

Biological Side Effects and Reproductive Hazards in Laboratories of Plasma Physics and Nuclear Fusion Research School of Iran

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Abstract

Objective: Reporting some biological side effects with special attention to reproductive points which were seen after different experiments in laboratories of the Plasma Physics & Nuclear Fusion in atomic energy organization of Iran.

Materials and methods: Dosimeter analysis and interpretation of biological side effects of research studies in nuclear fusion laboratories.

Results: In the last 3 decades, neglecting the principles of the radiation protection has been confirmed in laboratories of the plasma physics and nuclear fusion research school of Iran, especially on DAMAVAND and ALVAND Tokamaks and DENA Plasma Focus. Also a series of biological side effects such as alopecia and thyroid function disorders, oligospermia and stomach cancer have been seen in personnel working in related laboratories.

Conclusion: As in our laboratories transportation of the peripheral components such to further distances from the main devices seems not to be cost effective. The level of the absorbed dose of the personnel must be decreased in other ways such as: lowering the number of attended shots for each person and proper shielding.

Keywords: side effects, nuclear fusion laboratory, reproduction, radiation protection principles

Introduction

It is known that the sources of fossil fuels and nuclear fission are limited and using them may results in great environmental difficulties such as acidic rain and greenhouse effect. Wood, hydroelectric and new ener-

gies (such as solar, wind or geothermal) can not cover a main part of the energy of the world. Therefore, a new source of energy is needed to supply the increasing demand of the world (1–3).

On base of the research activities in the 20th century, it has been concluded that the only method that can solve this problem is nuclear fusion.

In the fusion reactions, the nuclei of light atoms like Hydrogen combine with each other and make heavier atoms like Helium. Proper fuels for fusion are the isotopes of Hydrogen & Helium and other light atoms such as Lithium and Boron (1–4).

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This method has not the difficulties such as limitation of the sources, environmental problems, nuclear and chemical wastes and so on. Also the possibility of the implosion or notable accident in a fusion reactor is almost zero.

Despite of the noted benefits for nuclear fusion, its commercial using is not practical yet. In the past six decades several devices such as θ -Pinch or Z-Pinch, Plasma Focus, Laser Fusion, and Tokamak have been designed and constructed for generation of the hot & dense plasma for making a commercial fusion reactor and Tokamak is the most important one (1–3).

From the total experimental and theoretical investigations, it is concluded that the Deuterium-Tritium compound is the best fuel for fusion, but because the Tritium is radioactive and is not found in nature, in most of the small research laboratories and universities the pure deuterium has been used as fuel. For using the D–T mixture as fuel, it must be heated to temperatures more than 100 million Kelvin degree. In such temperatures the fuel will be on plasma form (the forth state of the matter) (1–3). In D–D and D–T fusion reactions in addition to high energy neutrons, large amounts of hard and soft x-rays will be generated, which all may cause important health dangers for operators (1–3, 4–6). By constructing a proper shield around the radiation source, it is possible to reduce the received dose by personnel to negligible levels. The principal parts of the shields are: water for slowing the fast neutrons, Boron or polyethylene for absorption of slow neutrons and lead for absorption the x-rays. The total necessary thickness of shield is about one meter and the major part of it is water (5,7). Usual radiations received by human include:

1. **Natural radiations**, such as cosmic rays and the rays that originate from the radioactive materials of the outer layer of the earth, building materials and existing radiating particles in water and air.
2. **Radiations from man-made sources**, like x-rays and other rays that are used for therapies, radiations of the nuclear industries and other industries that use ionizing rays, radiations from wastes of nuclear reactors and so on. These rays are separated into 2 groups of ionizing & non-ionizing (7,8), The International Commission on Radiological Protection (ICRP) separated the ionizing rays to "2 groups" (7,8):
 - a. Direct ionizing rays including charged particles such as alpha, beta, proton and heavy ions.
 - b. Indirect ionizing rays including x-rays, gamma and neutron.

Non-ionizing rays are the range of electromagnetic rays including ultraviolet, infrared, microwave, laser, radio waves and very low frequency waves such as ultrasound, that the energy of their photons is not enough for doing ionization in the biological tissues. Absorption of the non-ionizing electromagnetic waves by organic tissues make them warm, and most of the biological effects of these rays results from this point. Some other effects have been observed not resulting from the generated heat in the tissues. Some of them results from the chemical reactions and the mechanism of the others are not still identified (8). Radiochemical effect causes the variations in chemical components of the cells. As water is the major of weight and volume part of the cells, the main part of this effect is related to interactions between rays with the molecules of water & generation of new molecules from of the reactions between the resulted ions and free radicals. One of the most important resulting toxic materials is H_2O_2 (7–9).

