Review of technical-economic trends for currently operating nuclear power reactors

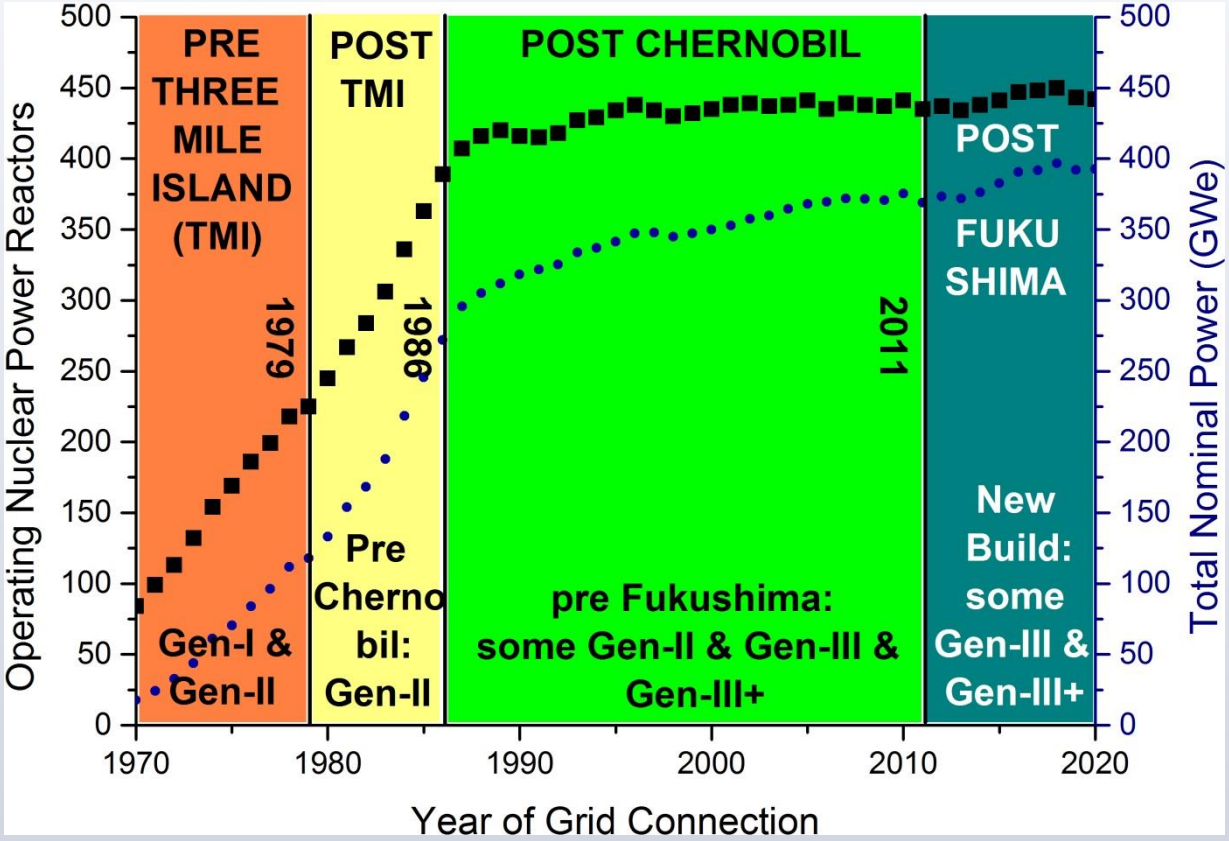
E.D. Poulopoulou*, D. Mitrakos, N.P. Petropoulos
Nuclear Engineering Laboratory, National Technical University of Athens, 15780 Athens, GREECE (*eleprc@mail.ntua.gr)

