A Strategy for Deployment of Thorium and U233 (In Italy)

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ABSTRACT

Thorium is an unavoidable nuclear fuel generator and a gigantic energy source, should nuclear technology become a strategy for the electricity production in regions like EU or in Countries like Italy. The history of the exploitation of thorium in nuclear technology provides a number of dead-end endeavors; at the same time, a large number of initiatives and ideas are fluorescent in various parts of the world dealing with the deployment of thorium as nuclear fuel.

After examining the history and the current trends, the present paper deals with a dream project (for Italy): the ^{233}U extracted from a thorium breeder reactor is stored to constitute an energy deposit, suitable for decades energy consumption, which has the potential to make stable the energy market, without targeting electricity production in the Country. Three topics touched in the paper are: a) ^{233}U generation details; b) chemical separation of fissile and fertile materials; c) challenges for a nuclear reactor to produce electricity, desalinated water and fissile material, simultaneously.

Keywords: *Strategic Energy Reservoir, Thorium Fuel, Uranium-233, CANDU Reactor*

1 INTRODUCTION

Nuclear electricity production is on an edge in several countries including EU and Italy in particular: it may continue or come back again (e.g. in Italy), or humanity may abandon it forever, i.e. for current generations (wide uncertainties affect forecasts of energy production for periods longer than 5 years). Thorium may play a key role in any case also looking at the conquest of space.

Scientists and technologists well know thorium as a fertile material and originator of the ^{233}U fissile isotope since the dawn of nuclear energy. Its limited deployment for power reactors and the use in a small number of pioneering research applications are conducible to market directions rather than technology difficulties. Needless to state that the abundance of thorium on the earth makes this material as the highest contributor for energy production inside a virtual warehouse where, excluding fusion, all energy sources for a century are stored. Definitely, thorium might achieve in the global energy market the same, strategic and stabilizing role of precious metals, i.e. gold, in financial market.

When dealing with nuclear technology (NT), whatever sound scientific plan and forecast reveals a dream in those countries where NT is on an edge. Having this in mind, the scope for the paper is to promote the exploitation of thorium for industrial energy production, i.e. not only electricity, in one of those countries. The objective is to arrive at a proposal-plan, which may trigger a feasibility investigation.

Therefore, comprehensive and systematic investigations of any aspects (safety, security, financial, logistic, siting, etc.), whose consideration is necessary to finalize an engineering project, are far beyond the scope of the paper. Rather, four complementary themes located along an ideal roadmap for the exploitation of thorium constitute its focus.

At first, we mention the past use of thorium and ^{233}U providing emphasis to current trends. Then, the attention moves towards the production of ^{233}U following irradiation of a ThO_2 pellet: to this aim, we adopt, suitable computational techniques. We pursue the idea, possibly inefficient in terms of cost of produced energy, of physical separation of the uranium: separated ^{233}U is stored to constitute the reservoir of a 'strategic-energy-bank' and then imagined as the 'only' fissile fuel for long term exploitation, i.e. half-a-century.

The last two themes in the paper are an overview of the chemical separation process for ^{233}U from the irradiated $ThO_2$and the description of results from calculations, which approximately connect the material masses (^{233}U and ThO_2), the energy production and the involved time scale.

2 THORIUM USE FOR ELECTRICITY PRODUCTION

One can read in Wikipedia: already "*in 1946, the public first became informed of uranium-233 bred from thorium as a third available source of nuclear energy and atom bombs (in addition to uranium-235 and plutonium-239), following a United Nations report and a speech by Glenn T. Seaborg".* As a continuation of the history, the scientific and technology community completed thousands of thorium based projects and activities, which originated a corresponding number of papers and reports.

A comprehensive and systematic review of those activities or documents is not the purpose for the present section; rather, the idea is to provide a view of the relevance of thorium for energy production focusing on electricity.

2.1 Synthesis view

Akbari-Jeyhouni et al., 2018, provided the following synthesis view, including relevant citations (reported hereafter with minor changes) [1]:

"*The Shippingport nuclear reactor (connected to the electrical grid in 1957) adopted thorium fuel and successfully showed breeding of* ^{233}U *in the 3rd core design. Namely, the seed and blanket concept, where seed is an U/Zr alloy and the blanket is (Th0.9-U0.1)O_2, Radkowsky, 1985, has been used. The reactor with highly enriched uranium fuel (HEU) worked during 1200 effective full power days with final burn-up of 60 MWd/kg, Kasten, 1998. Recently, Tucker et al., 2015, and Tucker and Usman, 2018, investigated the feasibility of using a thorium–plutonium mixed oxide fuel for a Westinghouse-type 17 x 17 PWR. Maiorino et al., 2014, 2017, and 2017a have investigated the use of (U-Th)O_2 fuel for PWR reactors. Permana et al., 2011, have analyzed the heavy metal closed-cycle water-cooled thorium reactor. Lindley et al., 2014, have studied the closed thorium-transuranic fuel cycle in reduced-moderation PWR and BWR, and Ashley et al., 2014, have modelled the open cycle thorium-fuelled nuclear energy systems*"[2-11].