Considering different types of the non-ionizing rays, it is observed that the effects of the ultrasonic waves & very low frequency electromagnetic waves on human body is very small. For microwave and radio frequency waves the biological effects are very tortuous. Specially at frequencies from about 100 MHz to 3 GHz they have high influences on the internal organs because the major part of the energy is absorbed by internal organs. Their penetration depth in the human body is more than light rays and their effects specially in lower frequencies is not restricted to skin and eye (7,8).

A microwave interferometer with power of 100mW and frequency of 105 MHz is mounted on ALVAND Tokamak, the output wave is modulated by a 5 MHz wave that is generated by a separate modulator). The effects of rays on biological tissues can be categorized as below (7,8):

- **Certain effects:** When the amount of the received dose is high enough, the certain effects will appear and cause the damaging of a lot of cells. There is always a threshold level and at levels higher than threshold, intensity of the certain effects will increase with the amount of received radiation, maintaining the dose under the threshold level is the way of protection against certain effects such as skin inflammation, blood cell count alterations and cataract.
- **Possible effects:** These effects may happen on any dose level, but in the case of occurrence it is dependent to the dose level. The most important of its

results are different types of cancer that generally maybe recognized several years after the first radiation absorption or even included in next generation in this series. The incidence of this type of effects is very low in general population and seems to be negligible in comparison to other risk factors in daily life such as smoking.

The International Commission on Radiological Protection (ICRP) determined the maximum permissible effective dose to be 2 mSv per year for general population and 20mSv per year for personnel working with rays and this dose must not be received abruptly (7). However, it is the maximum limit and in practice the principle of ALARA (As Low As Reasonably Achievable) must be observed, it means that collective equivalent dose must be kept as low as reasonably achieved. This principle has been legislated with respect to the possible effects. For this purpose three tasks must be carried out: Decreasing the time of receiving radiation to minimum, increasing the distance from the radiation source to maximum and shielding around the radiation source (7, 8). Similar to some other chemical and physical factors, radiation can destroy base arrangement of DNA molecules conducting to incongruity in germinal cells, including single and double chain fracture resulting in gene mutations.

In this paper some biological effects that have been observed in previous years in our laboratories are reported. The subject of the paper then shifts to the safety principles in fusion laboratories recommendations are given for safety of the personnel who will work in these laboratories in future.

Materials and methods

In the Plasma Physics and Nuclear Fusion Research School of the Nuclear Science and Technology Research Institute of the "Atomic Energy Organization of Iran" two small size Tokamak devices (ALVAND and DAMAVAND) and one medium size Plasma Focus Facility (DENA) are in operation. In most of the experiments with these Tokamaks Hydrogen has been used instead of Deuterium for plasma generation because the Deuterium is expensive & in these little devices fusion doesn't happen in a high rate. In order to investigate some biological side effects of them, the absorbed dose of the personnel in DAMAVAND Tokamak was measured and analyzed (the working gas was Hydrogen). The estimations on the base of the experimental results of the "Dena" Plasma Focus Device (using Deutrium, Argon, Neon and Krypton

as working gases) have shown that the absorbed dose of the personnel in this device is so much lower than the maximum permissible effective dose and very small in comparison to "DAMAVAND". Although the emitted radiation from ALVAND is very small in comparison to DAMAVAND still notable side effects have been observed in these devices.

In the experiments of the DAMAVAND and DENA the thermoluminescence crystal dosimeters (TLD's) have been used to measure the equivalent absorbed dose of the personnel. These devices include: TLD-100, TLD-400 and TLD-700 and their material is LiF. The reason of the selecting this crystal is its effective atomic number (8.1) which is close to the effective atomic number of the soft tissue (7.4) (9). Therefore, these dosimeters are considered to be equivalent with the soft tissue and the equivalent absorbed dose in the soft tissue is estimated directly by them. Another advantage of this type of dosimeters is their high resistance against the environmental parameters such as temperature and moisture. Because of their small sizes it is possible to install them in different points of the body and get the equivalent effective dose of a specific organ (7,9).