1. Introduction

Data available at IAEA's PRIS Database were compiled in terms of performance and evolution indicators for today's (2021) operating nuclear power reactors. The aim was to identify past, present and future trends related to the usage of nuclear power for electricity production. The examined time span extends as far back as the 70's, when some of today's reactors have been grid connected. Several operational periods could be identified: a) pre 1979 Three-Mile-Island (TMI), b) post 1979 TMI (or pre Chernobyl), c) post 1986 Chernobyl (or pre 2011 Fukushima), d) post 2011 Fukushima and, finally, e) New Build. These periods are loosely connected to the reactor generations as licensed and constructed, i.e. Gen-I, Gen-II, Gen-III, Gen-III+. The periods do not include the long-debated Gen-IV reactors, which, yet, have not been through the demonstration phase. Instead, the New Build period involves Gen-III+ types and a controversial long and heavy discussion on the market possibilities of Small Modular Reactors (SMR) and Mini Modular Reactors (MMR). Overall, there are indicators that (i) there is no negative trend on the number of active power reactors, (ii) the yearly electrical power by nuclear sources is steadily increasing, (iii) the reactor performance indicators are steadily getting better, (iv) despite their negligible number, the reactor accidents have been the main factors, which prohibited the expansion of nuclear generated electricity, (v) all such accidents were followed by a period of conservative usage of most operating reactors, and, (vi) all such accidents have led to the long-term improvement of the average reactor operational characteristics. Further, it could be supported that renewables (RES) have not significantly affected the nuclear reactors operational mode, since their role as base units is further supported by the extensive retirement of fossil fuel - fired conventional plants.

The Chernobyl accident disrupted the development rate of nuclear reactors. However, despite otherwise anticipated, the Fukushima accident does not seem to have influenced the current (2020) number of reactors in operation

2. Reactors in operation (1970 – 2020)



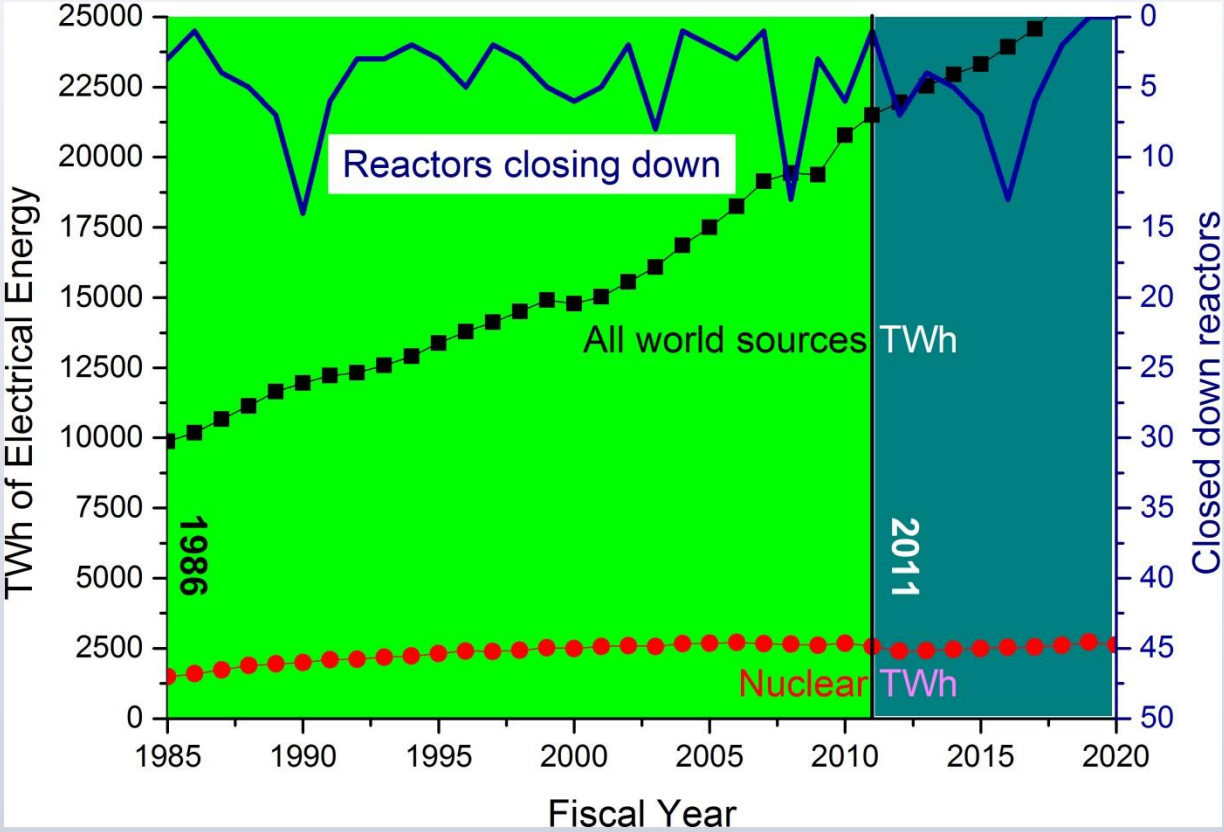
Old units closing are of capacity < 1000 MWe

There is no negative trend on the number of active power reactors.
The currently operating power reactors are ~440.
Their increase rate after 1986 is about 1 - 2 1000 MWe reactors per year.

