specific investment. Thus, considering all assumptions regarding uncertainty parameters, nuclear energy, to date, remains unprofitable.[97]

New nuclear power plants cost 2.3 to 7.4 times those of onshore wind or utility solar PV per kWh, and take 5 to 17 years longer between planning and operation.[98] So, nuclear energy seems to make limited economic sense for the Gulf states – and as desert kingdoms, they have some of the best solar energy resources in the world, with solar energy having both lower investment costs and lower generation costs than nuclear power.[99] Hence, the economic case for solar power in the Gulf states is hugely favourable.[100] For example, Saudi Arabia recently tripled its renewable energy target and has successfully tendered for large-scale projects in wind and solar energy,[101] with a consortium led by Saudi Arabia based ACWA Power lodging a world record low-price bid of $17 per megawatt hour for a 900 MW solar park in Dubai.[102]

Worldwide and in the Gulf, the fate of new nuclear is inextricably linked to, and determined by, renewable energy technology roll-out. And when considering only part of the nuclear life-cycle (construction, operation, plant dismantling), nuclear provides an average value of

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97. Wealer B., Bauer S., Göke L., von Hirschhausen C., and Kemfert C. (2019) : *High-priced and dangerous: nuclear power is not an option for the climate-friendly energy mix*, DIW Weekly Report: https://www.diw.de/documents/publikationen/73/diw_01.c.670581.de/dwr-19-30-1.pdf

98. Jacobson M. (2019) : *Evaluation of Nuclear Power as a Proposed Solution to Global Warming, Air Pollution, and Energy Security*, In : *100% Clean, Renewable Energy and Storage for Everything*, in press, Cambridge University Press: https://web.stanford.edu/group/efmh/jacobson/Articles/I/NuclearVsWWS.pdf

99. The 2018 Lazard estimate for the construction cost of a nuclear plant in the United States was over $9,000 per kilowatt and each megawatt-hour of electricity produced cost around $150. In contrast, a utility-scale solar plant in the United States would cost around $1,100 per kilowatt and each megawatt-hour of electricity would cost around $40: Lazard (2018) : *Levelized Cost of Energy and Levelized Cost of Storage 2018*, Lazard : https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

100. Murphy A., Ramana M.V. (2019) : *The Trump administration is eager to sell nuclear reactors to Saudi Arabia. But why?* April 16, 2019, Bulletin of Atomic Scientists : https://thebulletin.org/2019/04/the-trump-administration-is-eager-to-sell-nuclear-reactors-to-saudi-arabia-but-why/

101. Michael Safi (2019) : *How real is Saudi Arabia's interest in renewable energy?* The Guardian, 12.10.2019 : https://www.theguardian.com/environment/2019/oct/12/how-real-saudi-arabia-interest-renewable-energy

102. Institute for Energy Economics and Financial Analysis (2019) : *Solar Prices Fall to a new Record Low in Saudi Led Bid for 900 MW Dubai Project*: http://ieefa.org/solar-prices-fall-to-new-record-low-in-saudi-led-bid-for-900mw-dubai-project/

66 grams of CO_2 e/kWh – 20% of the emissions of a gas-fired power plant.[103,104] Thus, even without attempting to internalise the very great emission burden from radioactive waste management, nuclear is significantly more carbon intensive than renewable power.

Whilst lower CO_2 emissions and ramping improvement in renewable technology is one explanation for the dynamic fall in new nuclear, and the ramp in new renewable generation capacity, the main driver seems to be the plummeting costs of renewable energy and the increasing costs of nuclear construction.[105] As the International Energy Agency (IEA) reports: in terms of 2017 global output growth, solar increased by 35%, wind by 17%, and nuclear by only 1%.[106] This trend continued in 2018, with global renewable generation capacity seeing the largest annual increase ever, and new solar outstripping additions in coal, natural gas and nuclear.[107]

Correspondingly, the IEA concluded that a trillion watts of renewable power (1.3 terawatts) will be installed worldwide over the next five years – more than the entire current generation capacity of the EU – and by 2023, renewables will account for a third of total electricity generation worldwide. The European Bank for Reconstruction and Development have also stated that renewables are now the cheapest energy source, cost-competitive with fossil fuels, even taking into account effective fossil fuel subsidy.[108]

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103. Sovacool B.K. (2008) : *Valuing the greenhouse gas emissions from nuclear power: A critical survey, Energy Policy* 36 (2008): 2950–2963.

104. Wealer et al (2019) : *(ibid.)*

105. As Nobuaki Tanaka, former head of IEA and a long-standing nuclear advocate, noted: *“Nuclear power can’t compete with solar power”*, is *“ridiculously expensive”* and *“utterly uncompetitive”* : Asahi Shinbun (2018) : Ex-IEA official: Nuclear power can’t compete with solar power: http://www.asahi.com/ajw/articles/AJ201807240045.html

106. The International Energy Agency concluded that a trillion watts of renewable power (1.3 terawatts) will be installed worldwide over the next five years - more than the entire current generation capacity of the EU – and by 2023, renewables will account for a third of total electricity generation worldwide.