Without having the ambition to identify all topics connected with the exploitation of thorium in nuclear technology, the following summary statements provide an idea of recent investigations in the area. We attempted to list selected literature papers in a logical order, starting from availability of thorium on the earth, first bullet item (thorium-related subject order is in the paper at the second bullet item):

- Degueldre and Joyce, 2020, compared he abundances of U and Th in the Earth and the extent of their known and recoverable resources (they also considered thorium abundance in the universe, which is outside the scope for present paper). They emphasized the greater abundance on the Earth of uranium related to thorium and proposed a value for the recoverable amount of thorium at the price of 130 USD/kg in the order of a few 10^6 tons [12].
- Ault et al., 2017, identified and categorized the "*literature on the thorium fuel cycle spanning eight decades from the 1940s to the 2010s. … The publications are divided among twelve topical categories …, 1449 publications are identified, with the most prevalent topics being reprocessing and Waste Management, Molten Salt Reactors, Fuels, and Light Water Reactors"*. As a key conclusion, "*The breadth and depth of the studies identified in this literature review suggest that technologies related to the thorium fuel cycle are more mature than often credited*" [13].
- Jeong et al., 2008, discuss the use of thorium in a CANDU core and propose a closed cycle. Their investigation provides substantiation (already fifteen years ago) for the proposal in the section 6 of the present paper. Earlier, Milgram, 1983, discussed the applicability of thorium cycle in CANDU reactors, pointing out a possible paradox connected with strategies for nuclear fuel cycles [14].
- Maitra, 2006, based on fundamentals of neutron physics, discusses the strategic importance for India (including addressing the proliferation issue) to use thorium as nuclear fuel. One of his background related statements "*… thorium has some 40 times the amount of energy per unit mass … compared with uranium*", may need clarification considering the investigation by Degueldre and Joyce, 2020 (first bullet above) [15].
- Vijayan et al., 2017, ten years after the paper in the item above, investigates technological details for the exploitation of thorium in India, with main reference to the heavy water (CANDU-type) nuclear reactors [16].
- Schaffer, 2013, discusses the advantages of using thorium as nuclear reactor fuel in the US, noting that thorium does not need enrichment; his background information (i.e. about thorium abundance) may appear in contradiction with the results of the analysis by Degueldre and Joyce, 2020 (first bullet above) [17].
- Björk et al., 2011, studied from the viewpoint of neutron physics, mainly criticality and depletion, the feasibility of using thorium in the core of the Forsmark-3 BWR in Sweden. The authors did not identify specific problems although the smaller amount of fission-emitted delayed neutrons needs attention [18].
- Castro et al., 2020, studied the criticality and the depletion analysis of the core of the Angra-2 PWR in Brazil. Among other things, they found that the smaller value of the delayed neutron fraction in a thorium fuel core, compared with an equivalent uranium fuel, deserves special attention in safety and design analyses [19].
- Galahom et al., 2022, discuss the effect of using ^{232}Th instead of ^{238}U on the neutron physics and the main operating parameters of the pressurized water reactor [20].
- Liu et al., 2020, investigated the performance of the thorium-based fuel with Zircaloy within a multi-physics nuclear fuel computational framework. SiC cladding was at the center of attention and the pellet-clad-mechanical interaction constitutes the key parameter for the study [21].
- Ibrahim et al., 2018, investigated selected neutron physics aspects relevant to the use of thorium in large gas cooled reactors. The results from their analyses, considering isotopic transmutation and burn-up, confirm the feasibility of both open and closed thorium cycles including the capability to use thorium in combination with plutonium coming from the operation of LWR [22].

