Nano-structures materials for Energy Direct Conversion and Fuel Breeding

L. Popa-Simil, I.L.Popa-Simil

LAVM LLC, Los Alamos, NM 87544, USA

ABSTRACT

Almost all the modern applications (e.g. terrestrial and space electric power production, naval, underwater and railroad propulsion and auxiliary power for isolated regions) require a compact-high-power electricity source. One solution to reduce the greenhouse emissions and delay the catastrophic events occurrences may be the development of massive nuclear power. More, there is a concern that the modern civilization may exhaust the oil based energy resource within few decades. Thus, it is better to find other sources of energy that can replace the Carbon based energy resources. The actual basic conceptions in nuclear reactors are at the base of bottleneck in enhancements. The actual nuclear reactors look like high security prisons applied to fission products. It is not about release of the fission products, but to give them the possibility to acquire stabile conditions outside the hot zones, in exchange for advantages – possibility of enhancing the nuclear technology in power production. Three main developments are possible by accommodating the materials and structures with the phenomenon of interest like the high temperature fission products free and direct conversion nuclear reactors, cleaner nuclear fuel breeding and the fusion energy harvesting.

Keywords: nano structure, nanograin, breeding, nuclear fuel

1 INTRODUCTION

The actual planet thermal power is about 14 Tw, which does not include the transportation. The total irradiation power received from sun is about 200 Pw, which shows that soon the technological power is becoming 0.1% from the average power received from the sun and the thermal pollution started to count in the planetary energetic balance.

Global warming and global dimming, the two facets of the climate change put the civilization in front of capital choices. The message from the nature says now:"Stop burning carbon!" because the chemical mechanism influence over planetary climate is orders of magnitude more efficient than the direct thermal pollution. That translated means: "It is still OK not having high efficiency but burning carbon is prohibited", and even if everything will be set by tomorrow there will be a hard price to be paid next hundred years for what have been achieved up to date. In front of this decision the world realized that there is NO good solution, no really clean and reliable energy, most of the solutions having distorted images by the politico economic speculations based on partial knowledge of the population. That turns into the following brief evaluation based on what means to have a power unit and how reliable that power source is.

To produce 1 Gwday of thermal energy is required 1 kg of ^{239}Pu or ^{235}U, less than ¼ cup of material generating about same amount of primary waste but less dense, and 3 times more secondary waste from the neutron capture. The initial investment scales about 2-4 \$/w, while the price of fuel is another 5,000 \$/day, with lifetime >30 y.

To get the same amount with oil it takes about 2.6 kt, and more than 4 kt with coal, which means about 2,500 m^3/day, releasing twice as much CO_2. The initial investment is about 0.5-2 \$/w and the cost of fuel is about 2.5 mil. \$/day, with a lifetime >30 years.

To get this amount from the wind may take about 20-100 windmills, with about 1 windmill/ha takes about 1 km^2, but not for the whole day. For only ⅓ of day with solar power in the best deserts it may take 4 km^2 and about 100 Mt equipment, but does not work in cloudy days. The investment costs are 4-8 \$/w and the other costs and lifetime are undefined.

Adding a such unreliable source in a national grid, obliges all the baseline producer to waste an equivalent power between ½ and ¾ to dumb in the river just to be in stand by to deliver in the moments the renewable energy device is not receiving from the nature.

The power reliability national security and territorial safety are supplementary conditions that aggravate the problem. In order to harvest efficiently some renewable power there is necessary to have a reliable fast response backup which to take the fluctuations from the nature and keep the right balance between the supply and demand.

The nuclear alternative remains the only good compact solution, but for backup the response time is not good enough, and that requires hydro or gas turbines.

2 THE NUCLEAR OPTION

The nuclear option seems to be among the few alternatives that comply to the most of the requirements and allows safe efficient renewable energy harvesting. In fact, it has its own drawbacks, making it unlikely for most of the population.

The most acute problem is that of the nuclear waste and the cost impact of the hazard exposure.

More the nuclear industry is mature, with more than 60 years of experience, and most of the technologies are near their physical limits, any small improvement being expensive and difficult to achieve.

The main drawbacks in nuclear power production come from the fundamental concepts applied to nuclear fuel.

The main problems of the nuclear fuels are:

- Low thermal conductivity of the fuel which drives to low power density (about 200-500 w/cm^3)
- Inappropriate temperature distribution which induces stress and mechanical failures
- Aggravation of the mechanical and thermal properties with the burnup

that drives to the direct consequences as:

- short fuel lifetime inside the nuclear reactor of about 10-30 months
- highly radioactive nuclear fuel, and important amount of low radioactive highly toxic waste
- high toxicity chemical processing as Purex and Urex to extract Plutonium and Uranium
- bottleneck of disposal process in the geological storage of the nuclear fuels
- anticipated nuclear fuel peaking in about 50 years if the actual slow development trend is maintained

All these drawbacks, which make the nuclear technology less attractive, and less clean and environmentally friendly by abusing environment resources, have the spring in obsolete concepts and technologies applied by highly conservative people.

