ISSN 0915-633X

NATIONAL INSTITUTE FOR FUSION SCIENCE

Characteristics of D-^{3}He Fueled FRC Reactor: ARTEMIS-L

H. Momota, O. Motojima, M. Okamoto, S. Sudo, Y Tomita,
S. Yamaguchi, A. Iiyoshi, M. Onozuka, M. Ohnishi and
C. Uenosono

(Received – Nov. 1, 1993)

NIFS-251 Nov. 1993

RESEARCH REPORT
NIFS Series

NAGOYA, JAPAN

CHARACTERISTICS OF D-^{3}He FUELED FRC REACTOR: ARTEMIS-L

H.Momota, O.Motojima, M.Okamoto, S.Sudo, Y.Tomita, S.Yamaguchi, A.Iiyoshi, M.Onozuka*, M.Ohnishi**, and C.Uenosono***

National Institute for Fusion Science, Nagoya 464-01,
*: Mitsubishi Heavy Industries Ltd.,Tokyo 105,
**: Kyoto University, Uji 611,
***: Kansai Electric Power Co. Inc., Osaka 530

[The essential part of this paper was presented at ICENES'93, Makuhari, Japan, 1993, AP-46]

kEYWORDS: D-^{3}He Fusion, Fusion Power Plant, FRC

CHARACTERISTICS OF D-^{3}He FUELED FRC REACTOR: ARTEMIS-L

H.Momota, O.Motojima, M.Okamoto, S.Sudo, Y.Tomita, S.Yamaguchi, A.Iiyoshi, M.Onozuka*, M.Ohnishi**, and C.Uenosono***
National Institute for Fusion Science, Nagoya 464-01, *: Mitsubishi Heavy Industries Ltd., Tokyo 105, **: Kyoto University, Uji 611, ***: Kansai Electric Power Co. Inc., Osaka 530

The paper introduces briefly the scenario and discuss the attractive characteristics of D-^{3}He fueled commercial fusion reactor ARTEMIS-L. By using favorable characteristics of a field-reversed configuration,.the fusion plasma of ARTEMIS-L is compact and its beta-value is extremely high. One find consequently a possibility of constructing an economical fusion power power plant on this prospect..The life of the structural materials is sound during the full reactor life (30 years) and the safety of the reactor is intrinsic to D-^{3}He fuels. The amount of disposed materials is rather small and the level of these intruder dose is so low that the plant appears to be acceptable in view of the environment.

1. Introduction

The discovery of minable helium-3 [1] on the Lunar surface stimulated researches on D-^{3}He fueled fusion appreciably. In a fusion reactor with these fuels, charged particles carry major part of the fusion power and the fusion neutrons decreases to a few percent of the fusion power. The plant efficiency of the reactor with D-^{3}He fuels can be very high if one introduces these charged particles to highly efficient direct energy converters. Damages and radioactivities of structural materials attributed to neutron bombardments consequently reduce appreciably. One finds, therefore, a possibility of constructing economical, safe, and environmentally sound commercial fusion reactors with these D-^{3}He fuels.

A US-Japan cooperative research has carried out a design study of a D-^{3}He fueled commercial fusion reactor ARTEMIS [2]. The prime purpose of this design study is to visualize these attractive characteristics and clarify critical issues needed to realize a D-^{3}He fueled fusion reactor for a commercial use. They fixed a set of plasma parameters optimized to give the maximum plant efficiency. An estimated plant efficiency is as high as 60.2 %, if one introduces a field-reversed configuration (FRC) as a plasma container. Nevertheless, the averaged neutron load on the first wall is 0.423 MW/m^2, which value appears still large to keep structural materials sound during whole life operation of 30 years.

ARTEMIS-L [3] is a modified version of ARTEMIS, i.e., modified to reduce the neutron yields of a reactor as low as possible. The design has also paid the care for the unwanted links to weapons. On the bases of this design study, we will introduce briefly the concept and discuss its attractive characteristics and needed issues for constructing the reactor.

2. D-^{3}He Fusion and an FRC

The neutron yields of a 1 GWe fusion reactor depends on the operating plasma temperature, concentration of fuels, and the confinement of ashes components. In a case of high deuterium concentrations or low operating temperatures, comparatively dominant D-D tritium reacts with deuterium to produce 14 MeV neutrons. On the other hand, due to their large radiation losses, fusion power decreases for high plasma temperatures or high helium-3 concentrations of the plasma. Thus one has to select carefully these quantities to construct favorable fusion reactor. Fig.1 shows the fusion power carried by neutrons, which takes its minimum if the temperature is 83.5 keV and helium-3 density is 1.35 times the deuterium density. We have assumed reinjection of fusion tritium that escapes out of the plasma region .