- Ashraf et al., 2020, discuss the use of thorium for Gen IV reactor, making reference to an early idea from 1960: "*the Single-fluid Double-zone Thorium-based Molten Salt Reactor (SD-TMSR) with a thermal power of 2,250 MWth was proposed for the first time by ORNL as early as in the 1960s, which was called Molten Salt Breeder Reactor (MSBR), Robertson, 1971*". Relevant to the proposal formulated in section 6, the authors conclude " ... *continuous flow of reactor-grade Pu allows the transition to the thorium fuel cycle in a relatively short time (around 4-5 years) compared to 26 years for Th/233U startup fuel*" [23, 24].
- György and Czifrus, 2017, investigated the feasibility of thorium as nuclear fuel of a sodium fast reactor considering two different core designs. Fresh fuel assemblies filled with thorium, ^{233}U and plutonium, are placed in the inner core while the used fuel assemblies are relocated to the inner core (first design); in the second design only the inner core is changed to thorium containing one and the outer core remains the same as that of the reference core [25].
- Rummana et al., 2022, investigated, preliminarily, neutron physics features for a possible application of thorium in the MYRRHA-ADS (i.e., adopting an accelerator delivering a proton beam towards a molten lead bismuth eutectic transmutation target): "*an asymptotic ^{232}Th/^{233}U mixture is considered, together with the standard MOX fuel and a possible ^{232}Th/MOX starter*" [26].

3 ^{233}U FROM THORIUM

Due to the more abundance, lower radioactive wastes, chemically stable, high radiation resistance, higher thermal conductivity, lower coefficient of thermal expansion and the non-proliferation, ^{232}Th has a high potential as an additional fertile isotope for the current commercial nuclear fuel. As shown in Figure 1, ^{232}Th could breed ^{233}U fissile material by transmutation to ^{233}Th and then ^{233}Pa.

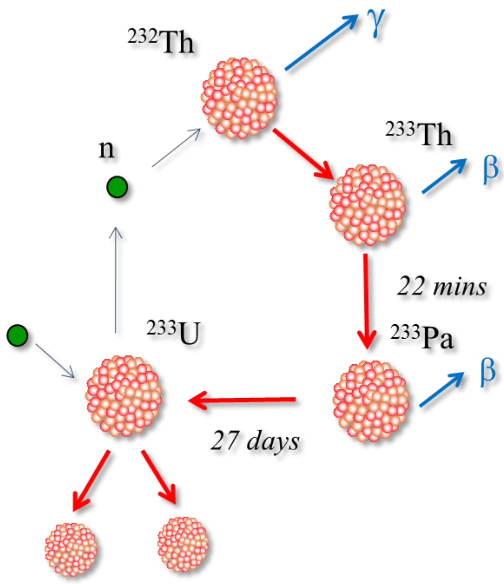

Figure 1: ^{232}Th to ^{233}U conversion overview

From the neutron physics point of view, ^{232}Th has 4 times greater absorption cross section than ^{238}U and also the reproduction factor (neutron yield per fission to neutron absorbed) of ^{233}U is higher than ^{235}U (Table 1), which shows the higher fission performance of ^{233}U than ^{235}U and better conversion ratio of ^{232}Th with respect to ^{238}U which shows ^{233}U.

Table 1: Reproduction factor of nuclear fissile materials.

Reproduction Factor	Thermal	Epithermal	Fast
^{233}U	2.29	2.1	2.45
^{235}U	2.07	1.62	2.3
^{239}Pu	2.15	1.77	2.7

In this section an examination of how much ^{233}U can be produced in an irradiation process using a research reactor flux by Bateman equations and also directly from a CANDU reactor has been provided.

3.1 U-233 Production calculation using Bateman equations

The Bateman equations based on production and consumption of different isotopes for producing U-233 according to the Figure 1 are:

$$\frac{dN_{Th232}}{dt} = -\sigma_{Th232}\phi N_{Th232}$$

$$\frac{dN_{Th233}}{dt} = \sigma_{Th232}\phi N_{Th232} - \lambda_{Th233} N_{Th233}$$

$$\frac{dN_{Pa233}}{dt} = \lambda_{Th233} N_{Th233} - \lambda_{Pa233} N_{Pa233}$$

$$\frac{dN_{U233}}{dt} = \lambda_{Pa233} N_{Pa233} - \sigma_{U233}\phi N_{U233}$$

The required average cross sections and half-lives for ^{233}U production calculation using Bateman equations are provided by the KAERI table of nuclides [27]. The MATLAB software **ode23t** has been used as the equation solver. For a typical research reactor the thermal flux has been considered equal to 5.0E+13 n/cm^2-s. By considering this flux and 350 days of irradiation of a pellet of ThO_2 (10 g) the produced amount of ^{233}U is shown in Figure 2. ^{233}U production will continue after irradiation due to the ^{233}Pa decay, so for a 100 days of irradiation in a research reactor and considering the decay time, different curves in the Fig. 3 are given.

