MONTE CARLO CALCULATION FOR VARIOUS ENRICHMENT LITHIUM COOLANT USING DIFFERENT DATA LIBRARIES IN A HYBRID REACTOR

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The main objectives of this study

- Presentation of the effect of the natural lithium and different enrichment lithium for tritium breeding capability,
- Investigation of the neutronic parameters such as TBR in the blanket and radiation damage; DPA and He-production as a lifetime of one full power year (FPY) in the FW,
- Using the different data libraries for comparing neutronic parameters.

INTRODUCTION

In the 21st century, world energy needs have increased dramatically because of world population growth; the sustainable developing and the continuing improve living standards.

Today, combustion fossil fuel provides 88% of the world's energy. However, barriers of fossil fuel utilization include limited supply, pollution, CO_2 emissions, thought to be responsible for global warming, etc. In addition, they have storage problems and require a large plant to produce high levels of energy. Therefore, energy requirement of the future is nearly impossible to be met by the conventional methods of present-day energy production.

In this respect, nuclear fusion is safe, clean and unlimited energy source particularly the abundant fusion fuel, contrary to fission fuel and conventional fuels. Besides, it has environmental advantages compared to other energy sources.

But, the commercial pure fusion reactors have not been expected to run in the short period. Because the fusion reactor have many problems such as plasma instability, high material damage, high radiation, sensitive fluid jet design, high driver power and other complex problems.

Thus, a fusion-fission reactor namely hybrid reactor would be an appropriate solution for some of these problems. Furthermore, the aim of the hybrid reactor is to improve the eutronic and economical performances of fusion reactors by means of higher energy production and/or significant fissile fuel breeding.

Some advantages and main structure of the hybrid blanket has been given in earlier works.

Geometrical model for neutronic calculations

Figure 1 shows that a line neutron source in a cylindrical cavity simulates the fusion plasma chamber in this concept. The latter is surrounded by a FW. In this study, a stainless steel (SS304) was considered as FW and fuel cladding material. In the fissile zone, a typical LWR spend fuel, UO2 in hexagonal geometry as 10 rows in the radial direction was used. The fuel zone is considered to be cooled with natural and different enrichment lithium which contributes to tritium breeding ratio, at the same time, as a working fluid for the nuclear heat transfer out of the fuel zone. The coolant to fuel volume fraction is Vc/Vf = 2. The radial reflector is made of Li2O for production of tritium (T) and graphite in a sandwich structure. This measure reduces the neutron leakage drastically and leads to a better neutron economy.

