Nuclear For Climate Australia

PO BOX 7071, BERRIMA, NSW 2577, AUSTRALIA

Email: [redacted]

Web: *https://nuclearforclimate.com.au/*

5th January 2023

Submission to Committee Secretary

Senate Standing Committees on Environment and Communications

Environment and Other Legislation Amendment (Removing Nuclear Energy Prohibitions) Bill 2022

1 Introduction

This submission supports the repeal of legislation that prevents the civilian use of nuclear energy in Australia.

The existing legislation damages the nation's efforts to transition to a secure low carbon, low-cost energy future while providing no safety benefits.

We reference three key issues pertaining to nuclear:

- Safety and hazards
- Sustainability and environmental benefits
- Cost benefits of using nuclear energy in a low carbon energy mix for Australia

2. Safety and hazards

The issues of safety and hazards are addressed first because some justification could exist for having a ban if an overwhelming case could be made that the health and safety risks of nuclear energy significantly out way its benefits.

This however is not the case and we quote the findings of the European Union Joint Research Centre technical assessment of Nuclear Energy with respect to the 'do no significant harm' criteria.

> The JRC analyses *did not reveal any science-based evidence that nuclear energy does more harm to human health or to the environment than other electricity production technologies already included in the Taxonomy as activities supporting climate change mitigation.*

Further, the JRC found that:

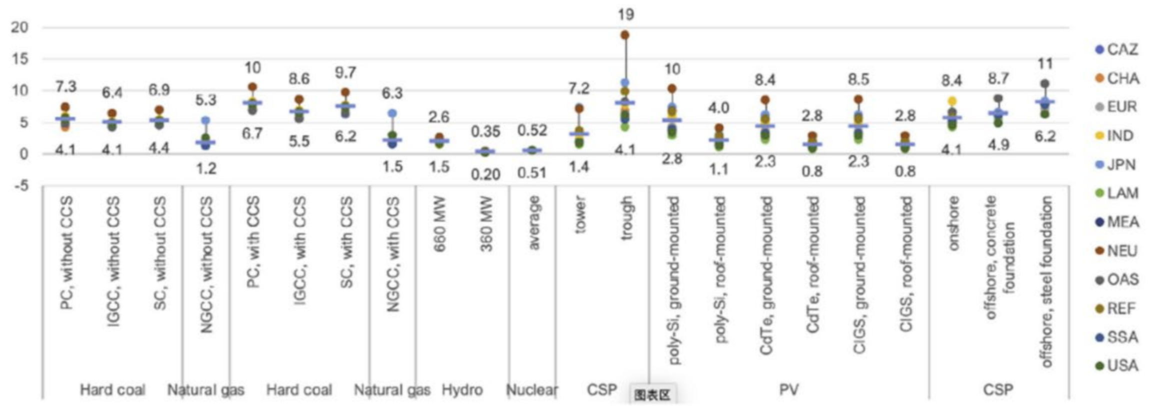
> *The fatality rates characterizing state-of-the art Gen III NPPs are the lowest of all the electricity generation technologies*

The United Nations Economic Commissions for Europe 2021 performed a Life Cycle Assessment of Electricity Generation Options. Its findings are summarised in the following images:

The following Figure 42 from the UN report shows that the carcinogenic impact of electricity generating technologies. It shows that nuclear energy has about the lowest cancer forming potential of any energy source. Its lower than solar and wind with only small-scale hydro being lower.

Figure 42 Lifecycle human toxicity (carcinogenic)' regional variations for year 2020. Variability is explained by several factors: electricity mix (all regions), region of extraction (fossil fuels), load factors (renewables). Nuclear power is modelled as a global average except for front-end.

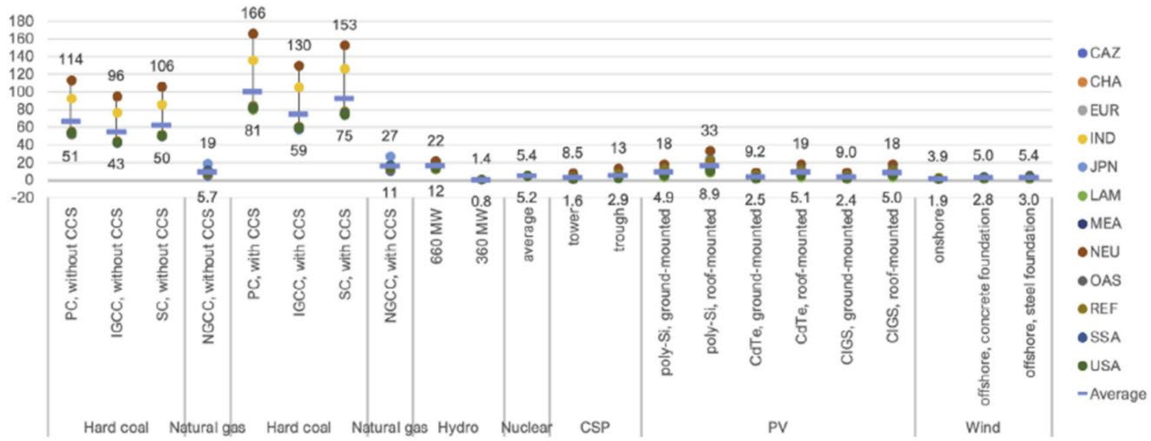
Lifecycle human toxicity potential, carcinogenic, in CTUh per TWh, regional variation, 2020



From the following Figure 41 from the UN report, for non-cancer forming toxic impacts found nuclear energy is lower than all fossil fuels, has similar impacts to wind energy and is lower than solar.

Figure 41 Lifecycle human toxicity (non-carcinogenic)' regional variations for year 2020. Variability is explained by several factors: electricity mix (all regions), region of extraction rates (fossil fuels), load factors (renewables). Nuclear power is modelled as a global average except for back-end.

Lifecycle human toxicity potential, non-carcinogenic, in CTUh per TWh, regional variation, 2020



Finally, in respect of health and safety impacts, we have carried out a very comprehensive review of the literature covering the Health Impacts of Radiation to Workers and Populations near Nuclear Power Plants. This appears in Appendix A to this submission and has received review by an expert in radiation protection.