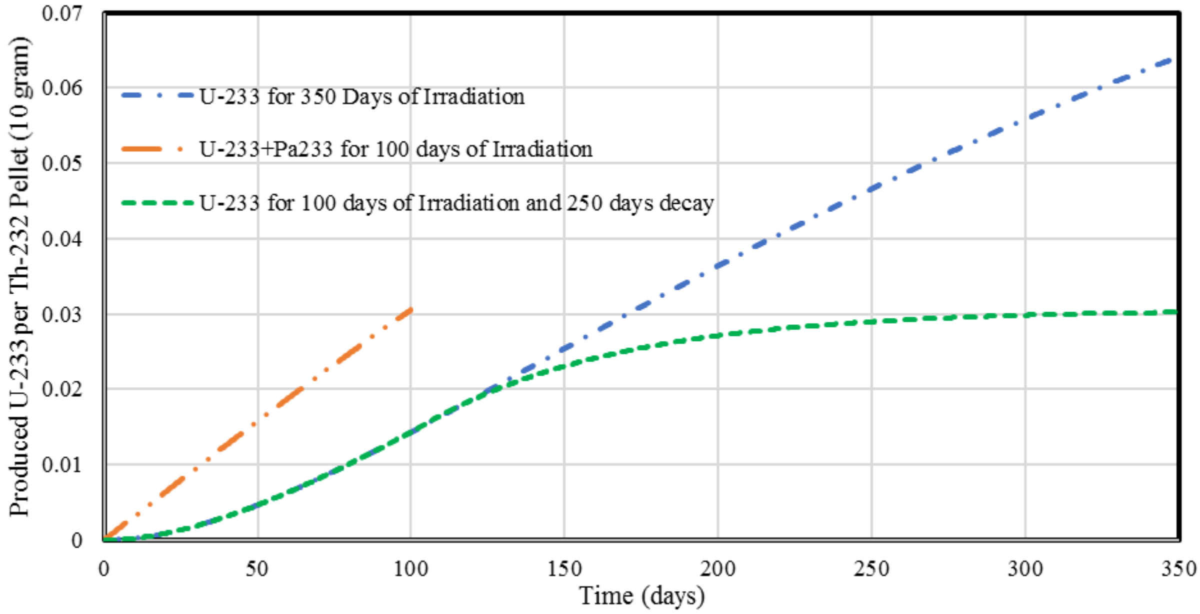

Figure 2: Produced ^{233}U per ^{232}Th pellet (10 gram) for (a) 350 days of irradiation, (b) ^{233}U+^{233}Pa for 100 days of irradiation and (c) ^{233}U for 100 days of irradiation and 250 days decay.

According to the Figure 2, the amount of produced ^{233}U depends upon the fuel burn-up. Also the fuel should be stored for ^{233}Pa decay time and, after that, more ^{233}U could be extracted. Also according to the Figure 2, by comparing curve (b) and (c), it could be concluded that in the calculation process the decay time may be ignored and the accumulated amount of ^{233}U+ ^{233}Pa be considered instead. The figure also shows, using the 10 g of ^{232}Th after 100 days of irradiation with a flux of a typical research reactor, that the yield is 0.0143 gram ^{233}U. After the irradiation time and 'by spending' the decay time of related isotopes, the produced ^{233}U will reach 0.0304 g. These results are independent of the neutron spectrum and the possible burn-up limit; therefore, for a heavy water reactor, the best estimation of yield could be attained according to neutron flux, spectrum and burn-up.

3.2 U-233 Production of a CANDU

CANDU reactors are well suited for thorium fuels due to their combination of: (1) excellent neutron economy (their low parasitic neutron absorption means more neutrons can be absorbed by thorium to produce useful ^{233}U), (2) slightly faster average neutron energy which favours conversion to ^{233}U, (3) flexible on-line refuelling capability. Furthermore, heavy water reactors (especially CANDU) are well established and are part of a widely-deployed commercial technology, in relation to which there is extensive licensing experience.

The production of ^{233}U requires the addition of the fertile material ^{232}Th. For the CANDU reactor where the fuel is natural uranium, only a relatively small percentage of thorium can be added before it becomes impossible to sustain a chain reaction and/or the core becomes subcritical. To evaluate the possible burn-up of a CANDU with mixed UO_2/ThO_2 fuel, a CANDU-6 Standard 37-element bundle has been considered (Table 2).

Table 2: CANDU-6 cell parameters for fuel bundle.