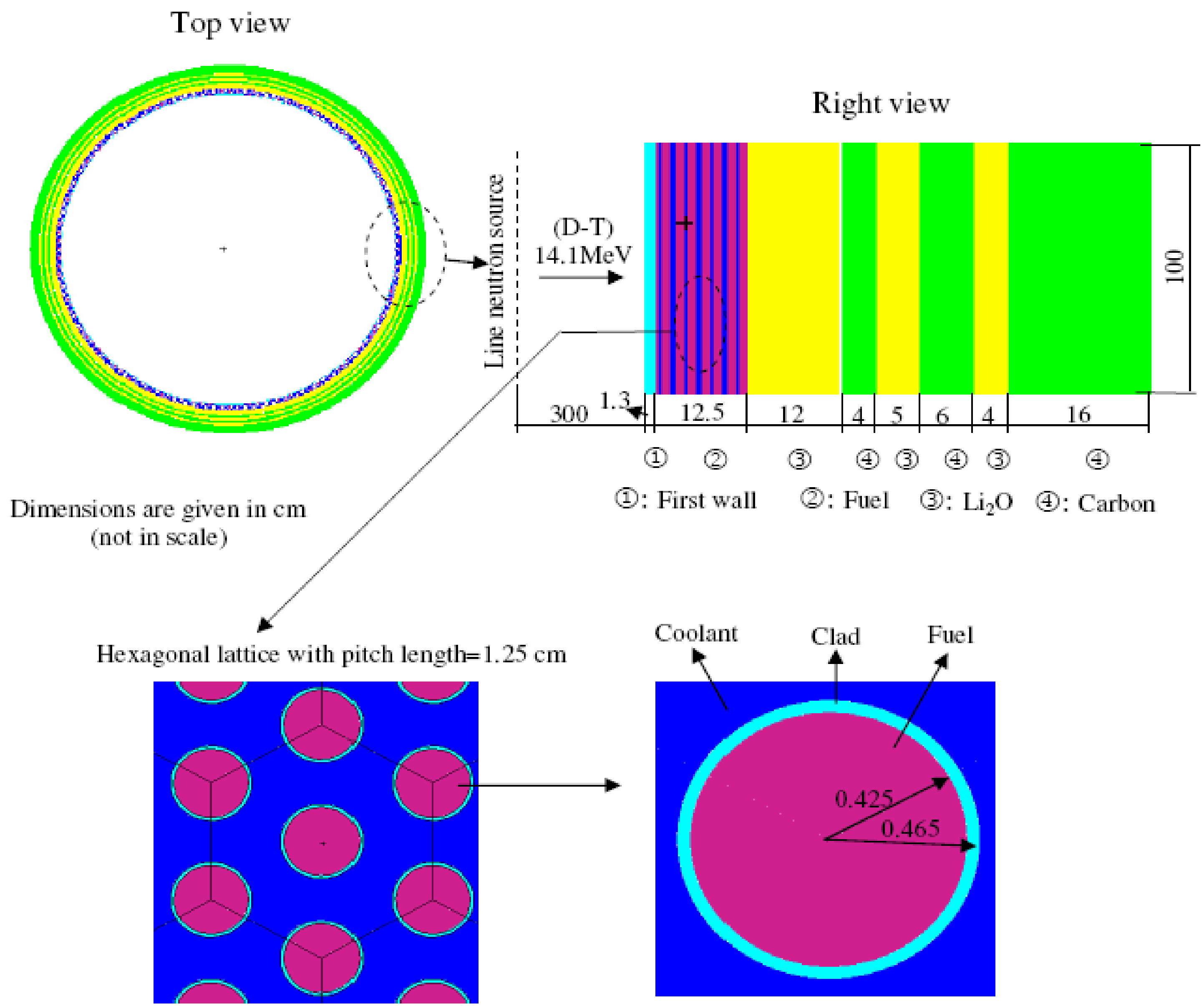

Figure 1. Cross sectional view of the investigated blanket.

Table 1: The blanket materials of the hybrid reactor

Material	Density(g/cm^3)	Zone
UO_2	8.76	Fuel
SS304 Stainless Steel	7.94	First wall
Natural-Li (Enrichment of $_6Li$)	0.53	Moderator (coolant)
Li_2O	2.01	Tritium breeding
Carbon	2.26	Reducing neutron leakage

In hybrid reactors, one of the most important parameters is the selection of the suitable coolant to improve its neutronic performance remarkably and also to breed sufficient tritium for a self sustaining operation as well as to transfer nuclear heat out of the blanket.

The most important properties of tritium breeders would be summarized as: high breeding properties, low melting point, high boiling point, high thermal conductivity, low density, low vapor pressure, high chemical stability, no tritium solubility, low viscosity, low cost.

Considering this properties, a suitable material in the candidate liquid coolants is natural lithium for tritium breeding.

Moreover, the operation temperature required for the natural lithium is between 180.5 oC (melting point) and 1342oC (boiling point).

Therefore, the natural lithium obtains a wide range for the operation temperature of the working fluid

NUMERICAL CALCULATIONS

Calculations were conducted using a (D,T) fusion neutron driver for the hybrid reactor.

The neutronic performance of the hybrid blanket have been evaluated for the NWL of 2.25 MW/m2 by full reactor power (plant factor PF=100%).

This corresponds to the fusion neutron flux of 10e14 n/cm2.s (14.1 MeV) at FW for conventional (D,T) driven hybrid reactor.

Calculation tools

The neutron transport calculations were carried out with Monte Carlo Methods, three-dimensional particle transport code MCNP, the most recent version MCNP5 1.4.

MCNP5 allows an authentic geometrical description limited only with available computational power.