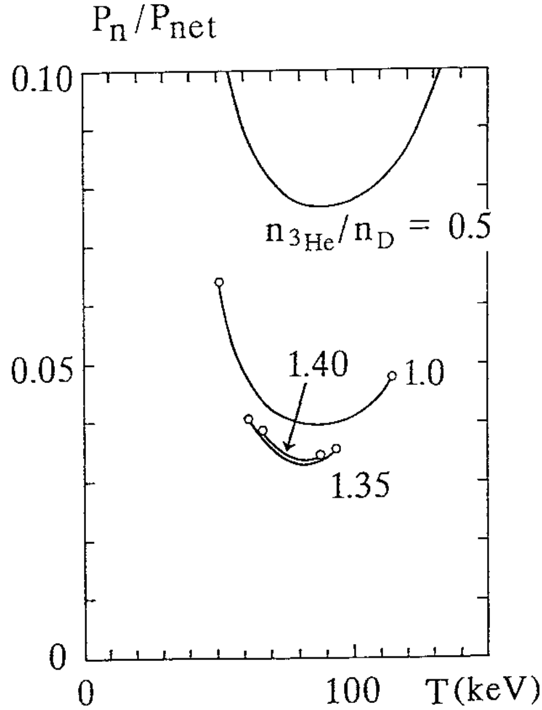

Fig.1: The fusion power carried by neutrons

The confinement parameter $<n_e>\tau_E$ of a D-^{3}He burning plasma is required to be 3.5×10^{21} s/m^3, which value is one order larger than that required for D-T fusion. A high beta-value of the burning plasma can reduce the synchrotron radiation loss of the plasma and produces a larger amount of the fusion power by charged particles. carried

Once one obtains a needed high-beta plasma, accessibility of a high power direct energy converter is required for obtaining an economical fusion reactor. This requirement seems difficult to meet with closed magnetic systems such as a tokamak, because coils for toroidal magnetic field surround plasma closely and no space for installing high power direct energy converters is available.

Among various ideas so far presented for plasma confinements, a field-reversed configuration (FRC) appears to meet those requirements for D-^{3}He fusion. Absence of toroidal magnetic field allow us to produce very high plasma beta-values, which values observed in experiments are much higher than 50 % [4]. An FRC plasma is experimentally stable if their averaged gyroradius is comparable to the plasma radius. The energy confinement time τ_E of a plasma in an FRC is comparable to that of tokamaks and expressed empirically [5] as

$$\tau_E(\text{sec}) = 3.0 \times 10^{-5}(r_s / \sqrt{\rho_0})^{2.7}\, T_{(\text{keV})} \qquad (1)$$

where r_s and ρ_0 stand for the separatrix radius and the averaged gyroradius of ions, respectively in the MKS unit system. Open lines of force in free space surround an FRC plasma, that allow us to install a high power direct energy converter system. Kinetic effects attributed to a large averaged gyration radius of ions stabilize [6] MHD modes in an FRC. Further, a directed flow of energetic protons due to the preferential trapping of fusion protons inside the plasma region produces a bootstrap current needed to keep a plasma in a steady equilibrium of a burning FRC plasma.

3. Burning Plasma Formation

The method to obtain a burning plasma succeeds to that developed in ARTEMIS study. The reactor has a formation chamber, a burning chamber, and a pair of direct energy converter systems. The formation chamber is the section for producing an initial FRC with a conventional reverse-biased fast theta pinch method. An energy of 1.8 GJ stored in two set of fast capacitor banks connected to 4-staged tandem coils produces a seed FRC. With a fast acting gas puff for feeding 52 mPa of D_2 gas and use of an axial contraction of an initial FRC, we obtain a plasma with an averaged electron density of 4.1×10^{20} m^{-3} and a plasma temperature of 3 keV. For obtaining an FRC plasma reliably, the aluminum oxide vacuum chamber keeps its axial symmetry as perfectly as possible to avoid unwanted disturvances and has only a small port for gas puffing.

An applied current in cusp-magnetic field coils translates the FRC plasma to the adjacent burning chamber, just after the FRC formation. Injections of 1 MeV-100 A deuterium atom beam, magnetic compressions, and injections of D-^{3}He fuel

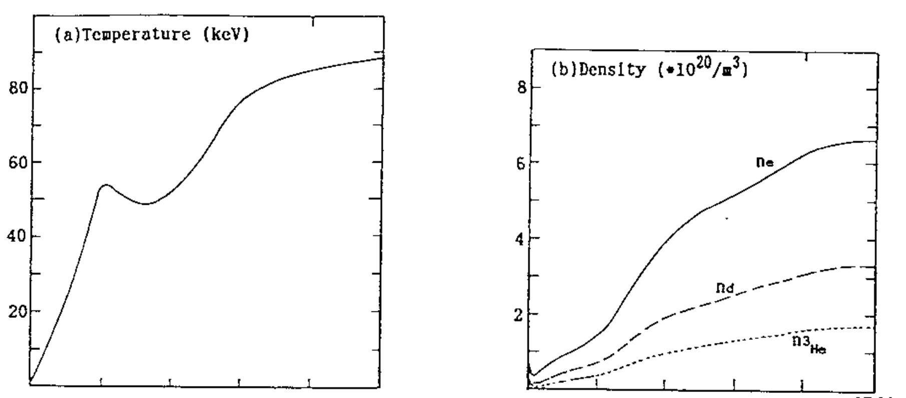

Fig.2: A development of plasma attributed to the injections and magnetic compression