Structure	Material	Density [g/cm3]	T [K]	Inner Radius [cm]	Outter Radius [cm]
Coolant	D2O	0.8121	560.66	0.0000	5.1689
Pressure Tube	Zr-Nb	6.5700	560.66	5.1689	5.6032
Helium Gap	He	0.0014	345.66	5.6032	6.4478
Calandria Tube	Zr-II	6.4400	345.66	6.4478	6.5875
Moderator	D2O	1.0829	345.66	6.5875	14.288
Fuel	UO_2	10.438	941.29	0.0000	0.6122
Cladding	Zr-II	6.4400	560.66	0.6122	0.6540

For the modelling of the CANDU fuel bundle, the DRAGON code [28], as one of the reactor physics computer codes which has been selected by the Canadian nuclear industry for use in safety analysis, licensing and routine operation of CANDU reactors, has been used. This 3-D multigroup neutron transport code uses collision probability model and has been developed and maintained at the École Polytechnique de Montréal. The geometry of the fuel bundle (coloured by region) modelled by DRAGON code is shown in Figure 3.

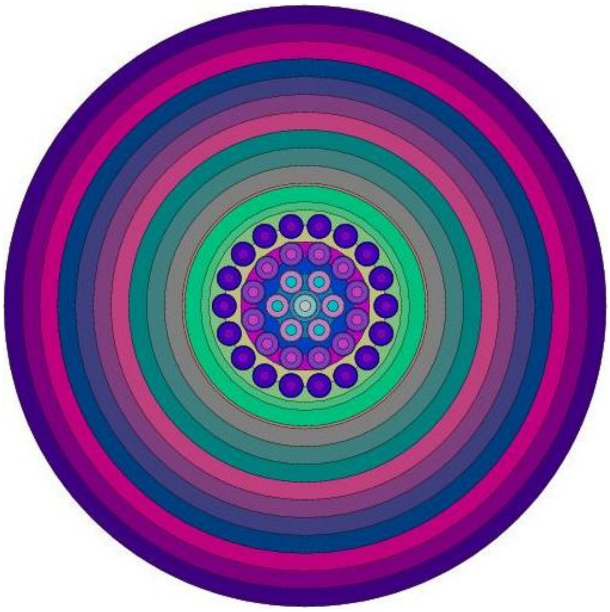

Figure 3: Standard 37-element bundle cell modelled by DRAGON code (coloured by region)

Different amounts of ThO_2 have been added to the natural UO_2, to investigate the possible amount of fertile material before it becomes subcritical. Figure 4 shows the Keff change by burnup for 1-8% of adding ThO2 to the CANDU fuel.

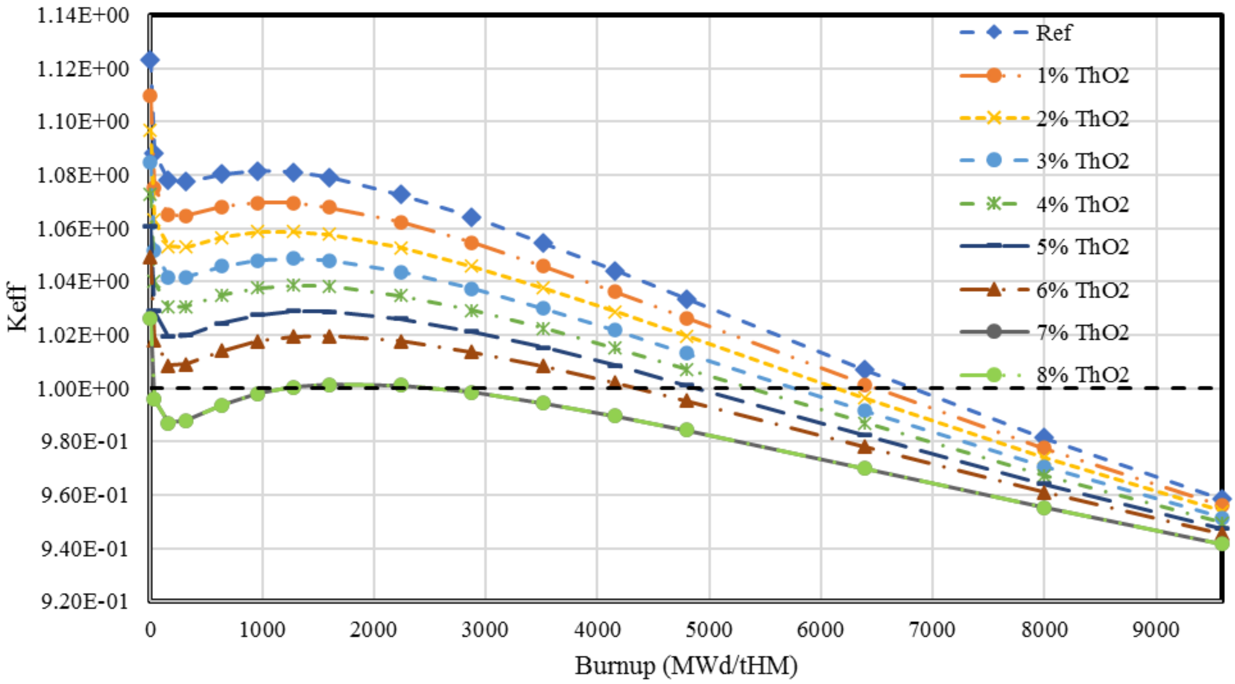

Figure 4: Keff changes by various addition of ThO2 to the CANDU-6 fuel calculated by DRAGON code