The most important is related to inappropriate treatment of the fission products in opposition with the nature's laws, of equally distributing the mass and energy on all the available freedom degrees (space and time). That is why the imprisonment concepts based on up to nine confinement layers with the sole purpose of immobilizing the fission products on spot drives to high costs for any enhancement.

In fact, this paper do not state that these fission products are less dangerous as is scientifically established and have to be released, it only states that a better nature understanding with better physics may bring a relief.

3 THE MICRO-HETERO-STRUCTURE

The fission products induced damage was observed and addressed since 1950 in the dispersion fuel research[1, 2], attempting to create a new fuel material called "cermet".

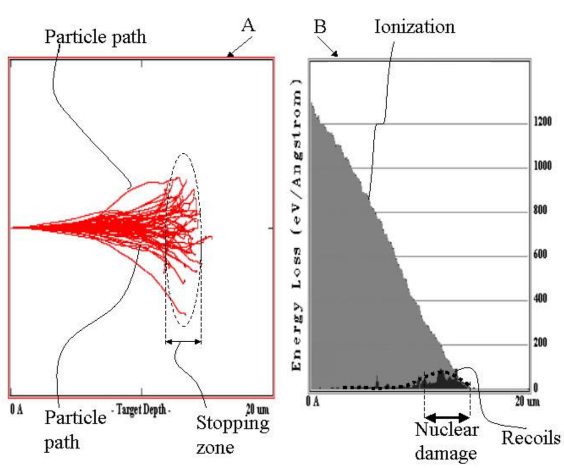

Fig. 1 The radiation damage simulation

The cermet studies showed that the smaller the fuel particle is, so are the fission products damage, but the damage is transferred to another solid that has its limitations. The MC simulation [3] of the fission process in Fig. 1 clearly showed that up to 80% of the path the fission products are inducing less than few percents of damage; all the damage takes place towards the end of the range.

This result driven to the concept of the tri-layer micro hetero structure [4], where the fuel is made shorter than the effective fission products range. This development offered the possibility of releasing the fission products out of the nuclear fuel with the possibility of being collected outside the reactor's hot zone and separated accordingly.

The behavior of the poison accumulation in the nuclear fuel in the hypothesis of using a micro-beads fuel, coated in a stabilizer material and washed by a liquid metal drain fluid is presented in Fig.2.

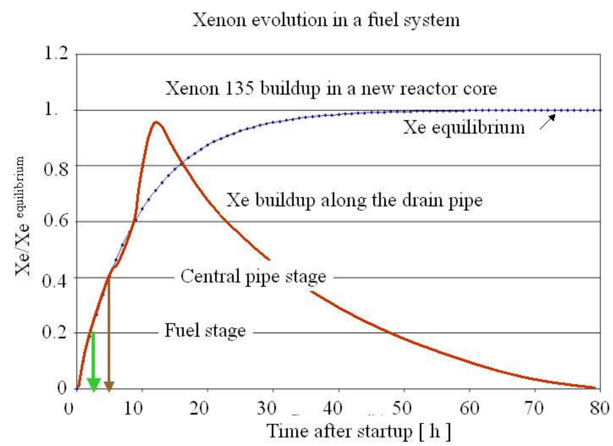

Fig. 2 – Fission products buildup modification

Fig. 2 shows that in a PWR nuclear reactor the ^{135}Xe is building up to an equilibrium value [5], being continuously burned out due to its high n absorption cross-section of about several thousands higher than the fissile material. If the reactor is stopped the Xe peaks and then decays as shown in Eq. 1.

$$^{135}Te \xrightarrow{<.5\,\min} {}^{135}I \xrightarrow{6.7h} {}^{135}Xe \xrightarrow{9.2h} \xrightarrow{9.2h} {}^{135}Cs \xrightarrow{2\times10^{6}\,y} {}^{135}Ba \qquad (1)$$

The other isotopes simply reach the power dependent equilibrium value, and remain there following the power.

The advantage of the drain system is that after generation in short time the fission products are removed from the high neutron flux zone and the poisoning effect is dimmed simultaneously with a simplification in the decay schemes where the n absorption branches are missing.