pellets develop the plasma into a burning state after 50 seconds. A set of lead-acid storage batteries supplies the energy of 32 GJ (720 MW) needed to develop the plasma. An example of the development of plasma parameters up to the burning state is exhibited in Fig.2. The method to inject D-^{3}He fuels is so-called "Pac-man" method. A fuel pellet made of liquid helium-3 in a solid deuterium vessel falls into the plasma chamber. FRC plasma moves, then, toward the pellet with a very high speed to involve the pellet deeply inside the plasma region before it evaporates.

Table 1: Plasma Parameters of ARTEMIS-L

Electron Density	5.1×10^{20} m^{-3}
Density Ratio of ^{3}He and D	1.35
Averaged Plasma Temperature	83.5 keV
External Magnetic Field	5.36 T
Averaged Beta-Value	98 %
Energy Confinement Time	6.9 s
Fusion Power	1757 MW
Neutron Power Fraction	0.032
Heating Power (NBI)	100 MW
Plasma Radius × Plasma Length	1.68 m × 22.2 m
Plasma Current	189 MA

Table 1 shows a set of principal plasma para-meters of 1 MWe fusion reactor ARTEMIS-L. The plasma volume is as small as 200 m^3. The separatrix radius r_S that is needed to obtain the required energy confinement (1) is 1.68 m. An edge injection of fuel pellets gives an extremely high beta-value [7] of an FRC equilibrium. The bootstrap current supplemented by a seed current due to a preferential trapping of fusion protons provides a plasma current needed to keep plasma in an equilibrium state.

4. Reactor Concept of ARTEMIS-L

On the bases of these considerations, a modification of the conceptual design of ARTEMIS has been carried out, i.e., ARTEMIS-L, a whole view of which is exhibited in Fig.3. The reactor has a formation chamber, a burning chamber, and a pair of direct energy converter systems.

A converter system has a cusp type direct energy converter and a travelling wave direct energy converter. The former is a double cusped shape for controlling the energy carried by leaked fuels and ashes components. The first cusp is the electron separator that separates electrons from ion components and introduces them to collector plates installed at the first line cusp. Because of its large moment of inertia, an ion pass through the first cusp and goes to the second line cusp. Due to the applied electrostatic field, the ion decreases its kinetic energy and then goes to an ion collector plate. An efficiency of 65 % is estimated with this cusp type direct energy converter. Details of the cusp type direct energy converter will be presented at this conference, separately.

The travelling wave direct energy converter has a modulator and a decelerator. The energy of 14.7 MeV carried by fusion protons is too high to handle with an electrostatic device. The travelling wave direct energy converter [8] controls