CANDU-6 Keff changes by burn-up (Figure 4, Ref. Curve) shows that the fuel could reach up to approximately 7000 MWd/tHM, which is consistent with CANDU-6 technical documents. According to the Figure 4, adding more than 7% ThO2 to the natural UO2, makes CANDU-6 reactor core subcritical. For 7% ThO_2 mixed with natural UO_2, the core could reach up to 4000 MWd/tHM. To have greater inventory of ^{233}U in the CANDU core, next step is compromising and finding near optimum point between possible burn-up and ^{232}Th loading amount which may lead to more ^{233}U should be investigated (using fuel assemblies with a few rods of THO_2 may be investigated in more detail studies).

Figure 5 shows the amount of (^{233}U+^{233}Pa) production by 1-7% ThO_2 loading in the CANDU-6 core. As shown in the previous section, the amount of (^{233}U +^{233}Pa) is equal to the ^{233}U after decay time in storage facilities and the production of short-lived precursors has been included.

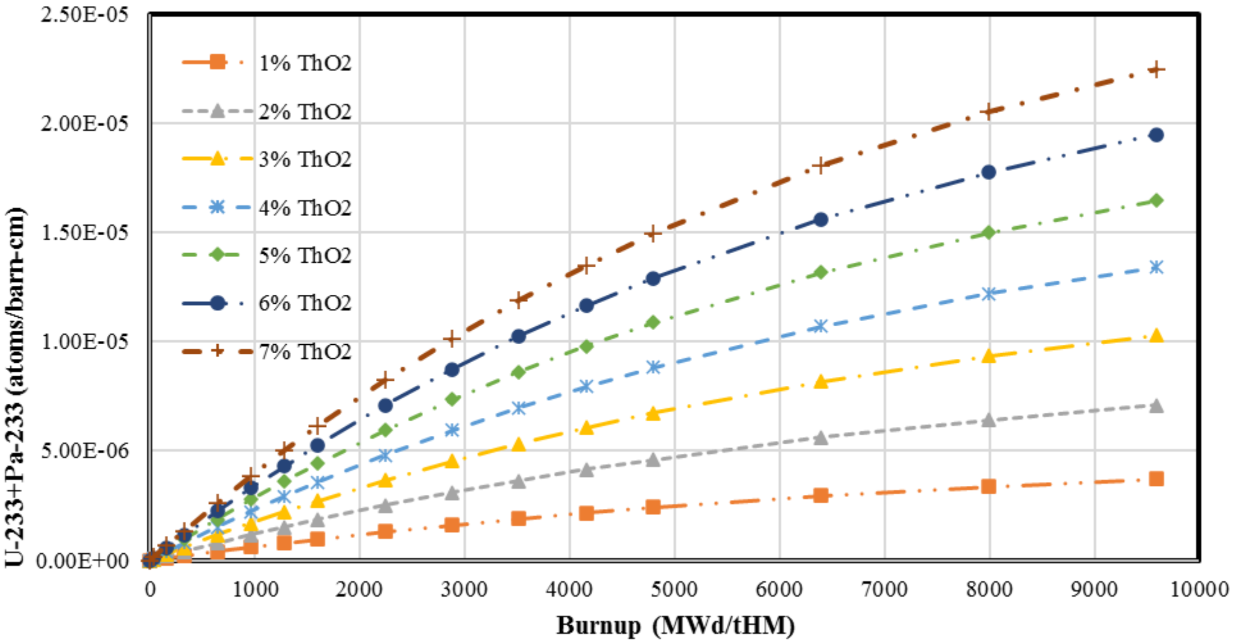

Figure 5: (U-233+Pa-233) production by Burnup changes for different ThO2 loadings

Figure 5 shows that between more ^{232}Th loading and higher burn-up steps, more ^{232}Th loading has an advantage and will produce more ^{233}U. According to Figure 5, for the first MWd/tHM, 2.5E-03 $W_{(U233+Pa233)}/W_{Th232}$ will be produced while for the last step of burn-up (7000 MWd/tHM) 1.4E-03 $W_{(U233+Pa233)}/W_{Th232}$ (%) will be produced. It could be concluded that for more production of U-233, loading more ^{232}Th in less burn-up steps is better. Finally, the average amount of ^{233}U production during the first half of CANDU reactor burn-up (less than 4000 MWd/tHM) is 2.3 g per kg of loaded ^{232}Th per MWd/tHM.