It uses the built-in most recent continuous energy nuclear and atomic data libraries (ENDF/B-V and ENDF/B-VI) and activity cross-section data library CLAW-IV for atomic displacement (DPA)and the gas production in the FW structural materials.

RESULTS AND DISCUSSIONS

Tritium Breeding Ratio

For a self sustaining fusion reactor, TBR > 1.05 will be required. The DT driven fusion-fission (hybrid) reactor should contain lithium as a fusion fuel source material.

In this study, there two main contributors to tritium breeding, namely coolant in the fuel zone and in the sandwich structure of the blanket, which Li2O zones locate at outer of the fuel zone.

The TBR values were calculated 1.15, 1.16 and 1.10 for natural lithium using ENDF/B-V, ENDF/B-VI and CLAW-IV cross-section data libraries, respectively.

While the TBR values increase with enrichment of Li-6, the TBR values reach 1.32, 1.30 and 1.38 at 90 % enrichment of Li-6, seen in figure 2.

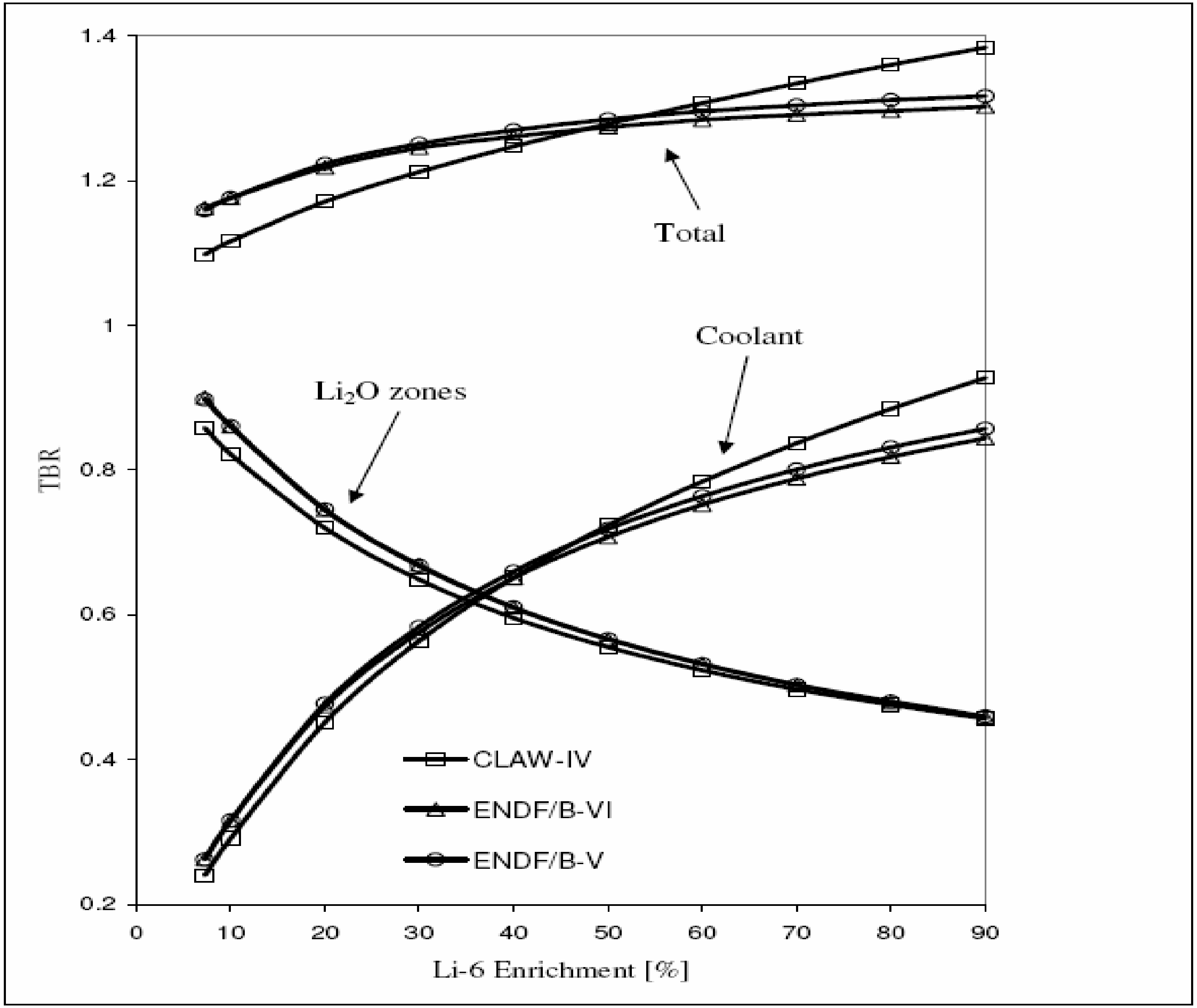

Figure 2. TBR values in the blanket versus ^{6}Li enrichment of the coolant using three data libraries

Radiation Damage