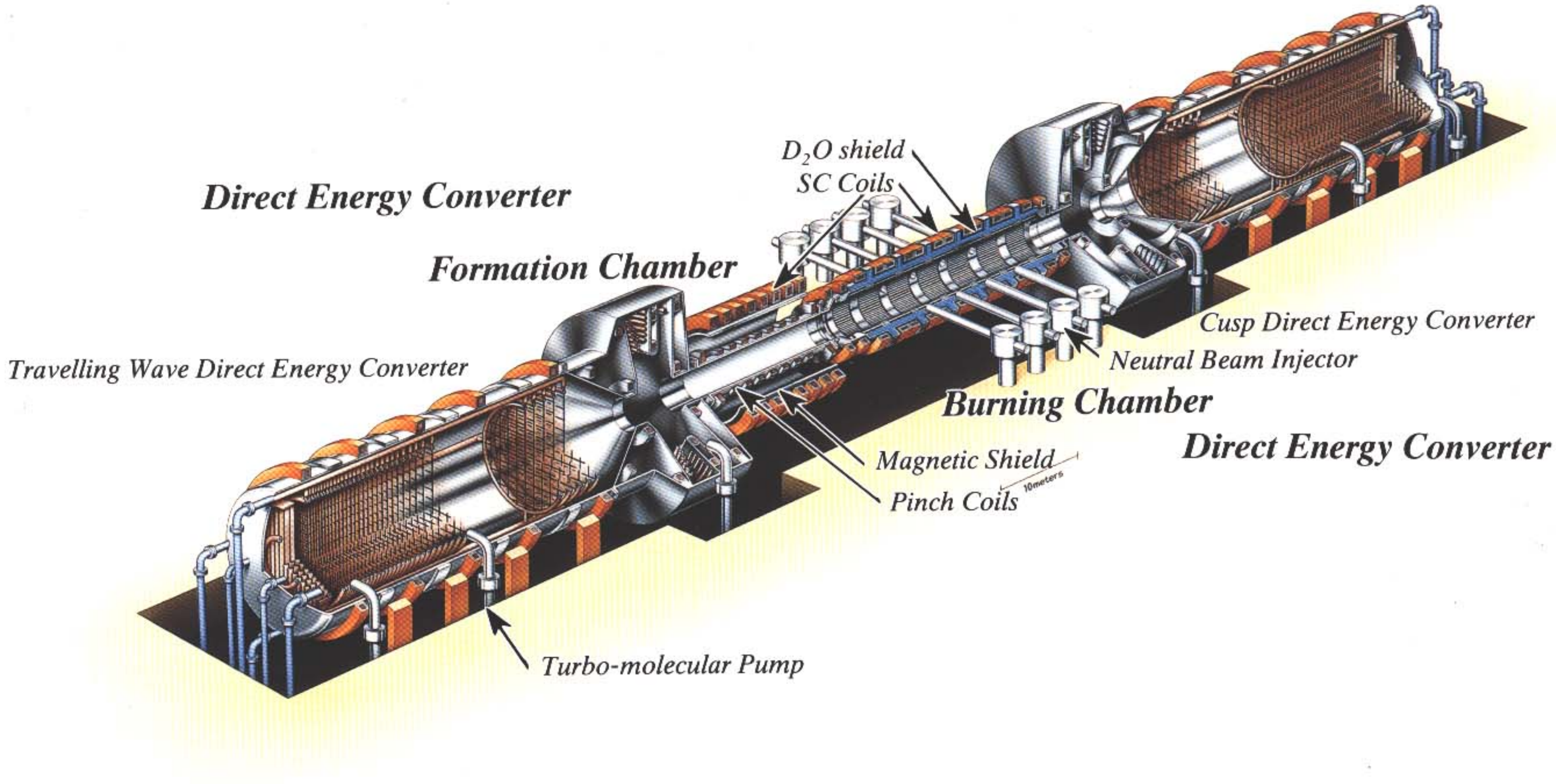

Fig.3: A whole view of the D-^{3}He fueled FRC reactor ARTEMIS-L

this high energy particle on the base of the principle of a Linac. Because of their high energy, fusion protons pass through a cusp type direct energy converter. An applied travelling electric wave moderates the velocity of the proton beam. Then the proton beam forms a bunch at the entrance of the decelerator at a downstream. The decelerator has a set of meshed grids, each of which are connected to a transmission circuit. One has to adjust the location of bunched protons at a decelerate phase of the travelling wave. The phase velocity of the transmission circuit also decreases as same as that of protons. Protons, therefore, decrease their velocity along the stream. Auto-phasing of the proton bunching persists during deceleration. The kinetic energy of 14.7 MeV protons changes to an oscillating electromagnetic energy in the transmission circuit with an efficiency of 76 %.

We are now studying a possibility of introduction of an advanced direct production of hydrogen and thermoelectric and galvano-magnetic converters instead of a turbine-generator. High energy photons radiated from burning plasma excite electron-hole pairs in a metal oxide semiconductor. This can produce more than 100 tons/day of hydrogen with ARTEMIS-L reactor. The energy corresponds to the hydrogen is 110 MWe and the efficiency of producing hydrogen fuel is approximately 18 %. Energies carried by neutrons and the synchrotron radiation can be converted to heat that are introduced together with the heat from the hydrogen plants into thermoelectric and galvano-magnetic generators. The generator produces electricity by using temperature gradient of a semiconductor in a magnetic field. An efficiency of 20 % can be estimated for this energy conversion system and the total conversion efficiency might be 36.7 %. Details of this hydrogen production will be presented in this conference, separately.

Fig.4 is the power flow diagram of ARTEMIS-L. Radiations carry approximately 1/3 of the fusion power, leaked thermal fuels and ashes carry 1/3, and