Since 1986, the rate of increase for nuclear electricity TWh is stable at 0.1 – 0.2% annually. In the same period world electricity TWh have increased at a rate of about 2% annually following the respective increase of actual needs

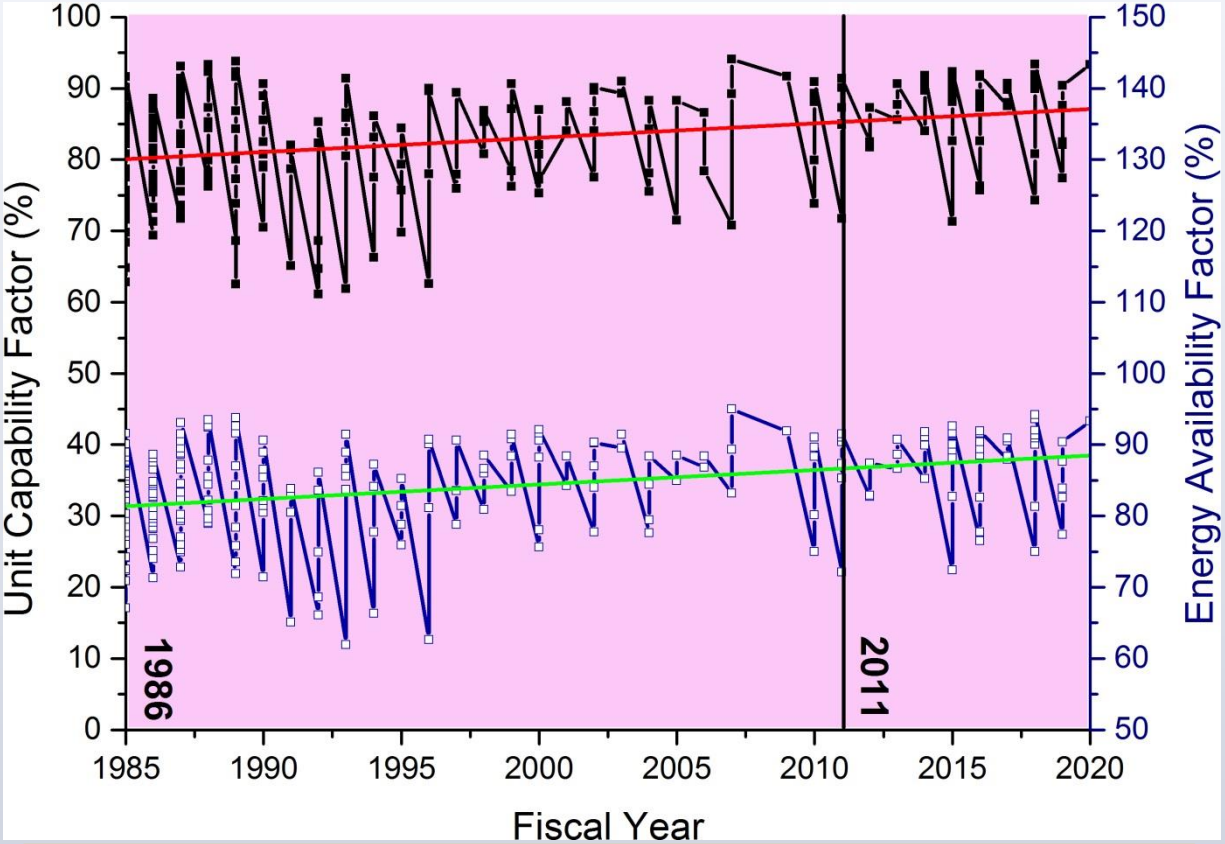
3. Annual world and nuclear TWh of electricity (1986-2020)

There is no negative trend on the electricity TWh from nuclear reactors. **The rate of reactors closing down is about 4 annually.** This, in conjunction with the previous slide, means that the new reactors grid connection rate is between four and six yearly (1986-2020).



Reactors operational quality indicators, such as the UNIT CAPACITY FACTOR (UCF, mean 83%, from 61 - 94%) and the ENERGY AVAILABILITY FACTOR (EAF, mean 84%, from 62 – 95%) have been increasing yearly at a rate greater than 0.2%

4. UCF (%) and EAF (%) for PWR type reactors (1986-2020)



*beyond reactor management control

Not included: scarce UCFs and EAFs below 60% indicate reactors operating far below nominal settings.