The high energy neutrons will cause atomic displacement via displacement cascades and gas productions various nuclear reactions within structural materials. The radiation damage will limit life time of the FW material. Design concepts for fusion energy reactors indicate a life time of FPY for the FW structure. This means that every year first wall material must be replaced.

Calculations of Radiation Damage in the FW were made for three different data libraries; ENDF/B-V, ENDF/B-VI and CLAW-IV.

Gas Production

All hydrogen isotopes, produced by (n,p), (n.d), (n,t) reactions will diffuse out of the metallic lattice or form metal hybrids.

The H-production values were obtained 833.9, 735.2 and 717.9 appm/FPY for the ENDF/B-V, ENDF/B-VI and CLAW-IV at natural lithium, respectively. (atomic parts per million [appm])

The H-production values decrease rather quietly with increasing enrichment of Li-6, and they reach 815.8, 725,1 and 701,3 appm/FPY at 90 % Li-6.

Alpha-particles will remain in metal and produce helium gas bubbles. The highest He-production values were found 264.6, 235.5 and 238.6 appm/FPW for natural lithium using the ENDF/B-V, ENDF/B-VI and CLAW-IV, respectively.

He-productions decrease rather quietly with increasing enrichment of Li-6, and they reach 260.8, 232.6 and 234.2 appm/FPY at 90 % Li-6, seen in figure 3