The relation in Eq 2. gives the total amount of radioactive waste.

$$\frac{1}{\langle n_{fission} - 1 \rangle} = \frac{\sum_{fissile} \sigma_i N^i}{\sum_{absorbtion} \sigma^j N_j + S_L} = \frac{F}{L} \qquad (2)$$

where S is the fission term, generating the fission products while L is the loss term containing the leakage through the surfaces S_L and the neutron absorption term.

To minimize the nuclear secondary waste given by the so called “neutron activation” process is needed to design the nuclear reactor in such a manner that most of the absorption to be made in fertile materials as depleted uranium or thorium, or other desired isotopes instead in structural and shielding materials.

Here comes in place the concept of using super-grade isotopic enriched materials that often comes into conflict with the so-called “non-proliferation” [6-9] forethoughts and international and states own capabilities distrust.

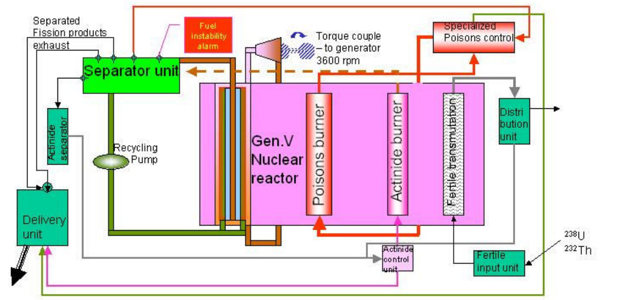

Fig. 3 – The structure of a isotopic nuclear reactor

In such a nuclear reactor the fuel is made from isotopic enriched material as ^{235}U, or ^{239}Pu, surrounded by fertile transmutation unit, specialized poison and residual actinides burner systems.

This type of reactor requires a more complex operation, similar to a “living being” not to a “hot rock”, and manifesting life like cycles. The advantages are related to ecologic compatibility releasing less volume of waste and less toxic.

4 THE NANO-BREEDING STRUCTURE

To obtain super-grade material with minimal chemistry a new process based on nuclear selectivity of recoils have been developed. Fig. 4 shows the principal operation diagram. A fast neutron n n is heating a ^{238}U or ^{232}Th nucleus located into a nano grain of cluster size. Due to the impulse transfer and further beta decay as in Eq. 3 the nucleus becomes a Frenkel defect being driven out by a process of diffusion enhanced by cluster rejection.

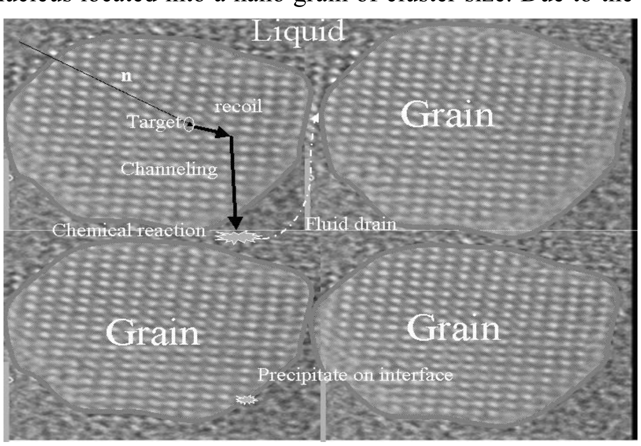

Fig. 4 – The recoil selective isotopic separation

$$^{238}_{92}U+^{1}_{0}n+\ddot{v}=^{239}_{92}U+\beta+\ddot{v}=^{239}_{93}Np+\beta+\ddot{v}=^{239}_{94}Pu \quad (3)$$

The cluster-enhanced rejection is applied to the transmuted nucleus as ^{239}Np and is acting as cluster-attractive force for ^{238}U recoiled by neutron scattering.

The combined effect of cluster enhanced selective diffusion with selective recoil reaction drives to a high concentration of ^{239}Np in the drain fluid, which takes it out from the hot zone. Fig. 5 shows a nano-structure stabilized under a gradient of particle magnitude based on nano-flow of a reactive fluid selective to the new product and inert for the fertile material, having in the same time small n absorption cross-section.

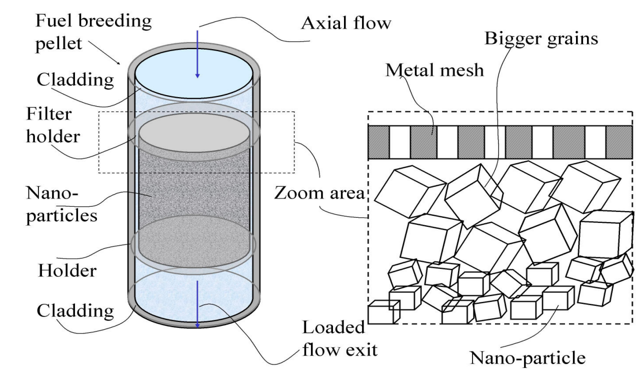

Fig.5 – The nano-breeding pellet

The collateral results in nuclear medicine interest isotopes showed a difference between the low purities predicted by the recoil model, versus the high collection yield and purities obtained experimentally [10].