On a safety and hazards basis there it is not reasonable to maintain a ban on civilian nuclear energy in Australia

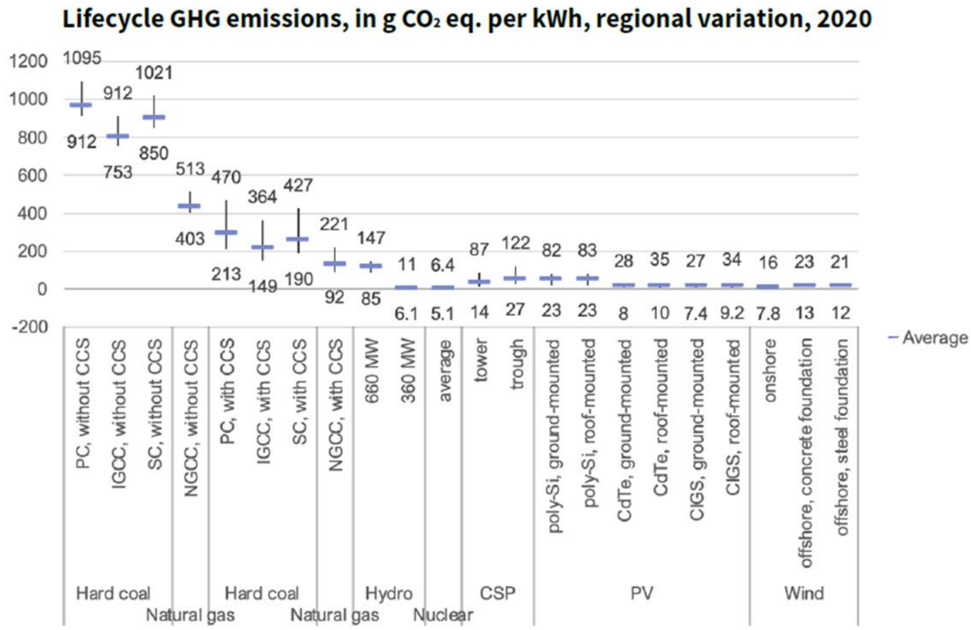
3. Sustainability and environmental benefits

Legislation preventing nuclear energy production and the failure of governments to support the technology means Australia is being denied the most sustainable and environmentally beneficial low carbon energy resource.

The United Nations[ii], the European Union Joint Research Centre[iii] and EDF[iv] have reported on the life Cycle Assessment of electricity generation options. They found that nuclear energy has lower emissions than any other generating source including wind and solar. Current nuclear plants have emissions as low as 4 gr CO2/kWh as reported by the EU Joint Research Centre. Wind is typically around 16 gr CO2/kWh but with the addition of material’s hungry batteries the embodied emissions climb to 100 gr CO2/kWh. Solar is similarly afflicted with emissions intensities up around 70 gr CO2/kWh inclusive of batteries even in ideal conditions.

The following Figure 1 from the United Nations report

Figure 1 Lifecycle greenhouse gas emission ranges for the assessed technologies



In view of the embodied carbon emissions in wind, solar, storage devices and transmission it is physically impossible to achieve net zero using these devices. Their constant replacement, weather dependency and lack of reliability will render methods of negative emissions such as carbon sequestration or atmospheric removal entirely uneconomic.

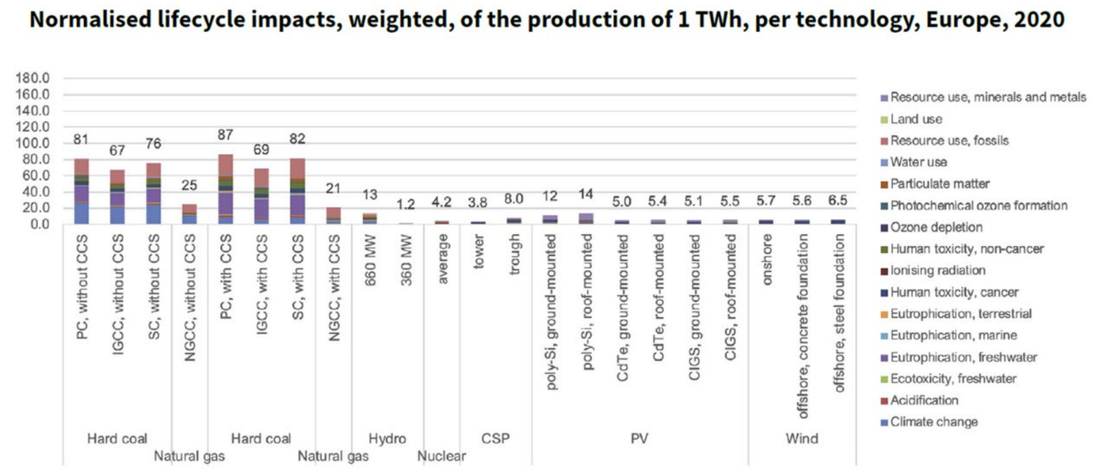
Nations and states with nuclear energy such as France (82 gr CO2/kWh), Sweden (18 gr CO2/kWh) and Ontario (62 gr CO2/kWh) consistently have amongst the lowest emissions and no nation, without strong backup from its neighbours, has yet achieved low carbon emissions with wind or solar.

The energy density of nuclear fission drives its very low materials consumption. If the term “renewable” is to mean anything sensible then nuclear energy is the best example.

In addition to the climate change potential, the UN report expanded its comparisons to a further thirteen environmental metrics covering things such as exotic minerals, particulate matter, pollution of the land and seas and water use.

When all factors were tallied in the following Figure 53 of the UN report, nuclear energy performed better on environmental grounds than wind and PV and was only beaten by small hydro.

Figure 53 Normalised, weighted, environmental impacts of the generation of 1 TWh of electricity



From an environmental and sustainability perspective Australia is at a fork in to road. At present we are on a destructive route of transitioning from energy intense sources to materials intense as shown in Figure 1. Harvesting our environment for low grade energy carries all the implications of massive mining, forest and land clearing, habitat loss. We will be hitching our economy to off shore production and continuing replacement of wind, solar and battery systems in perpetuity with all the security issues that this entails.