Results

Unfortunately during November and December 2005 neglecting the protection principles resulted in some undesirable bio effects in two expert technicians working in DAMAVAND laboratory. They made about 5000 shots in two subsequent months without sufficient protection. The first complications of the radiation absorption such as vertigo and nausea appeared in the first month. After one month i.e. about the first 3000 shots, some more obvious complications appeared in the form of skin eruptions. Other manifestations included alopecia and thyroid function disorders. At the end of second month the film badges showed the absorbed dose resulting from about 5000 shots to be more than 27 mSv.

The case of alopecia was documented to be the result of an immune disorder. Dermatologic complaints resolved completely in one year taking cyclophosphamide as an immune suppressor. The thyroid function disorder included hyper and hypothyroidism in the same person resembling immune disorder of thyroid gland and lasted for at least four years and was symptom free in recent three months.

In the 1980s in a 6 year period, 5 married men have been working in ALVAND laboratory and 2 of their children have been born with congenital anomalies.

Meanwhile, one of the personnel died because of stomach cancer and one case of sexual dysfunction were reported.

Fortunately, by regarding the principles of the radiation protection, no congenital problems were observed in 4 pregnant women working in our laboratories until the last months of pregnancy (one in ALVAND and 3 in DAMAVAND).

In 1995 and 1996, during the peak activity of DAMAVAND, 3 of 5 male involved personnel underwent medical evaluation due to general systemic symptoms. Lab data revealed oligospermia in all three and they were advised to start fertility workup as soon as possible. In first case his wife conceived uneventfully, in the second case infertility was treated with assisted reproductive techniques and the third case had long lasting untreated infertility and related familial problems for more than 5 years.

Primitive radiation symptoms such as vertigo, nausea and fatigue were seen even in technicians working with DENA plasma focus device. During active period even 90 shots per day were being tested by this device, though the mean received dose was less in comparison to DAMAVAND and ALVAND tokamaks. Oligospermia was shown in two personnel working with DENA plasma focus device and other technicians were not evaluated in this regard.

Discussion

Averaging the experimental results in DAMAVAND shows that in areas near the forbidden zone around this device the level of the received dose is very high (more than 6 mSv for each 100 shots). Fortunately, laboratory personnel mostly do not attend this region. With increasing the distance from device the radiation absorption dose decreases and in regions around the control panel and shielding room that personnel usually attend the level of the effective absorbed dose is about 1.16 mSv for each 100 shots (9). Considering the ICRP recommended maximum permissible dose of the 20 mSv/year (8,10). It is estimated that each of the personnel can attend these regions during about 1700 shots per year (140 shots/month). Also, as mentioned before, 20 mSv is the maximum limit and in practice the absorbed dose must be much less than it. In each working period (3–5 days) in DAMAVAND Tokamak about 100 shots are being done, Hence, each of the personnel will absorb about 1.16 mSv. According to health physics references the level of the permissible dose for pregnant women is mentioned 4 mSv from beginning until full term pregnancy (11) and spe-

cially in the critical months (the first three months) of pregnancy their received dose must be as low as possible. Therefore it is recommended that they only attend in experiments from 4th until 8th month of pregnancy. It means that they can receive the permissible dose in five months and the average value of this permissible dose is $4/5=0.8$ Sv per month that is equal to the absorbed dose in 60 shots. It is better that their contribution to be a little less than this value (for example, 50 shots) because they absorb some extra doses from the experiments with "DAMAVAND" Tokamak and "DENA" Plasma Focus device while attending in the building of laboratory. The number of shots per year in DAMAVAND Tokamak is more than permissible threshold (more than 2000). As in DAMAVAND and our other laboratories transportation of the peripheral components such as power supplies and control systems to further distances from the main devices seems not to be cost effective, the level of the absorbed dose of the personnel must be decreased in other ways such as:

1. Decrement of the time of absorption by lowering the number of attended shots for each person and serializing the personnel (especially when someone arrives at dangerous internal regions during the main problems of laboratory experiments including: difficulties in some parts of the magnetron system, turning on and off the feedback circuit, testing the capacitor bank during the discharge and so on).
2. Proper shielding.

Conclusions

Considering the biological side effects that happened in previous years in our laboratories and analyzing of them, we have obtained useful information to recommend about the design of proper shielding and the working program for the personnel according to the principles of radiation protection.

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