5 HIGH BURNUP STRUCTURES

The micro-hetero structure fuel made of a refractory micro mesh material used as mechanical support to deposit nuclear fuel beads made of oxides or carbides incorporating fissile material These fuel beads are coated in a refractory material, making a delta layer with role in faceting and adhesion forces matching between the fuel bead and the drain liquid metal. The fuel made with beaded mesh structure is looking like an elastic, compressible felt. When squeezed, the material reactivity is increasing because some of the liquid metal is eliminated. During the operation, the fissile material is burned and eliminated into the drain liquid as fission products. In this way the fissile material mass in the bead is reducing, while the drain fluid mass is increasing if the volume is maintained constant. By squeezing the fuel the ratio is corrected and the reactivity of the fuel is brought back to criticality. As shown in Fig. 6 the new fuel is introduced at the large end and while it advances in burnup is pushed towards the narrow end, being squeezed.

In this manner more than 99% of the initial fissile material load may be burned, the limitation being brought by the mechanical safety of the highly irradiated structure.

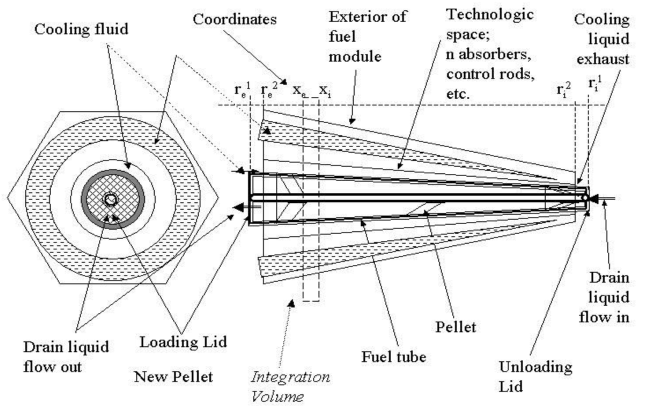

Fig. 6 – Variable geometry nuclear reactor fuel channel

A near "perfect burning reactor" it is achieved, which delivers as nuclear waste the mass of the burned nuclear structure and the residual structure activated mass, which represents another 10-20% from the fuel mass. The rest of the leakage neutrons are used to generate new fuel almost twice as much than burned. By this procedure the entire reserves of nuclear fuel, Uranium, Thorium may be converted in energy, and is expanding the nuclear fuel resources more than 200 times.

6 DIRECT NUCLEAR ENERGY CONVERSION INTO ELECTRICITY

Developing a repetitive structure of nano-layers there is

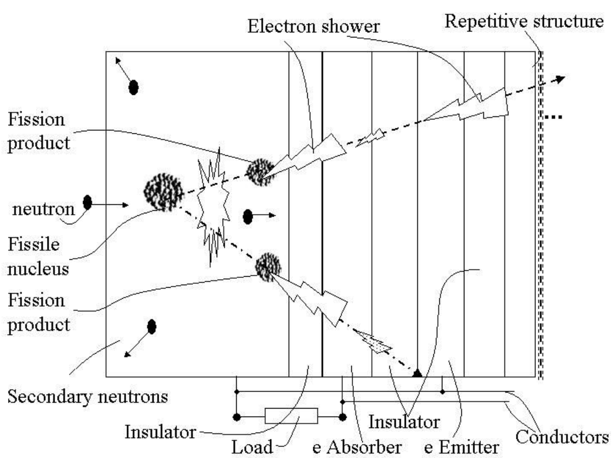

Fig. 7 – The direct conversion principle

possible to collect the knock-on electrons and to obtain a voltage between the layers and electric current. The device looks like a super-capacitor, loaded by the fission or any other radiation energy, as shown in Fig. 7 and discharged on an electric Load. This structure may contain or not nuclear fuel and may even operate in cryogenic conditions, giving by quantum effects efficiencies higher than 90%.

The device may be used with fusion nuclear reactors too, where the final product might be He, with no radio toxicity.

7 CONCLUSIONS

The new developments brought by nano-technologies transforms the actual nuclear industry into the cleanest environmentally friendly power production.

The revolutionary enhancements possible to be brought to nuclear power production improve almost all parameters by more than two orders of magnitude, the progress being similar to that obtained by the transition from the massive stone wheel to the actual metallic mesh based tires.

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