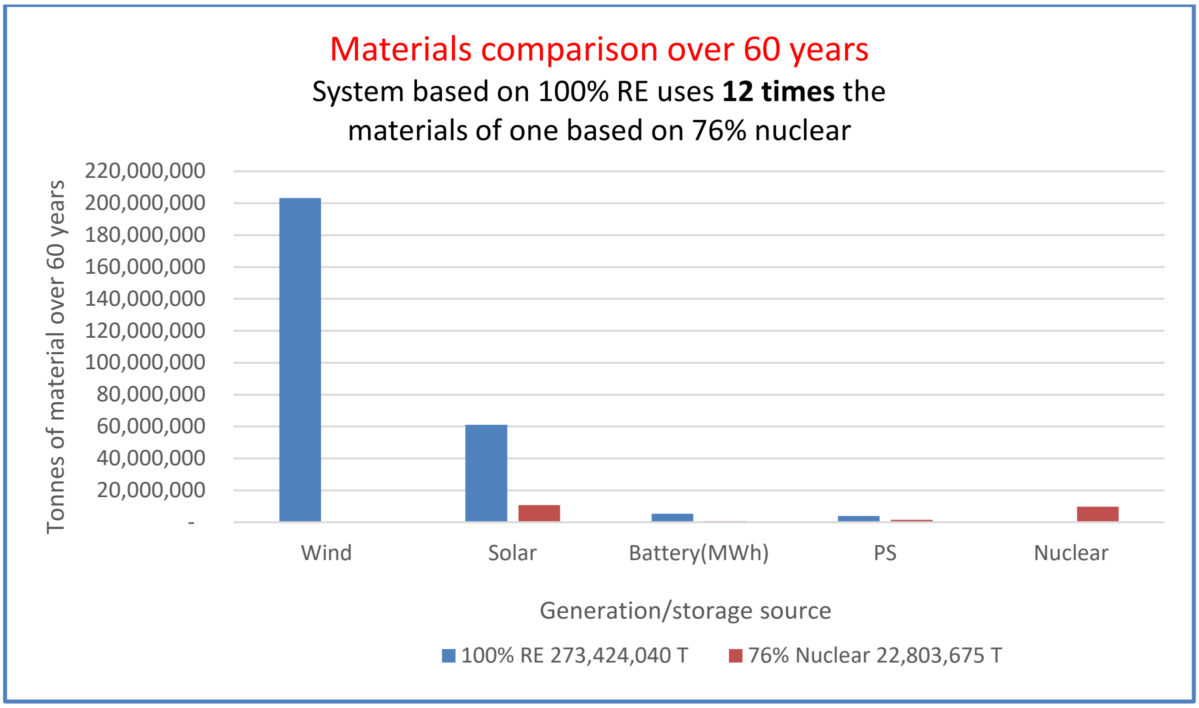


Figure 1 - Materials sage of renewables vs nuclear energy

After 1650AD coal burning started and societies went from gaining ten units of energy at subsistence levels to thirty units for every unit expended. The world grew and flourished from surplus energy. Nuclear power can deliver vastly better gains. Current nuclear plants provide a hundred units of energy for every unit invested. Newer fourth generation types such as molten salt reactors could see this multiplier double again. Atom for atom, splitting the uranium nucleus gives us 20 million times more energy than burning an atom of carbon.

Most of us hoped that switching to low carbon energy sources would create a system with reduced environmental impact. Unfortunately attempting this with wind and solar ignores history's valuable lesson – increased energy density drives wealth and creativity.

Australia is being denied the most sustainable and environmentally beneficial low carbon energy resource.

Legislation preventing nuclear energy production must be repealed and government policy must be restructured to embrace the technology

4. Cost benefits of nuclear energy in a low carbon energy mix for Australia

4.1. Introduction

Legislation preventing nuclear energy production and the failure of governments to support the technology means the National Electricity Market (NEM) can't provide the lowest cost, low carbon secure electricity generating system.

Systems which incorporate nuclear energy have, according to research carried out by Massachusetts Institute of Technology[1] and by Electric Power Consulting (EPC) in Australia, the lowest system levelised cost of energy (SLCOE).

EPC's energy model was used to assess the costs of the Australian Electricity Market Operator's (AEMO) Integrated System Plan (ISP) in the year 2050 and ultimately to a future decarbonised electricity sector. The results demonstrate that a system using nuclear energy will have much lower costs and achieve deeper carbon reductions more quickly than those based exclusively on wind and solar. It will achieve these cost benefits, in part, by eliminating the need for large amounts of energy storage and the expansion of the existing transmission and distribution system.

4.2 Modelled scenarios of RE and Nuclear

The results of six energy plans are shown in Figure 2. These correspond to various mixes of energy generators and storage devices to meet the demand on the National Electricity Market (NEM) in 2050.

The EPC Energy model relies upon actual demand and production data for three consecutive years from 2017 measured at half hour intervals. This results in reliable wind and solar traces based on actual field performance. These traces can be amplified to match any increased level of renewable generation in the AEMO scenarios. The model calculates the System Levelised Costs of Energy (SLCOE) and energy prices to wholesale industries such as smelters and low voltage retail customers such as families.

The model also calculates the emissions intensity of each plan.

Description of the six energy plans:

1. **NEM 2022 Current** – this uses the existing NEM based mix of coal, gas, wind, solar and hydro with the existing transmission, distribution and ancillary services costs to meet an annual energy demand of 199TWh. It is intended to act as a "control" for subsequent plans and demonstrate the correct order of costs and emissions.

2. **ISP Hydrogen 2050 –** This AEMO ISP plan uses wind, roof top and utility level solar, hydrogen burning turbines, and existing hydro as the generators with no fossil fuelled generators to match 1,152 TWh of electricity demand per year. That's greater than the current demand of Germany and France combined! Storage is provided by batteries from EV's and various levels of commercial, utility and domestic level DER and pumped hydro.

3. **ISP Step 2050 –** This AEMO ISP plan uses existing hydro, open cycle gas plants, plus wind and roof top and utility grade solar to meet an annual energy demand of 438TWh or similar to the current generation in France. Storage is provided by batteries from EV's and various levels of commercial, utility and domestic level Distributed Energy Resource (DER) and pumped hydro.

4. **ISP Progressive 2050 –** This AEMO ISP plan is a less aggressive option than the Step Change and uses coal and gas together with wind and solar to meet an annual energy demand of 467TWh. Storage is provided by batteries from EV's and various levels of commercial, utility and domestic level DER and pumped hydro

5. **Nuclear ISP 43% + VRE 2050.** This Nuclear Integrated System Plan (NISP) eliminates coal use and allows for the use of 29.5GW of nuclear power plants on the NEM plus hydro, open cycle

[1] The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables/OECD NEA No 7299

gas, wind and solar to meet an annual electricity demand of 438TWh or the same as the AEMO ISP STEP change scenario. Nuclear generators would be located primarily at the sites of existing coal and gas generators or close by the grid at coastal locations. Storage is provided by pumped hydro and batteries.

6. **Nuclear ISP 78% + VRE 2050**. This NISP plan eliminates all coal and gas. It also eliminates the use of wind energy due to its high reliance on gas energy as a backup resource. It utilises 47.2GW of nuclear power plants on the NEM plus additional generation is provided by existing hydro, roof top and utility solar to meet an annual electricity demand of 438TWh or the same as the AEMO ISP STEP Change Scenario. Storage is provided by pumped hydro and batteries.

4.3 Technologies and Cost Data

A conservative nuclear power deployment cost of A$7,402/kWe is used in these comparisons. It covers a suitable allowance for front end indirect costs, site specific issues such as cooling and site enabling and localised design. These are over and above the vendor's "Overnight Capital Cost" or OCC. It assumes a hybrid system of large and small plants such as the South Korean APR1400 combined with small plants such as the BWRX 300 boiling water nuclear power plant. The first of these plants will be deployed by 2027 at Ontario Power Generation's Darlington Facility.

The completion of 500kV transmission links between NSW and Victoria such as VNI- West and Murray link will make the operation of large plants like the APR 1400 quite viable on the NEM.