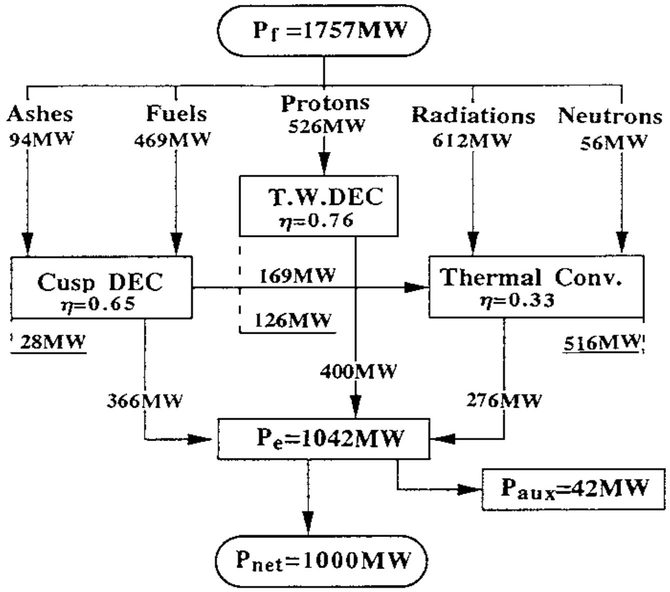

Fig.4: The power flow diagram of ARTEMIS-L

14.7 MeV fusion protons carry another 1/3. We have employed a high-beta FRC plasma that allows us to produce a large portion of the fusion power carried by charged particles if one applies D-^{3}He fusion fuels. Since a device for an FRC is linear, one can install high power direct energy converter systems with a very high conversion efficiency at both ends of the device. It is these two facts that provides a very high plant efficiency of 56.9 %.

Fig.5 shows particle flows in ARTEMIS-L. If assumed capacity factor is 75%, consumption of helium-3 fuel is 67.3 kg/yr and that of deuterium is 50.4 kg/yr. To

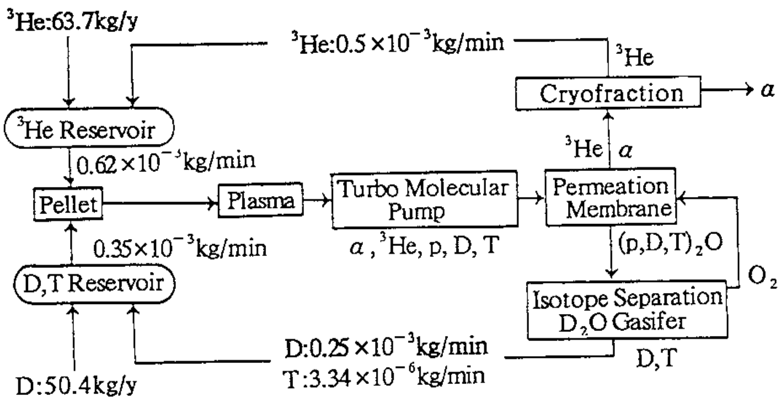

Fig.5: The particle flow diagram of ARTEMIS-L

reduce stored tritium, one has to reinject diffused tritium after separating those from others. The plant contains, consequently, only a few grams of tritium.

Table 2 lists engineering characteristics of ARTEMIS-L reactor. The maximum magnetic field of 6.3 T on the coils is weak enough to apply present technology. The averaged neutron load on the first wall is as low as 0.18 MW/m2. Since the life of the structural materials in a neutron irradiation is approximately 10 MW•yr/m2 with a ferritic steel, the wall load enables

Table 2: Engineering characteristics of the reactor

Fusion Power	1,757 MW
Output Electric Power	1,000 MWe
Power to Heat Converters	668 MW
Power to TWDECs	526 MW
Power to Cusp DECs	563 MW
Total Weight	4,900 tons
Total Length	160 m
Maximum Magnetic Field	6.3 T
Radius of the First Wall	2.28 m
Heat Load on the First Wall	2.0 MW/m^2
Neutron Load on the First Wall	0.18 MW/m^2

us to keep the first wall sound during the full reactor life of 30 years.

5. Characteristics of ARTEMIS-L

Detailed studies on the reactor components are still needed to clarify their performances precisely. The cost of electricity (COE) from ARTEMIS-L, however, can be estimated after ESECOM [9] studies approximately. The estimated direct cost of the plant is 1,030 M$ and the total capital cost is 1,800 M$. Since the average neutron wall load is 0.18 MW/m^2 or equivalently their approximate fluence is ~60dpa after 30 years operation, a ferritic steel as the first wall material appears to be sound during 30 years operation. Thus we can assume a life of the reactor to be more than 30 years. As is show in the Table 3, the cost of electricity is 30.5 mill/ kW•h. The assumed cost of helium-3 is 0.2 M$/kg. This assumption affects slightly the cost of electricity and an expensive cost of helium-3 by a factor 5 gives still a cheep COE as 38.4 mill/kW•h.

Table 3: The estimated cost of electricity

Net Electric Rating (PE)	1,000,000 kW
Total Direct Cost	1,030,000,000 $
Total Capital Cost (CT)	1,800,000,000 $
Annual Capital Cost (Ca = CT 0.0844)	
O&M Cost (Com)	36,000,000 $
Fuel Cost (Cf)	13,000,000 $
COE = [Ca + Com + Cf]/[PE 8760 0.75] = 0.0304 $/kW h	
Assumptions: a fixed-charge rate of 0.0844, interest during the construction of 8.56%/yr, and a capacity factor of 75 %. Costs are in constant 1986 U.S.Dollars.	

One also can imply the following approximate results concerning the safety and environmental effects on the bases of previous studies such as ESECOM studies. The neutron yield in the reactor is as small as 4×10^{19} n/s and a plant contains only a few grams of tritium. The public surface exposure in normal operations is consequently less than 4 mSv for 50 years that is much smaller than the allowable maximum of 0.25 Sv/50years. The occupational whole body exposure is less than 1.4 mSv for the 13 days that is much smaller than the allowable maximum of 2.0 Sv/13days.