4 THE CHEMICAL SEPARATION OF ^{233}U AND THE STORAGE

Uranium-233 can be recovered and purified from neutron-irradiated thorium reactor fuels through the thorium extraction, or THOREX (Thorium-Uranium EXtraction) process. The Any process chosen in the first instance is likely to be as close as possible to familiar practice. Thorex employs tributyl phosphate extraction chemistry. THOREX is a liquid-liquid extraction process similar to the PUREX process; it was first described in 1955 by A.T. Gresky (Gresky, 1956) of ORNL. This process (and its variants) has been successfully used at pilot scale, notably in the United States to reprocess about 900 tonnes of thorium fuel (~1.5 tonnes ^{233}U) and also in France [29].

Irradiated fuel, containing either thorium metal or oxide, is dissolved in nitric acid containing a small amount of fluoride ions. Uranium-233 and thorium are coextracted into a tributyl phosphate (TBP) solution, which is then contacted with an aluminium nitrate solution to remove traces of accompanying fission products. Dilute nitric acid is used to preferentially remove thorium from the scrubbed organic phase. Uranium-233 remaining in the TBP solvent is stripped into acidified water;

the resulting strip solution is passed through an ion-exchange resin bed in order to concentrate and purify the ^{233}U. Thorium fuel is more difficult to dissolve, and it needs the addition of hydrofluoric acid. Since the thorium oxidation state cannot be modified, U-Th separation is based only on the difference in the affinity (separation factor ~10) of these two elements for TBP. The THOREX process still needs to be industrially developed.

A major challenge associated to thorium reprocessing is related to the unavoidable presence of ^{232}U, which accompanies ^{233}U. One of its decay products, ^{208}Tl, is a 2.6 MeV gamma emitter that will require substantial changes in the downstream fuel fabrication process because it cannot be handled in glove-boxes. In these conditions, the process of conversion to oxide and the recycle fuel fabrication process would need to be developed and demonstrated to be remotely operated within a fully shielded facility. A related challenge is the handling and storage of excess thorium, which will contain ^{228}Th and its highly radioactive daughters for about 20 years [30].

5 THE DREAM OF A CANDU REACTOR

Garland, 2014, and Riznic, 2021, including thermal hydraulic design and safety, extensively discuss Canadian Deuterium Uranium Reactors (CANDU) design and safety. Geometric features and operational conditions make CANDU reactors different from standard light water reactors as PWR and BWR [31, 32]. Differences involve various sectors of nuclear technology, primarily, adoption of natural uranium as fuel and heavy water as moderator, daily loading of fuel, pressure tubes instead of vessel, coolant and moderator flowing in separate circuits. Furthermore, Choi and Park, 2006, and Neacsa et al., 2018, discuss technology aspects connected with the use of thorium in CANDU (see also Jeong et al., 2008, and Milgram, 1983) [14, 33-35].

A snapshot view of the possible strategy of exploitation for a CANDU reactor, e.g. installed in an island like Sardinia, neglecting any decisive issue connected with the use of nuclear technology in Italy and without entering into technology aspects like the occurrence of accidents and the nuclear fuel waste management, includes the following delivery:

a) Production of electricity.
b) Production of desalinated water (high benefit in an island).
c) Production of fissile material (^{233}U) to reduce energy dependence.

Furthermore, the construction in Italy of a Canadian reactor puts specific ‘additional’ challenges like political feasibility of a project based on a non-EU reactor design (although the reactor is already installed in Romania with construction started when Romania was not an EU Country) and earthquake-tsunami resistance. Here we skip related discussions, although we recognize their importance.

We pursue the objective hereafter to determine the amount of thorium that may constitute a strategic energy reservoir sufficient to satisfy electricity needs for half a century (50 years) in Italy, assuming (for simplicity’s sake) the current yearly electrical energy consumption. The achievement of the objectives needs a specific calculation for the mass of ^{233}U achievable from unit mass of ThO_2 under assigned neutron flux and energy spectrum.

The analysis consists of eight steps assuming the availability of two 1000 MWe (or 3000 MWth) reactors: an ‘ideal CANDU reactor’ from which ^{233}U is directly (and daily) recoverable and a standard PWR working indifferently with ^{235}U and ^{233}U fissile isotopes, to fix the needs of fissile material.