All other technology costs were derived from the CSIRO GenCost 2021-22 Final

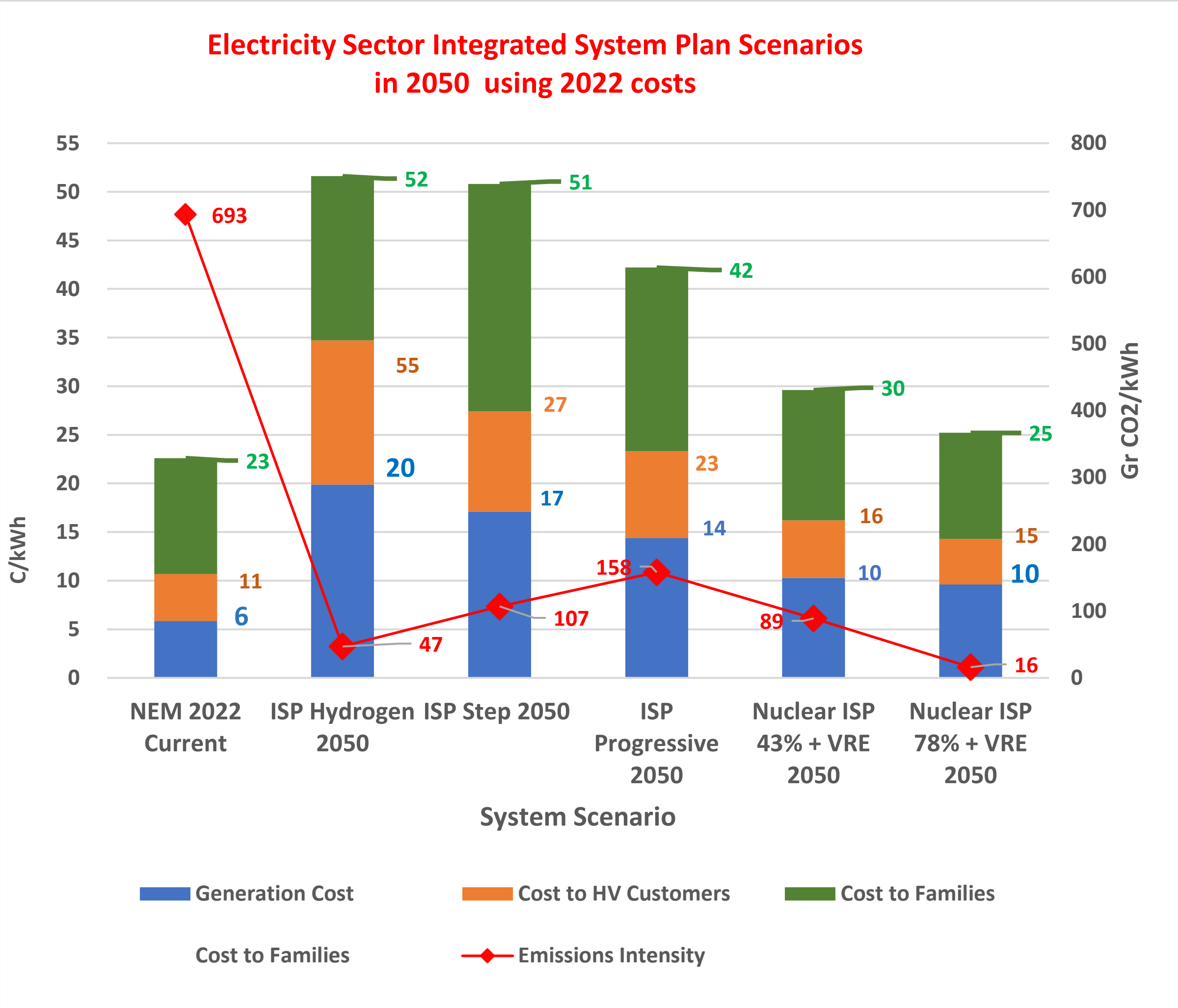


Figure 2 - Impact of nuclear energy on future ISP scenarios

4.4 Results of Comparison

The columns in Figure 2 contain three colours.

- The blue is the cost of generation and corresponds to the wholesale energy provided to the NEM pool.
- The orange band shows the incremental increase paid by high voltage users such as aluminium smelters or urban rail systems.
- The green band is that additional amount paid to low voltage customers such as families.

Examination of the values in Figure 2 shows that a system with 78% of nuclear energy will provide electricity at half the cost of a system reliant exclusively on wind, solar and hydro. The high nuclear energy scenario eliminates all fossil fuel combustion. It has the lowest emissions intensity of all scenarios and its minor emissions of 16 gr CO2/kWh are derived from embodied carbon in the construction of all the generators.

These results are consistent with a recent OECD[2] study of the Texas ERCOT (Electricity Reliability Council of Texas) system. This highlighted the impact that variable wind and solar have on electricity system costs resulting from:

- Increased energy storage from batteries and pumped hydro
- Significantly increased transmission costs to Renewable Energy Zones
- Costs of backup generation and the "overbuild" required to deal with seasonal and yearly deviations from the norm.
- Costs of compensating consumers for degradation of EV and domestic battery storage linked to the NEM

The use of nuclear energy on the NEM would provide a system free from the consequences and complexity of juggling a variable renewable system with all attendant storage and ancillary services costs.

The nuclear power plants are running at high and economic capacity factors of 84% and are meeting the base load power demand in much the same way as coal generators have done. Daily cyclic demand is met by a combination of the existing hydro plus solar and storage.

This system has precedent – it's very similar to that deployed in France for the past 30 years and has created amongst the lowest cost energy systems in the EU. France built 63 GW of nuclear energy over a 22 year period.

In conclusion, the anti-nuclear energy legislation must be repealed to enable Australia to benefit economically and environmentally from generating electricity with a significant amounts of nuclear energy in an optimum mix.

[i][3] Decouple podcast and Commodities Investor Leigh Goehring

[ii] Life Cycle Assessment of Electricity Generation Options. United Nations Economic Commissions for Europe 2021

[iii] EU Joint Research Centre technical assessment of Nuclear Energy. Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation')

[2] The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables/OECD NEA No 7299

[3]