Since the plant lacks a breeding blanket and the neutron yield is very few, no nuclear heating of structural materials is appreciable in ARTEMIS-L even for a case of a loss of coolant accident or a loss of flow accident. Namely the plant is inherently safe The total volume of disposed radioactive wastes after 30 years operation is approximately 460 m^3, whose intruder dose is 0.0024 mSv/yr, which value is much smaller than the allowable limit of 5 mSv/yr.

6. Conclusions

1: A complete scenario to obtain and sustain a burning plasma is available. Nevertheless, experimental data bases available to construct the reactor are very poor. Extensive studies on FRCs and experimental verifications of the scenario (the Proof of Principle) are urgent.

2: Engineering bases applied in D-^{3}He fueled ARTEMIS-L design are conventional.Developments of high power-high energy neutral beam injectors and highly efficient direct energy converter systems are necessary.

3: The cost of electricity (COE) from ARTEMIS-L reactor is estimated to be cheaper than that obtained with a present power plant. The cost of helium-3 affects only slightly on the COE.

4: Inherently safe and environmentally sound characteristics of ARTEMIS-L is intrinsic to D-^{3}He Fusion.

[References]

[1] L.J.Wittenberg, J.F.Santarius, and G.L.Kurcinski, "*Lunar Source of ^{3}He for Commercial Fusion Power,*"*Fusion Technology* **10**, 167 (1986)

[2] H.Momota, A.Ishida, Y.Kohzaki, G.H.Miley, S.Ohi, M.Ohnishi, K.Sato, L.C.Steihauer, Y.Tomita, and M.Tuszewski, "*Conceptual Design of the D-^{3}He Reactor ARTEMIS,*" *Fusion Technology* **21**, 2307 (1992)

[3] H.Momota, Y.Tomita, A.Ishida, Y.Kohzaki, M.Ohnishi, S.Ohi, Y.Nakao, and M.Nishikawa"*D-^{3}He Fueled FRC Reactor: ARTEMIS-L,*" Paper presented at the Fourteenth International Conference on Physics and Controlled Nuclear Fusion Research (held at Wúrzburg, Germany, 30 September-7 October 1992)

[4] M.Tuszewski, "*Field Reversed Configurations,*" *Nuclear Fusion* **28**, 2033 (1988)

[5] A.L.Hoffman and J.T.Slough,"*Field Reversed Configuration Lifetime Scaling Based on Measurements from the Large s Experiment,*" *Nuclear Fusion* **33**, 27 (1993)

[6] Y.Nomura, "*Suppression of Tilting Instability of a Compact Torus by Energetic Particle Beams,*" *Journal of Physical Society of Japan* **54**, 1369 (1985)

[7] Y.Tomita and H.Momota, "*Steady Equi-librium of a Cylindrically Symmetric Plasma Sustained by Fueling,*" *KAKUYUGO KENKYU* **67**, 801 (1993)

[8] H.Momota, "*Direct Energy Conversion for 15 MeV Fusion Protons,*" **LA 11808C**, 8 (1990)

[9] J.P.Holdren, D.H.Berwald, R.J.Budnitz, J.G.Crocker, J.G.Delene, R.D.Endicott, M.S.Kazimi, R.A.Krakowski, B.G.Logan, and K.R.Schultz, "*Report of the Senior Committee on Environmental, Safety and Economic Aspects of Magnetic Fusion*

Energy," **UCRL-53766** (1989)

Recent Issues of NIFS Series

NIFS-198 K. Toi, S. Okamura, H. Iguchi, H. Yamada, S. Morita, S. Sakakibara, K. Ida, K. Nishimura, K. Matsuoka, R. Akiyama, H. Arimoto, M. Fujiwara, M. Hosokawa, H. Idei, O. Kaneko, S. Kubo, A. Sagara, C. Takahashi, Y. Takeiri, Y. Takita, K. Tsumori, I. Yamada and H. Zushi, *Formation of H-mode Like Transport Barrier in the CHS Heliotron / Torsatron* ; Oct. 1992

NIFS-199 M. Tanaka, *A Kinetic Simulation of Low-Frequency Electromagnetic Phenomena in Inhomogeneous Plasmas of Three-Dimensions* ; Nov. 1992

NIFS-200 K. Itoh, S.-I. Itoh, H. Sanuki and A. Fukuyama, *Roles of Electric Field on Toroidal Magnetic Confinement*, Nov. 1992

NIFS-201 G. Gnudi and T. Hatori, *Hamiltonian for the Toroidal Helical Magnetic Field Lines in the Vacuum*; Nov. 1992

NIFS-202 K. Itoh, S.-I. Itoh and A. Fukuyama, *Physics of Transport Phenomena in Magnetic Confinement Plasmas*; Dec. 1992