UCF(%)=100*(REG-PEL-UEL)/REG

EAF(%) = 100*(REG-PEL-UEL-XEL)/REG

where, for each year:

REG=reference energy generation

PEL=planned losses

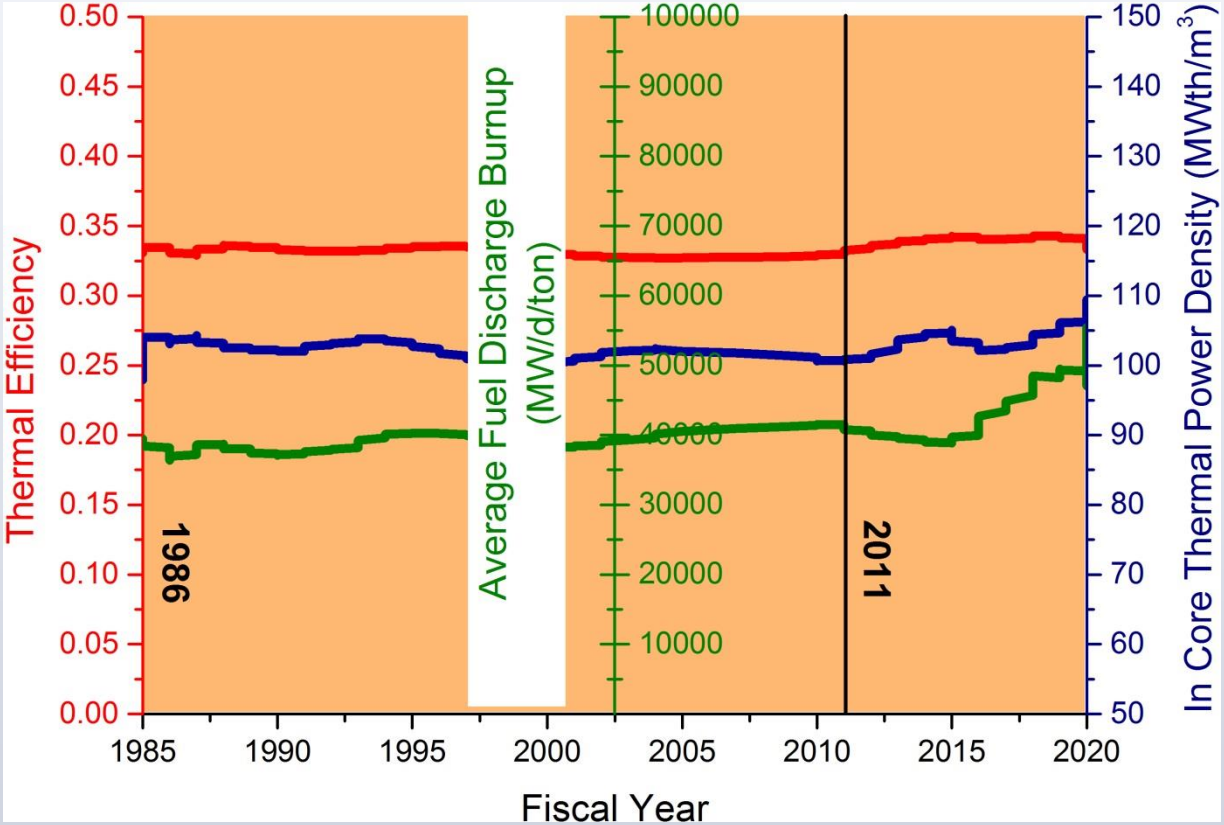
UEL=unplanned losses

XEL= external losses*

Since 1986, engineering quality indicators, like the THERMAL EFFICIENCY, the POWER DENSITY (MWth/m^3 core) and the FUEL BURNUP AT DISCHARGE (MW/day/ton fuel) remain fairly stable indicating the nuclear energy sector strong maturity