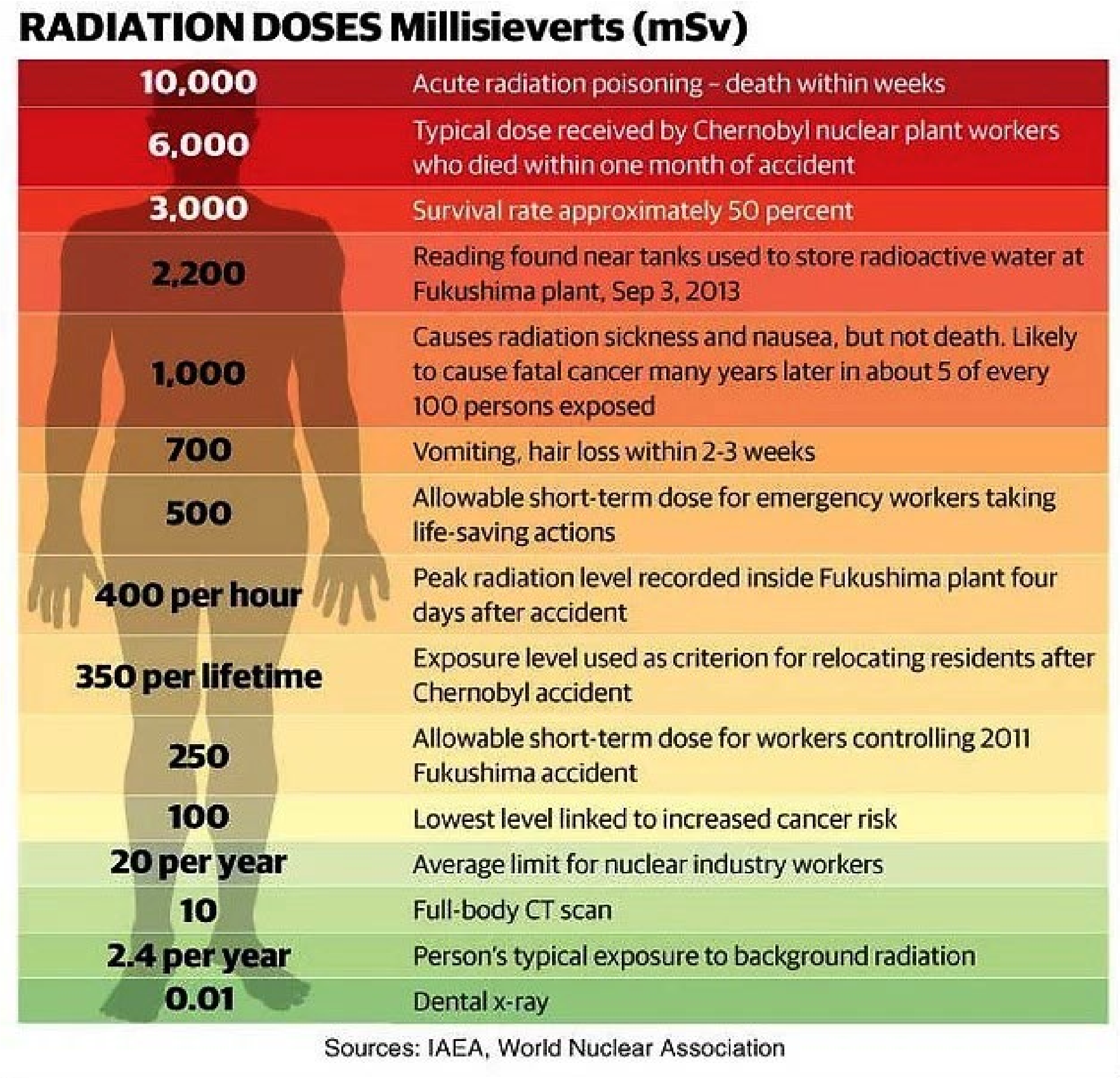
[iv] Life Cycle Analysis of the EDF nuclear fleet, 2019

[v] https://www.shu.ac.uk/helena-kennedy-centre-international-justice/research-and-projects/all-projects/in-broad-daylight

Appendix A

Health Impacts of Radiation to Workers and Populations near Nuclear Power Plants

We present here conclusions drawn from references for the health impacts on workers operating nuclear power plants and address concerns regarding leukaemia in children living near those plants. Throughout this document the measurement of radiation is the millisievert (mSv). Its impacts are shown in the following two images.



RADIATION DOSES Millisieverts (mSv)

10,000	Acute radiation poisoning – death within weeks
6,000	Typical dose received by Chernobyl nuclear plant workers who died within one month of accident
3,000	Survival rate approximately 50 percent
2,200	Reading found near tanks used to store radioactive water at Fukushima plant, Sep 3, 2013
1,000	Causes radiation sickness and nausea, but not death. Likely to cause fatal cancer many years later in about 5 of every 100 persons exposed
700	Vomiting, hair loss within 2-3 weeks
500	Allowable short-term dose for emergency workers taking life-saving actions
400 per hour	Peak radiation level recorded inside Fukushima plant four days after accident
350 per lifetime	Exposure level used as criterion for relocating residents after Chernobyl accident
250	Allowable short-term dose for workers controlling 2011 Fukushima accident
100	Lowest level linked to increased cancer risk
20 per year	Average limit for nuclear industry workers
10	Full-body CT scan
2.4 per year	Person's typical exposure to background radiation
0.01	Dental x-ray

Sources: IAEA, World Nuclear Association

Figure 3 Comparison of the effects of varying levels of ionising radiation in mSv

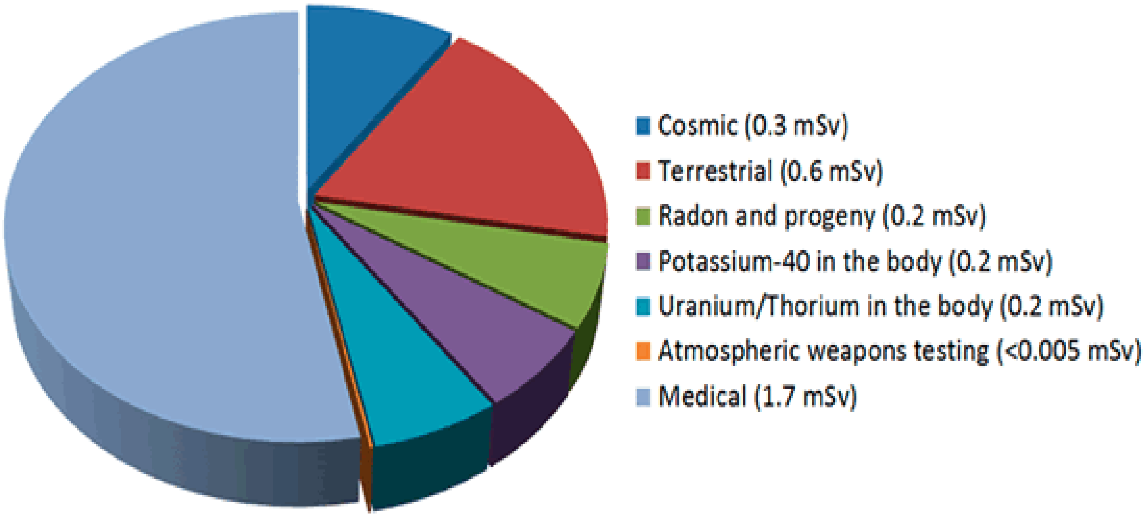


Figure 4 Average background radiation dose per year in Australia 1.5mSv excluding medical.

1. High background radiation and rates of cancer

Most studies into the impacts of high background radiation on resident populations have found no evidence of any increased rate of cancer incidence or mortality.