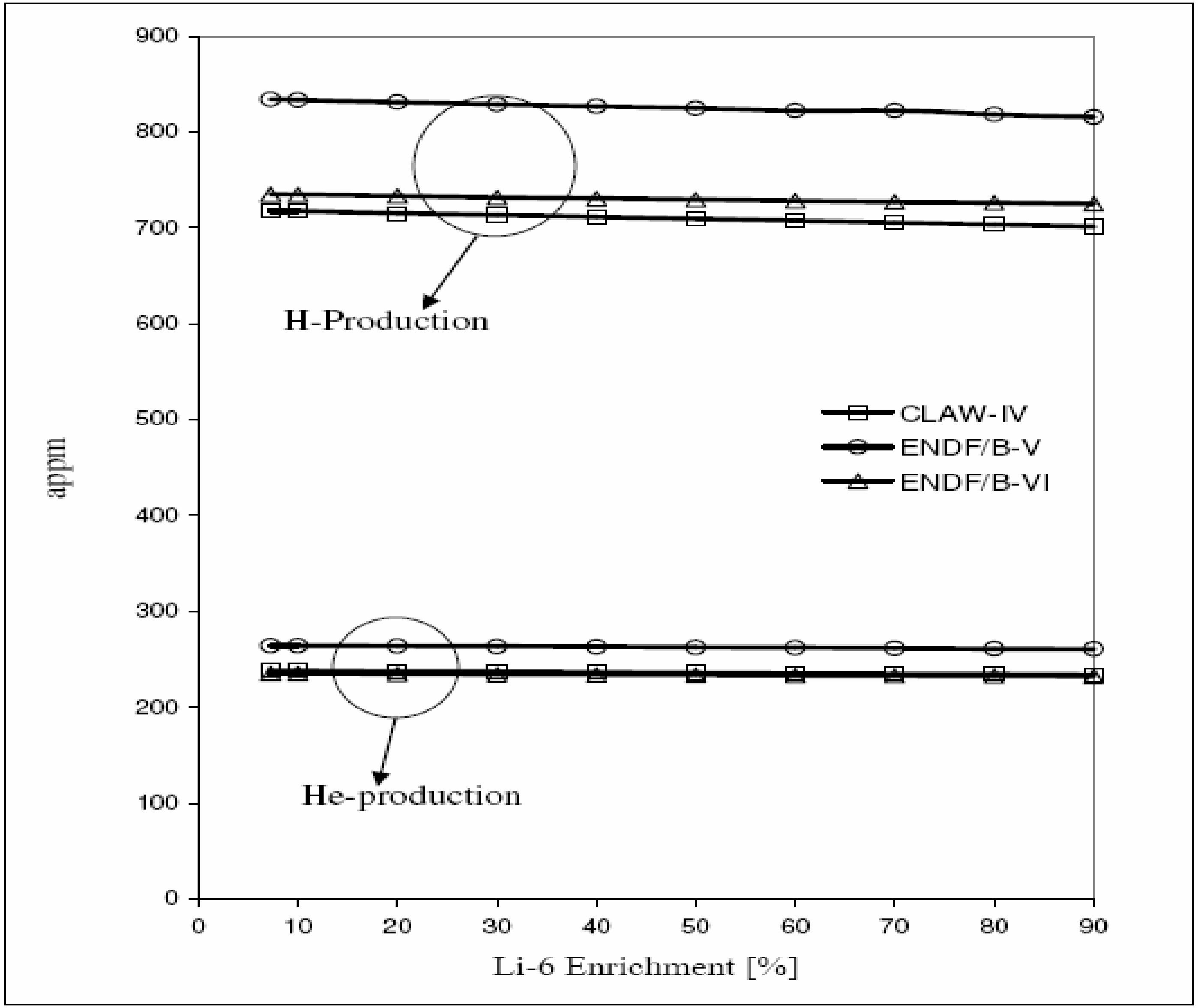

Figure 3. Gas productions in the first wall versus ^{6}Li enrichment of the coolant using three data libraries

- H-production values could not take into consideration of the material damage criterion of the fusion reactors.
- Blink, A. et al. and Perlado, M. et al. have suggested a helium production limit of 500 appm in the FW structure. When this limit was considered as criteria, the FW replacement will be needed every 2.1 years for all investigated cases.

Atomics Displacement

Displacement of the atoms from their lattice sites as a result of collisions with highly energetic fusion neutrons, called displacement per atom (DPA). The DPA is the fundamental process of radiation damage in metals.

In nuclear reactors, the DPA is caused by scattering of fast neutrons; on the contrary, thermal neutrons do not cause atomic displacement.

In the FW, after 1 year operation period as DPA/FPY using CLAW-IV cross-section data library, the highest value 29.66 was found for natural lithium while the lowest value 26.56 was for 90 % Li-6. Figure 4 shows DPA values as a function of enrichment of Li-6.

In the literature, two different DPA limit have been proposed for stainless steel of structural material in the FW: DPA=165 and DPA=100. In this study, a conservative radiation damage limit of 100 DPA was selected for calculations. Then, the FW will be replaced every 3.5 years.