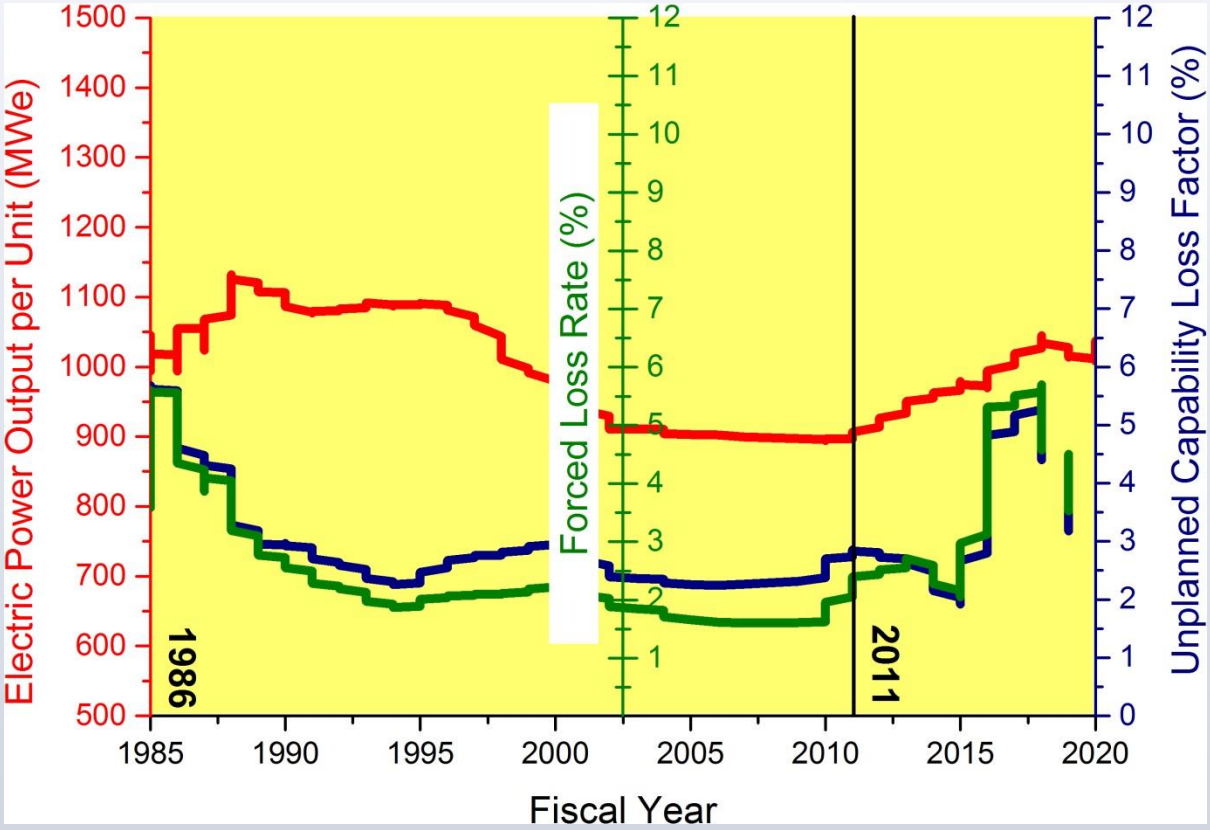
5. Engineering indicators for PWR type reactors (1986-2020)

All data smoothed by the adjacent average method.
Post Chernobyl data show a conservative reactors operation mode from 1986 to 2002.
On the other hand, improvement of indicators after the Fukushima accident show a somewhat aggressive trust in this technology.



Today's intensive use of currently operating reactors is further demonstrated by engineering indicators, like low FORCED LOSS RATE (FLR, %), low UNPLANNED CAPABILITY LOSS FACTOR (UCL, %) & high New Build energy output per unit

6. More engineering indicators for PWR type reactors (1986-2020)



All data smoothed by the adjacent average method.

UCL(%)=100*UEL/REG

FLR(%)=100*FEL/(REG-PEL-EPL)

where for each year:

REG=reference energy generation

UEL=total unplanned losses

FEL=unplanned forced losses

PEL=planned losses

EPL=unplanned extensions of planned losses

UCL and FLR after 2015 seem to increase, probably due to the introduction of more RES. SMRs and MMRs as part of the New Build era, up to 2050, are anticipated to present at least the engineering qualities of the so far operating 1 MWe units

7. Other facts and comments

- The annual consumption increase of electricity produced in nuclear reactors is at about 2% (almost equal to the world's annual TWh increase rate), reasons being lower costs and environmental friendliness.
- Electricity produced in nuclear reactors is around 30% of all electricity complying to low carbon requirements
- Further engineering advances for reactors are expected in the course of SMRs and MMRs development, which will be part of the New Build era.

Basic references

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[2] IAEA, International Atomic Energy Agency, Operating Experience with Nuclear Power Stations in Member States, 2020 Edition

[3] IAEA, International Atomic Energy Agency, Reference Data Series No. 2, Nuclear Power Reactors in the World, 2021 Edition

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