Possibly the strongest evidence supporting our ability to tolerate low dose radiation is the absence of health impacts to populations living in High Natural Background Radiation Areas (HNBRA). On average, Australians are exposed to about 1.5 mSv each year from natural sources[i]. Internationally some areas are much higher. Examples are[ii] Yangjiang, China with average annual internal effective doses of 4.27mSv, parts of Kerala in India with 15mSv, Brazil with 3.5 to 15mSv and Ramsar in Iran with 2.4 to 71.74mSv. A number of epidemiological studies have been conducted to analyse the risk of cancer incidence in the world's HNBRAs.

Most of these studies have concluded that there is no link between exposure to high background natural radiation and an increased rate of cancer or mortality.[ii,iii]

2. Current models for radiation dose response are challenged by many scientists

BEIR VII[iv] is the latest reference from the National Research Council in the US which addresses the effects of exposure to low dose ionizing radiation on human health. It sets the policy for the US EPA and radiation guidelines for the nuclear industry in the USA.

Central to its policy is the "Linear No Threshold" (LNT) hypothesis, which holds that there is a linear relationship between radiation exposure and radiation risks, without any "safe" dose level – See **Error! Reference source not found.**.

Many scientists are calling for a review of the LNT model. Levels of this support are shown in **Table 1**. In their publications many advocates such as Calabrese and O'Connor[v], Sacks, Meyerson and Siegel[vi,vii], Cardarelli and Ulsh[viii] and Tubiana, Aurengo, Averbeck and Masse[ix] have outlined their cases in detail.

A variety of plausible dose-response models exist and are shown in **Error! Reference source not found.**. The vertical axis shows risk to health with harm occurring above the horizontal axis and benefits existing below the axis.

These response models are:

1. A **Linear Threshold Model** where below a recognised Threshold dose of say, 100mSv no damage occurs or,
2. An **Hormesis Model** where benefits such as cancer protection and improved immune responses actually exist at low radiation levels – below the horizontal axis or,
3. **Supra-linear** and **linear quadratic** relationships exist which do not have significant support.

The initial data upon which the LNT concept is an extrapolation to low doses of acute exposure[x] at very high doses such as studies on the atomic bomb survivors at the end of World War II. Some have argued that in some cases Japanese survivors who received low doses of radiation had fewer cancers than unirradiated populations.[xi]

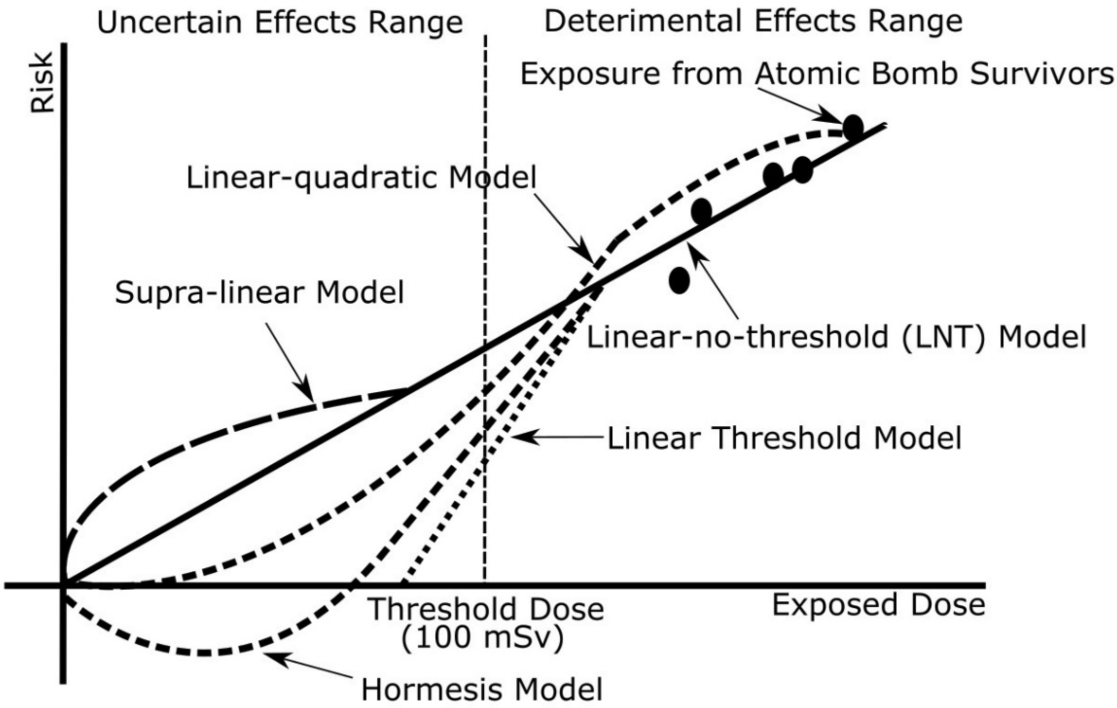


Figure 5 Dose-response models to estimate the risk of low-dose radiation from medical imaging based on high-dose radiation exposure.[xii]

Table 1 – Survey of Scientists Regarding the Most Accurate Radiation Dose–Response Model for Cancer.[xiii,xiv]

Surveys	Respondents	Percent Supporting LNT Model	Percent Supporting Threshold Model	Other
United States	National Labs	12	70	18[a]

	Union of Concerned Scientists	21	48	31[a]
Subscribers to Science	United States	19	75	6[b]
	Britain	21	71	8[b]
	France	18	70	13[b]
	Germany	22	64	13[b]
	Other European Union	23	69	8[b]

Abbreviation: LNT, Liner No-Threshold

[a] The “other” category includes “supralinear” and “don’t know” responses.

[b] The “other” category includes “supralinear” responses.

3. No Impact on Nuclear Power Plant Workers from Low Level Radiation – in fact their health is probably improved.

3.1. France

A French study was carried out on 22,393 workers employed over a 42-year period at EDF’s 58 nuclear power plants.[xv] They received an average cumulative occupational dose of 21.5mSv. With an average age of 49 years, their background radiation from non-occupational sources would be approximately 2-4mSv/yr or 98-196mSv cumulative. This significantly dominates the workplace dose and calls into doubt the accuracy of studies which focus solely on the occupational dose.

The French study found no increase in death relative to radiation dose except for an excess of 2 deaths out of 22 linked to cerebrovascular disease. Relative risks of cancer for these nuclear workers were lower than the general population.

3.2. Canada

Review[xvi] by the Canadian Government’s Nuclear Safety Commission has found approximately 42,200 Nuclear Energy Workers (NEWs) from Hydro-Québec, New Brunswick Power Corporation, Ontario Hydro, and AECL, first employed since 1965, had no increase in risk of solid cancer mortality due to their occupational radiation exposures.