1) Features of reactor core. The core of a PWR needs about 2 tons of enriched fissile material to keep criticality and produce thermal power.

2) Assuming that 40% of energy derives from Pu (as is the case of ^{235}U core), around 0.7 ton/year of fissile material is necessary.

3) In one year (full power operation) 9 x 10^6 MW-hours-e are generated using 0.7 tons of fissile.

4) At the end of the life (60 years) 5.4 x 10^8 MW-hours-e are generated, requiring (0.7 x 60 =) 42 tons of fissile material. Therefore, we may conclude that we need about 40 tons of ^{233}U to operate a standard 1000 MWe PWR for 60 years (we assume ^{233}U into a matrix of natural uranium; in this way contribution of Pu to the produced energy remains equal to the case of the standard PWR; Also the advantage of better reproduction factor of ^{233}U than ^{235}U has been neglected to cover the rough assumption in current estimation).

5) Now, we calculated the yield of (2.3 g ^{233}U) / (kg ThO_2), under conditions available in a typical CANDU core (i.e. a situation we can consider from an industrial viewpoint).

6) Now we assume that in a CANDU core we irradiate 6 tons (7% ThO_2) of ThO_2 per 1MWd/tHM and simultaneously maintain its criticality which according to the Figure 4 it's possible. Therefore we retrieve 14 kg of ^{233}U per 1MWd/tHM (approximately) equivalent to 100 kg of ^{233}U per year. Optimizing the processes, i.e. reducing the electricity production, possibly we can arrive at 300 kg/year of ^{233}U or approximately 20 tons of ^{233}U at the end of the life. This implies that we need two CANDU reactors to feed one 1000 MWe PWR reactor for its life.

7) Assuming for Italy in the forthcoming 50 years an average power need of 50000 MWe (actually this is lower today); we arrive at an electrical energy need of 2.2 x 10^{10} MW-hours-e. Considering item 4), this implies that we need approximately 1700 tons of ^{233}U to satisfy all electricity consumption, for the next 50 years.

8) Assuming CANDU be able to irradiate 6 tons of ThO_2 per year, approximately after one year ^{233}U could be separated from ThO_2 and after reprocessing at least 4 tons of ThO_2 could be used again. By considering these amounts of retrieved ^{232}Th, for 60 years around 130 tons of ^{232}Th will be required for 20 tons of ^{233}U production. Accordingly, for 1700 tons of ^{233}U production, around 11000 tons of ThO_2 will be required. This approximately corresponds to 1000 m^3 of ThO_2, or a couple of small sized warehouses, including packaging structures.

6 CONCLUSION

Based on the history and current trends for its exploitation, an easy confirmation of the thorium as a viable energy source for the future constitutes the main achievement from the documented activity, although not a cost-effective deployment of ^{233}U, is considered. The wide variety of possible thorium cycles results from the literature review together with the consequent need of designing a consistent related strategy, i.e. to optimize the thorium cycle.

Specific investigations show that 2.3 g of U-233 per kg of ThO_2 are a possible yield of thorium irradiation and that 1000 m^3 of ThO_2 (storable inside a couple of medium size industrial warehouses) may form a strategic energy reservoir suitable for half a century electrical energy consumption in a country like Italy.

The thorium dioxide yields ^{233}U following a few months irradiation in reactors like CANDU and Atucha type currently in operation, or AHWR under design in India, which is in the progeny of CIRENE reactor designed and built in Italy and never operated. Direct storage of ^{233}U involves technologically solvable issues and consideration of safeguards for the ownership and storage of fissile materials (not a part of present study).

The operation of a CANDU nuclear reactor in Italy may lead to creating a strategic energy resource equivalent to tons of gold in a bank in the area of financial markets, e.g. suitable to smooth instabilities of those markets. In the (dream) world of science and technology, the same reactor is suitable to produce at the same time:

1) Electricity,
2) Desalinated water,
3) Fissile material from the strategic energy reservoir above defined.

The performed study deals with the description of a dream: it does not consider the practical issue of acceptance for the nuclear technology, in addition to costs. Namely, people and political acceptances remain an unsurmountable obstacle in democratic countries, specifically true without the awareness of the environmental impact and of the duration and powerfulness of current energy sources. As a side comment, we may add here that, because of long-term strategies needs, nuclear technology for energy production is not an option for democratic countries, characterized by continuous changes in public opinions, easily driven.

Nevertheless, the present summary of a dream-investigation is the way to communicate to the public the loss of an opportunity.

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