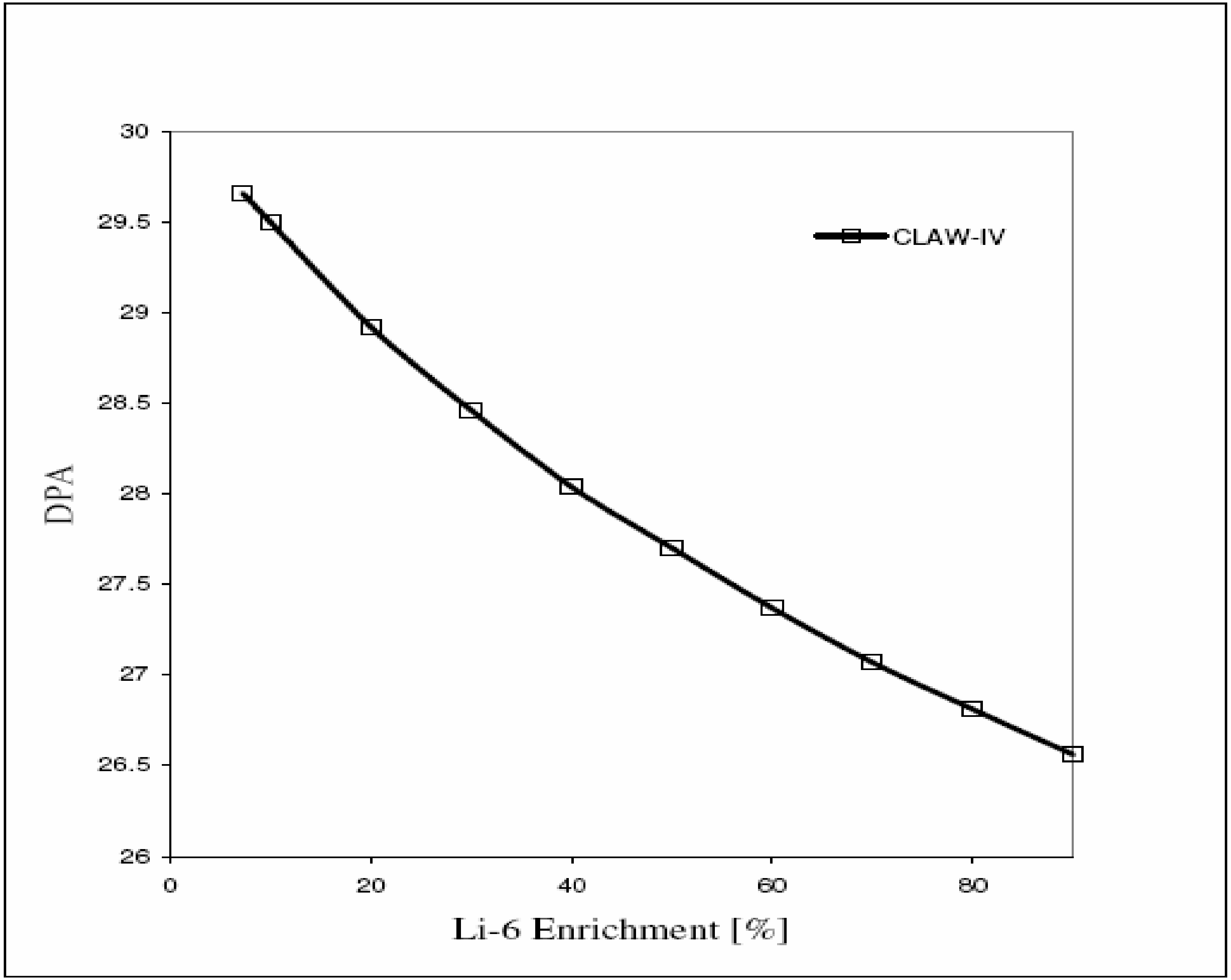

Figure 4. DPA value in the first wall versus ^{6}Li enrichment of the coolant

SUMMARY AND CONCLUSIONS

The main conclusions can be summarized as follows:

1. The most recent version MCNP5 1.4 code with three different data libraries (ENDF/B-V, ENDF/B-VI and CLAW-IV) was applied successfully for the evaluation of the neutronic parameters of a hybrid reactor. Obtained results indicated in a good agreement with previous studies.
2. The TBR values were calculated 1.15, 1.16 and 1.10 for the ENDF/B-V, ENDF/B-VI and CLAW-IV cross-section data libraries at natural lithium, respectively. While the TBR values increase with enrichment of Li-6, the TBR values reach 1.32, 1.30 and 1.38 at 90 % enrichment of Li-6.

3. H-production values could not take into consideration due to diffusing out of the metallic lattice or form metal hybrids.
4. When the limit of 500 appm is considered as criteria for helium production in the FW structure, the FW replacement will be needed every 2.1 years for all investigated cases.
5. The limit of 100 DPA was selected as criteria. Then, the FW will be replaced every 3.5 years.

Thank you