3.3. INWORKS

The International Nuclear Workers Study (INWORKS)[xvii] study examined risks in worker cohorts from the United States, France, and the United Kingdom (a subset of the larger cohort included in the 15-country study). It claimed analysis demonstrated a significant association between red bone marrow low dose radiation and the risk of leukaemia (excluding chronic lymphocytic leukaemia) and between colon dose and the risk of solid cancers.

It came under criticism from Cardarelli, Ulsh[viii], Pennington, Sacks, Siegel and Meyerson[vi,xi], Calabrese and O'Connor[v] and Scott[xviii] for significant methodological errors including:

1. failure to account for natural background radiation exposure, the differences in which potentially dwarf the occupational exposures of the study cohort;
2. failure to account for medical exposures experienced by the public;
3. failure to account for dose–rate effects;
4. the a priori assumption of an LNT dose response;
5. mischaracterization of the y-intercept as 0 total dose when in fact it was 0 occupational dose;
6. arbitrary exclusion of all dose responses except LNT and linear-quadratic

3.4 Nuclear shipyard worker study (1980–1988): A large cohort exposed to low-dose-rate gamma radiation

The 1991 Final Report of the Nuclear Shipyard Worker Study (NSWS)[xix] was a very comprehensive study of occupational radiation exposure in the US. The NSWS compared three cohorts: a high-dose cohort of 27,872 nuclear workers, a low dose cohort of 10,348 workers, and a control cohort of 32,510 unexposed shipyard workers. The cohorts were matched by ages and job categories. Although the NSWS was designed to search for adverse effects of occupational low dose-rate gamma radiation, few risks were found. The high-dose workers demonstrated significantly lower circulatory, respiratory, and all-cause mortality than did unexposed workers. Mortality from all cancers combined was also lower in the exposed cohort.

<u>The workers exposed to radiation had a 24% lower standardised mortality ratios (SMR) than the unexposed workers which implies a 2.8-year increase in average lifespan.</u>

3.5 No evidence that radiation causes childhood leukaemia clusters.

The claim has been made by the Medical Association for Prevention of War (Australia) that there is an increase in lifetime cancer risk of an additional 10mSv. This claim is not based upon any measurable evidence but is a mere application of the LNT hypothesis, for which ANY exposure would entail additional risks. However, this is a misuse of the quantity Collective Dose and of the dose-risk relationship, as here indicated:

> *Collective effective dose is an instrument for optimisation, for comparing radiological technologies and protection procedures. Collective effective dose is not intended as a tool for epidemiological studies, and it is inappropriate to use it in risk projections. This is because the assumptions implicit in the calculation of collective effective dose (e.g., when applying the LNT model) conceal large biological and statistical uncertainties.*
>
> *"Specifically, the computation of cancer deaths based on collective effective doses involving trivial exposures to large populations is not reasonable and should be avoided. Such computations based on collective effective dose were never intended, are biologically and statistically very uncertain, presuppose a number of caveats that*

tend not to be repeated when estimates are quoted out of context, and are an incorrect use of this protection quantity".[xx]

The claim has been made by the Medical Association for Prevention of War (Australia) that childhood leukaemia clusters near some nuclear power plants are caused by radiation on the grounds that "no possible cause other than radiation has been identified". Further, it is claimed that errors in radiation measurement are also a cause.

These claims are challenged. A review of the German KiKK report by COMARE[xxi] and reviewers from Oxford found the effective doses from discharges of between 0.0001 mSv and 0.02 mSv per year for individual NPPs, are totally dominated by doses from medical diagnostic radiation exposure per person of 1.9 mSv per year and natural background radiation exposure of 2.1 mSv per year.

A comprehensive summary of childhood leukaemia clusters in France, Germany, the UK and Finland exists in the Oxford Martin[xxii] "Health effects of low-level ionizing radiation" and a detailed discussion by Janiak[xxiii].

From these studies possible explanations for the German KiKK results include:

- statistical problems with the study or
- possible causes of childhood leukaemia such as virus infection from population mixing.

For the time being, no cause for the German cancer clusters has been identified but radiation has been rejected on the basis that the amounts are too low.

It is also noteworthy that based on data from the United Nations Scientific Committee on the Effects of Atomic Radiation on the Effects of Atomic Radiation 2016 Report[xxiv], nuclear power plants emit less radiation than coal fired power plants, especially of the brown coal variety in use in the Latrobe Valley. This is shown in the following image of Table 48 from Annex B, Radiation Exposures from Electricity Generation.

Table 48. Comparison of collective doses to the public, and collective doses normalized to electricity generation in 2010, integrated to 100 years, to the world-average population within a 1,500 km radius of each source for the electricity-generating technologies based on the coal cycle and the nuclear fuel cycle

Coal			Nuclear		
Source	*Collective dose (man Sv)*	*Normalized collective dose (man Sv/(Gw a))*	*Source*	*Collective dose (man Sv)*	*Normalized collective dose (man Sv/(Gw a))*
Coal mining	370	0.4	Uranium mining[a] and milling	53	0.2
Older coal plants	780	0.8	NPP generation	68	0.2
Modern coal plants	60	0.1			
From coal ash deposits	240	0.2	Reprocessing	7.6	0.03

[a] Of the 53 man Sv for uranium mining and milling, 40 man Sv is from mining only.

4. Nuclear Power Protects Lives and Our Environment

This final group of references addresses the benefits of nuclear energy in terms of reduced mortality per unit of output compared to other generating sources and also a reduction in carbon emissions.

Pushker Kharecha and James Hansen outlined in their paper "Prevented Mortality and Greenhouse Gas Emissions"[xxv] that global nuclear power has prevented an average of 1.84 million air pollution-related deaths and 64 gigatonnes of CO2-equivalent (GtCO2-eq) greenhouse gas (GHG) emissions that would have resulted from fossil fuel burning.

They calculate that nuclear power could additionally prevent an average of 420 000−7.04 million deaths and 80−240 GtCO2-eq emissions due to fossil fuels by mid-century, depending on which fuel it replaces.

In the following table from Electricity Generation and Health[xxvi] by Anil Markandya, Paul Wilkinson outlines the very low mortality of nuclear energy compared to fossil fuel use. References included[xxvii], Power generation and the environment—a UK perspective, vol 1.[xxviii] and European Commission report EUR 16524, Vol 5. Brussels: EC,1995[xxix].

	Deaths from accidents		Air pollution-related effects		
	Among the public	Occupational	Deaths*	Serious illness†	Minor illness‡
Lignite[30]	0·02 (0·005–0·08)	0·10 (0·025–0·4)	32·6 (8·2–130)	298 (74·6–1193)	17 676 (4419–70 704)
Coal[31]	0·02 (0·005–0·08)	0·10 (0·025–0·4)	24·5 (6·1–98·0)	225 (56·2–899)	13 288 (3322–53 150)
Gas[31]	0·02 (0·005–0·08)	0·001 (0·0003–0·004)	2·8 (0·70–11·2)	30 (7·48–120)	703 (176–2813)
Oil[31]	0·03 (0·008–0·12)	..	18·4 (4·6–73·6)	161 (40·4–645·6)	9551 (2388–38 204)
Biomass[31]	..	..	4·63 (1·16–18·5)	43 (10·8–172·6)	2276 (569–9104)
Nuclear[31,32]	0·003	0·019	0·052	0·22	..