107. REN21 (2018) : *Renewables 2018 Global Status Report*, Paris: REN21 Secretariat. ISBN 978-3-9818911-3-3.

108. European Bank for Reconstruction and Development (EBRD) (2018) : *EBRD says renewables are now cheapest energy source*, ERBD : https://www.ebrd.com/news/2018/ebrd-says-renewables-are-now-cheapest-energy-source-.html

Conclusions

There remain significant questions about the relative safety of Barakah. Although nuclear reactor design has evolved, KEPCO, realising that the cost of key additional safety features would make their APR1400 too expensive, decided not to include them. So the Barakah nuclear plant design failed to up-grade reactor containment defence-in-depth – which is important, since the APR1400 reactor design may provide inadequate defence against significant radiation release in the event of 'fault conditions' such as accidental or deliberate airplane crash, or military attack. Particularly worrying also is the lack of a 'core-catcher' which, in the event of a failure of the emergency reactor core cooling system, would catch the core if it breached the reactor pressure vessel. Having omitted these costly additional safety features, the Chief Executive of the French nuclear corporation, Areva, compared the Barakah reactor design to *a car without airbags and seat belts*.

These omissions are compounded by the discovery of cracking in all 4 reactor containment buildings. Added to which, faulty Pilot Operated Safety Relief Valves have been installed, casting a spotlight on the ability of the Korean nuclear corporation to maintain safety standards, and on the capacity of the Emirates to provide adequate nuclear regulation. These concerns are further complicated by South Korean nuclear corporate large-scale falsification of quality control documents, resulting in a far-reaching criminal investigation – which may help to explain why South Korea is dismantling its nuclear industry, shutting down older reactors and scrapping plans for new ones, with state energy companies being shifted toward renewables. All this has meant that the first Barakah reactor start-up has been delayed from 2017, to 2018, and now 2019 or 2020.

The tense geopolitical environment in the Gulf makes nuclear a more controversial issue in this region than elsewhere, as new nuclear power provides the capability to develop and make nuclear weapons. It's worth noting that emergent back-channels exist which may facilitate Gulf states obtaining advanced nuclear fuel cycle enrichment technologies if the decision is made to pursue a military proliferation option. Hence, due to risk of regional nuclear proliferation, it may be prudent for international nuclear suppliers to commit not to supply Gulf states with enrichment capabilities. Correspondingly, it may prove wise for intelligence capability to monitor any potential efforts to renege on commitments to not acquire advanced fuel cycle capabilities and look for signs as to whether states are carrying out research on weaponisation, or plan to share nuclear technology knowledge with other countries that are not bound by a non-proliferation regime.

As recent military strikes against Saudi oil refineries infer, nuclear safety revolves around the broader issue of security – especially since belligerent armed groups may view UAE military operations as a reason to target nuclear installations or intercept enriched uranium fuel or waste transfers nationally or regionally. Such back-draft from foreign policy and politics more generally, will increasingly dovetail with nuclear safety considerations in the region. Perhaps disconcertingly, Yemeni rebels already claim to have fired a missile at the Barakah nuclear power plant site in 2017. UAE subsequently denied the claim, insisting it had an air defence system capable of dealing with any threat. Yet the protection of Barakah may not be an easy task, and time available to scramble fighter aircraft or fire surface-to-air missiles may prove limited. Also, because a significant increase in transport of radioactive materials into and through the Gulf will occur once Barakah begins operation, this will present a major maritime risk, whether directly intended or un-intentional.

Nuclear power plants are vulnerable to unforeseen external events or through human or engineering based fault conditions, including accidental or deliberate harm. Accidents are by nature accidental, and the cost of ignoring this common-sense axiom can prove radiologically catastrophic. The Gulf region is one of the most water-scarce in the world, and with few freshwater resources and low rainfall, many Gulf states rely on desalination. Radioactive release to the marine environment following an accident or incident at the Barakah nuclear plant would have significant trans-boundary pollution consequences for Gulf desalination and, hence, drinking-water availability in the region.

Permitted marine radioactive discharges from normal operations at Barakah nuclear power plant will also carry risk, as releases will include a broad cocktail of at least 60 radionuclides, with very long half-lives. The UAE coast is a vulnerable environment, and an important nursery and juvenile area for a very large range of marine life. UAE's extensive mangrove habitats grow on and in coastal fine sediments and mudflats, notable for their ability to sequester radioactive pollution. Acting as a 'sink' and concentrating over time, discharge of radioactive materials from the 4 APR1400 reactors at Barakah will inevitably lead to human inhalation and dietary dose from sea foods.

Meanwhile, the International panel on Climate Change have just reported that extreme sea level events that used to occur once a century will strike every year on many coasts by 2050, whether climate heating emissions are curbed or not. Thus, Barakah coastal nuclear plant will be increasingly vulnerable to sea-level rise, storm surge, tidal ingress, flooding of reactor and spent fuel stores, and eventual nuclear islanding. These impacts are very likely to happen much quicker than planned for, and assessments of climate change impact on the Barakah nuclear plant are conspicuous by their absence.

Finally, market investment in new nuclear has proven to be uneconomic – this holds for all plausible ranges of investment costs, weighted average cost of capital, and wholesale electricity prices – and solar energy has both lower investment costs and lower generation costs than nuclear power. Unlike renewable energy, new nuclear can now only be built with very significant government subsidy. So, the question remains: Why has UAE cast significant resources at nuclear power, a quintessentially late 20th century technology, when other more efficient, less risky, technically and economically viable options already exist? Since new nuclear makes little apparent sense in the Gulf, which has some of the best solar energy resources in the world, the nature of the interest in nuclear may lie hidden in plain sight.

Gulf Nuclear Ambition: New Reactors in United Arab Emirates, December 2019
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