NIFS-203 Y. Hamada, Y. Kawasumi, H. Iguchi, A. Fujisawa, Y. Abe and M. Takahashi, *Mesh Effect in a Parallel Plate Analyzer*; Dec. 1992

NIFS-204 T. Okada and H. Tazawa, *Two-Stream Instability for a Light Ion Beam -Plasma System with External Magnetic Field;* Dec. 1992

NIFS-205 M. Osakabe, S. Itoh, Y. Gotoh, M. Sasao and J. Fujita, *A Compact Neutron Counter Telescope with Thick Radiator (Cotetra) for Fusion Experiment*; Jan. 1993

NIFS-206 T. Yabe and F. Xiao, *Tracking Sharp Interface of Two Fluids by the CIP (Cubic-Interpolated Propagation) Scheme*, Jan. 1993

NIFS-207 A. Kageyama, K. Watanabe and T. Sato, *Simulation Study of MHD Dynamo : Convection in a Rotating Spherical Shell*; Feb. 1993

NIFS-208 M. Okamoto and S. Murakami, *Plasma Heating in Toroidal Systems*; Feb. 1993

NIFS-209 K. Masai, *Density Dependence of Line Intensities and Application to Plasma Diagnostics*; Feb. 1993

NIFS-210 K. Ohkubo, M. Hosokawa, S. Kubo, M. Sato, Y. Takita and T. Kuroda, *R&D of Transmission Lines for ECH System* ; Feb. 1993

NIFS-211 A. A. Shishkin, K. Y. Watanabe, K. Yamazaki, O. Motojima, D. L. Grekov, M. S. Smirnova and A. V. Zolotukhin, *Some Features of Particle Orbit Behavior in LHD Configurations*; Mar. 1993

NIFS-212 Y. Kondoh, Y. Hosaka and J.-L. Liang, *Demonstration for Novel Self-organization Theory by Three-Dimensional Magnetohydrodynamic Simulation*; Mar. 1993

NIFS-213 K. Itoh, H. Sanuki and S.-I. Itoh, *Thermal and Electric Oscillation Driven by Orbit Loss in Helical Systems*; Mar. 1993

NIFS-214 T. Yamagishi, *Effect of Continuous Eigenvalue Spectrum on Plasma Transport in Toroidal Systems*; Mar. 1993

NIFS-215 K. Ida, K. Itoh, S.-I.Itoh, Y. Miura, JFT-2M Group and A. Fukuyama, *Thickness of the Layer of Strong Radial Electric Field in JFT-2M H-mode Plasmas*; Apr. 1993

NIFS-216 M. Yagi, K. Itoh, S.-I. Itoh, A. Fukuyama and M. Azumi, *Analysis of Current Diffusive Ballooning Mode*; Apr. 1993

NIFS-217 J. Guasp, K. Yamazaki and O. Motojima, *Particle Orbit Analysis for LHD Helical Axis Configurations* ; Apr. 1993

NIFS-218 T. Yabe, T. Ito and M. Okazaki, *Holography Machine HORN-1 for Computer-aided Retrieve of Virtual Three-dimensional Image* ; Apr. 1993

NIFS-219 K. Itoh, S.-I. Itoh, A. Fukuyama, M. Yagi and M. Azumi, *Self-sustained Turbulence and L-Mode Confinement in Toroidal Plasmas* ; Apr. 1993

NIFS-220 T. Watari, R. Kumazawa, T. Mutoh, T. Seki, K. Nishimura and F. Shimpo, *Applications of Non-resonant RF Forces to Improvement of Tokamak Reactor Performances Part I: Application of Ponderomotive Force* ; May 1993

NIFS-221 S.-I. Itoh, K. Itoh, and A. Fukuyama, *ELMy-H mode as Limit Cycle and Transient Responses of H-modes in Tokamaks* ; May 1993

NIFS-222 H. Hojo, M. Inutake, M. Ichimura, R. Katsumata and T. Watanabe, *Interchange Stability Criteria for Anisotropic Central-Cell Plasmas in the Tandem Mirror GAMMA 10 ;* May 1993

NIFS-223 K. Itoh, S.-I. Itoh, M. Yagi, A. Fukuyama and M. Azumi, *Theory of Pseudo-Classical Confinement and Transmutation to L-Mode;* May 1993

NIFS-224 M. Tanaka, *HIDENEK: An Implicit Particle Simulation of Kinetic-MHD Phenomena in Three-Dimensional Plasmas;* May 1993

NIFS-225 H. Hojo and T. Hatori, *Bounce Resonance Heating and Transport in a Magnetic Mirror;* May 1993

NIFS-226 S.-I. Iton, K. Itoh, A. Fukuyama, M. Yagi, *Theory of Anomalous Transport in H-Mode Plasmas;* May 1993