Data are mean estimate (95% CI). *Includes acute and chronic effects. Chronic effect deaths are between 88% and 99% of total. For nuclear power, they include all cancer-related deaths. †Includes respiratory and cerebrovascular hospital admissions, congestive heart failure, and chronic bronchitis. For nuclear power, they include all non-fatal cancers and hereditary effects. ‡Includes restricted activity days, bronchodilator use cases, cough, and lower-respiratory symptom days in patients with asthma, and chronic cough episodes. TWh=10^{12} Watt hours.

Table 2: Health effects of electricity generation in Europe by primary energy source (deaths/cases per TWh)

The benefits of nuclear energy were outlined in an Economic Analysis of Various Options of Electricity Generation - Taking into Account Health and Environmental Effects by Nils Starfelt Carl-Erik Wikdahl[xxx]

5. Final Comment

Thirty-one references have been provided which give a snapshot of the contested issues surrounding the safety of nuclear energy. Many hundreds of additional papers and studies no doubt exist. From the body of evidence that we have examined the introduction of nuclear energy provides improved health outcomes, increased community wealth and stability and a greatly improved environment.

---

[i] ARPANSA, https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/ionising-radiation-and-health

[ii] The world's high background natural radiation areas (HBNRAs) revisited: A broad overview of the dosimetric, epidemiological and radiobiological issues. https://www.sciencedirect.com/science/article/abs/pii/S1350448715000086

[iii] Cancer Mortality Among People Living in Areas With Various Levels of Natural Background Radiation. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4674188/

[iv] Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2 (2006), http://www.jstor.com/stable/24545417

[v] Estimating Risk of Low Radiation Doses - A Critical Review of the BEIR Report and its Use of the Linear No-Threshold (LNT) Hypothesis. http://www.jstor.com/stable/24545417

[vi] Epidemiology Without Biology: False Paradigms, Unfounded: Assumptions, and Specious Statistics in Radiation Science, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4917595/

[vii] LINEAR NO-THRESHOLD (LNT) VS. HORMESIS: PARADIGMS, ASSUMPTIONS, AND MATHEMATICAL CONVENTIONS THAT BIAS THE CONCLUSIONS IN FAVOR OF LNT AND AGAINST HORMESIS; https://pubmed.ncbi.nlm.nih.gov/30768437/

[viii] It Is Time to Move Beyond the Linear No-Threshold Theory for Low-Dose Radiation Protection. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6043938/

[ix] Recent reports on the effect of low doses of ionizing radiation and its dose–effect relationship. https://pubmed.ncbi.nlm.nih.gov/16468064/

[x] Origin of the linearity no threshold (LNT) dose-response concept. https://pubmed.ncbi.nlm.nih.gov/23887208/

[xi] The Linear No-Threshold Model of Low-Dose Radiogenic Cancer: A Failed Fiction, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6376521/

[xii] Ref Seong KM, Songwon S, Dalnim L, Min-Jeong K, Seung-Sook L, Sunhoo P, and Young WJ. (2016) Is the linear no-threshold dose-response paradigm still necessary for the assessment of health effects of low dose radiation? Journal of Korean Medical Science. 31(1): 10-23. https://epos.myesr.org/poster/esr/eurosafeimaging2020/ESI-10315

[xiii] Jenkins-Smith HC, Silva CL, Murray C. Beliefs about radiation scientists, the public and public policy. Health Phys. 2009; 97(5): 519-527.

[xiv] Silva CL, Jenkins-Smith HC, Barke RP. Reconciling scientists' beliefs about radiation risks and social norms: explaining preferred radiation protection standards. Risk Anal. 2007;27(3): 755-773.

[xv] Relationship between occupational exposure to ionizing radiation and mortality at the French electricity company, period 1961–2003, https://pubmed.ncbi.nlm.nih.gov/20148259/

[xvi] Verifying Canadian Nuclear Energy Worker Radiation Risk: A Reanalysis of Cancer Mortality in Canadian Nuclear Energy Workers (1957-1994) Summary Report,

[xvii] THE INTERNATIONAL NUCLEAR WORKERS STUDY (INWORKS): A COLLABORATIVE EPIDEMIOLOGICAL STUDY TO IMPROVE KNOWLEDGE ABOUT HEALTH EFFECTS OF PROTRACTED LOW-DOSE EXPOSURE. https://academic.oup.com/rpd/article/173/1-3/21/2558799

[xviii] A Critique of Recent Epidemiologic Studies of Cancer Mortality Among Nuclear Workers, https://pubmed.ncbi.nlm.nih.gov/29872372/

[xix] Nuclear Shipyard Worker Study (1980-1988): a large cohort exposed to low-dose-rate gamma radiation; https://nuclearforclimate.com.au/wp-content/uploads/2020/07/Sponsler-and-Cameron-2005-Shipyard-Worker-Study.pdf

[xx] ICRP. ICRP Publication 103: the 2007 recommendations of the International Commission on Radiological Protection. Ann ICRP. 2007;37(2-4):1-332. http://www.icrp.org/publication.asp?id=ICRP%20Publication%20103

---

xxi Committee on Medical Aspects of Radiation in the Environment (COMARE) 14th Report, https://www.gov.uk/government/publications/comare-14th-report

xxii Oxford Martin Restatement 5:A restatement of the natural science evidence base concerning the health effects of low-level ionizing radiation, https://royalsocietypublishing.org/doi/10.1098/rspb.2017.1070

xxiii EPIDEMIOLOGICAL EVIDENCE OF CHILDHOOD LEUKAEMIA AROUND NUCLEAR POWER PLANTS, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4146329/

xxiv United Nations Scientific Committee on the Effects of Atomic Radiation on the Effects of Atomic Radiation 2016 Report; https://www.unscear.org/unscear/en/publications/2016.html

xxv Prevented Mortality and Greenhouse Gas Emissions, https://pubs.acs.org/doi/abs/10.1021/es3051197

xxvi Electricity generation and health:Anil Markandya, Paul Wilkinson. https://www.sciencedirect.com/science/article/abs/pii/S0140673607612537

xxvii ExternE National Implementation; Germany, http://externe.jrc.es/ger.pdf

xxviii Power generation and the environment—a UK perspective, vol 1., http://externe.jrc.es/uk.pdf

xxix European Commission report EUR 16524, Vol 5. Brussels: EC,1995.

xxx Economic Analysis of Various Options of Electricity Generation - Taking into Account Health and Environmental Effects, Nils Starfelt Carl-Erik Wikdahl; http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.180.4490