NIFS-227 T. Yamagishi, *Anomalous Cross Field Flux in CHS ;* May 1993

NIFS-228 Y. Ohkouchi, S. Sasaki, S. Takamura, T. Kato, *Effective Emission and Ionization Rate Coefficients of Atomic Carbons in Plasmas;* June 1993

NIFS-229 K. Itoh, M. Yagi, A. Fukuyama, S.-I. Itoh and M. Azumi, *Comment on 'A Mean Field Ohm's Law for Collisionless Plasmas;* June 1993

NIFS-230 H. Idei, K. Ida, H. Sanuki, H. Yamada, H. Iguchi, S. Kubo, R. Akiyama, H. Arimoto, M. Fujiwara, M. Hosokawa, K. Matsuoka, S. Morita, K. Nishimura, K. Ohkubo, S. Okamura, S. Sakakibara, C. Takahashi, Y. Takita, K. Tsumori and I. Yamada, *Transition of Radial Electric Field by Electron Cyclotron Heating in Stellarator Plasmas;* June 1993

NIFS-231 H.J. Gardner and K. Ichiguchi, *Free-Boundary Equilibrium Studies for the Large Helical Device,* June 1993

NIFS-232 K. Itoh, S.-I. Itoh, A. Fukuyama, H. Sanuki and M. Yagi, *Confinement Improvement in H-Mode-Like Plasmas in Helical Systems,* June 1993

NIFS-233 R. Horiuchi and T. Sato, *Collisionless Driven Magnetic Reconnection,* June 1993

NIFS-234 K. Itoh, S.-I. Itoh, A. Fukuyama, M. Yagi and M. *Azumi, Prandtl Number of Toroidal Plasmas;* June 1993

NIFS-235 S. Kawata, S. Kato and S. Kiyokawa , *Screening Constants for Plasma;* June 1993

NIFS-236 A. Fujisawa and Y. Hamada, *Theoretical Study of Cylindrical Energy Analyzers for MeV Range Heavy Ion Beam Probes;* July 1993

NIFS-237 N. Ohyabu, A. Sagara, T. Ono, T. Kawamura and O. Motojima, *Carbon Sheet Pumping;* July 1993

NIFS-238 K. Watanabe, T. Sato and Y. Nakayama, *Q-profile Flattening due to Nonlinear Development of Resistive Kink Mode and Ensuing Fast*

Crash in Sawtooth Oscillations; July 1993

NIFS-239 N. Ohyabu, T. Watanabe, Hantao Ji, H. Akao, T. Ono, T. Kawamura, K. Yamazaki, K. Akaishi, N. Inoue, A. Komori, Y. Kubota, N. Noda, A. Sagara, H. Suzuki, O. Motojima, M. Fujiwara, A. Iiyoshi, *LHD Helical Divertor;* July 1993

NIFS-240 Y. Miura, F. Okano, N. Suzuki, M. Mori, K. Hoshino, H. Maeda, T. Takizuka, JFT-2M Group, K. Itoh and S.-I. Itoh, *Ion Heat Pulse after Sawtooth Crash in the JFT-2M Tokamak;* Aug. 1993

NIFS-241 K. Ida, Y.Miura, T. Matsuda, K. Itoh and JFT-2M Group, *Observation of non Diffusive Term of Toroidal Momentum Transport in the JFT-2M Tokamak;* Aug. 1993

NIFS-242 O.J.W.F. Kardaun, S.-I. Itoh, K. Itoh and J.W.P.F. Kardaun, *Discriminant Analysis to Predict the Occurrence of ELMS in H-Mode Discharges;* Aug. 1993

NIFS-243 K. Itoh, S.-I. Itoh, A. Fukuyama, *Modelling of Transport Phenomena;* Sep. 1993

NIFS-244 J. Todoroki, *Averaged Resistive MHD Equations;* Sep. 1993

NIFS-245 M. Tanaka, *The Origin of Collisionless Dissipation in Magnetic Reconnection;* Sep. 1993

NIFS-246 M. Yagi, K. Itoh, S.-I. Itoh, A. Fukuyama and M. Azumi, *Current Diffusive Ballooning Mode in Seecond Stability Region of Tokamaks;* Sep. 1993

NIFS-247 T. Yamagishi, *Trapped Electron Instabilities due to Electron Temperature Gradient and Anomalous Transport;* Oct. 1993

NIFS-248 Y. Kondoh, *Attractors of Dissipative Structure in Three Disspative Fluids;* Oct. 1993

NIFS-249 S. Murakami, M. Okamoto, N. Nakajima, M. Ohnishi, H. Okada, *Monte Carlo Simulation Study of the ICRF Minority Heating in the Large Helical Device;* Oct. 1993

NIFS-250 A. Iiyoshi, H. Momota, O. Motojima, M. Okamoto, S. Sudo, Y. Tomita, S. Yamaguchi, M. Ohnishi, M. Onozuka, C. Uenosono, *Innovative Energy Production in Fusion Reactors;* Oct. 1993