**TELKOMNIKA**, Vol.11, No.11, November 2013, pp. 6855~6861
e-ISSN: 2087-278X



# Decontamination and Decommissioned Small Nuclear AIP Hybrid Systems Submarines

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***Abstract***

*Being equipped with small reactor AIP is the trend of conventional submarine power in 21st century as well as a real power revolution in conventional submarine. Thus, the quantity of small reactor AIP Submarines is on the increase, and its decommissioning and decontamination will also become a significant international issue. However, decommissioning the small reactor AIP submarines is not only a problem that appears beyond the lifetime of the small reactor nuclear devices, but the problem involving the entire process of design, construction, running and closure. In the paper, the problem is explored based on the conception and the feasible decommissioning and decontamination means are supplied to choose from.*

***Keywords:*** *conventional submarine; small nuclear AIP; decommissioning; decontamination*



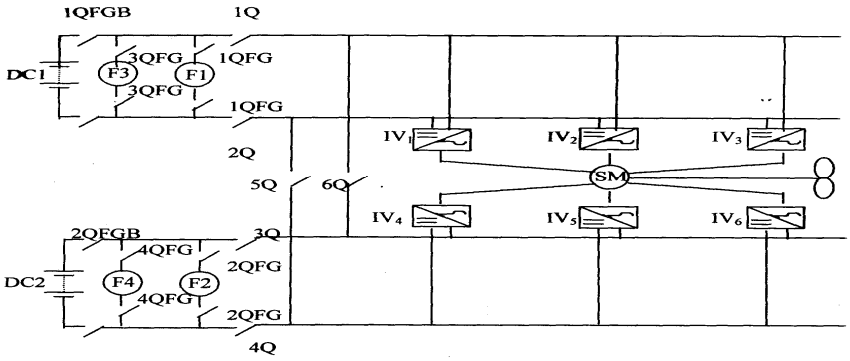
## 1. Introduction

Weapon, specially, the modern warfare weapon, needs the maximum limited stealth ability,The important value of stealth ability results to relying on the submarine in future naval battle [1]. To national military strengths, the submarine is an important one to put deterrent into effect. It may implement the nucleus deterrent, the non- nucleus to deter, and it may be an actual nucleus deterrent, also do psychological deterrent. In local area war, the attacking submarine may play the role on controlling partial sea area; it cooperates closely with other military forces, captures and maintains the mastery of the local sea area.

A conventional submarine is easy to build and repair; it's price is low, but underwater cruising range is short, relatively high exposure rates. While an underwater nuclear submarine has greater mobility, longer underwater endurance and greater underwater activities hidden and -attacking power. Because of it's technical complexity and high cost, the general states cannot afford for it's building. The conventional submarines equipped a small reactor power device, namely. On the conventional power submarine, a miniaturized atomic propulsion units is additionally built to constructs a set of diesel electric and small reactor hybrid motive propulsion system, fundamentally overcomes low submerged speed and short underwater cruising range as well as big exposition rate. The shortcomings of the conventional submarine, have greatly improved the stealth and the combat capacity of the submarine. And its construction cost and the technical complexity will also greatly be lower than the nuclear-powered submarine. It can achieve the goal strengthening the stealth and hybrid motive of the submarine, and will realize its mobility and best inexpensive run. Therefore, the conventional submarine in 21$^{st}$ century should be powered by the diesel-electric hybrid propulsion system involving small nuclear power reactors [2-3]. The principle is shown in the Figure 1.

The conventional submarines equipped with a small reactor AIP system will become a growing concern for the navies in the countries having conventional submarines in the world, but new problems arise as well: how to economically realize the decommissioning and decontamination of conventional submarines equipped with a small reactor based on the characteristics of the hybrid power propulsion system.

*Received May 9, 2013; Revised July 23, 2013; Accepted August 6, 2013*




$F_1$、$F_2$ —Diesel generator; $F_3$、$F_4$—Small Nuclear Power AIP Generator;
DC1、DC2—Storage battery ; IQFGB、2QFGB—Battery Circuit Breaker;
1QFG、2QFG—Generator Circuit Breaker; 1Q~6Q—Non-automatic switch;
3QFG、4QFG—AIP Generator Circuit Breaker; SM—Main Motor;
IV1~IV6——Inverter Circuit.

Figure 1. Principle of Small Nuclear Power AIP System

In the latest years, in order to promote mutually to exchange the practical experience amang the members in the world, which obtaines in the retirement, the movement, the maintenance and service, and the coordinated relations between the strategy and the implementary method. International Atomic Energy Agency (IAEA) has provided leading fundament of the practical retirement, and has established this set of mechanisms in the cooperation research plan (CRP), the retires rule and its mechanisms will finally build the work foundation for the retirement and decontamination of conventional submarines equipped with a small reactor.

## 2. Characteristics of the small Reactor Motive Propulsion System

### 2.1. Characteristics of the small Reactor

Diesel electric and small reactor hybrid motive propulsion system generally uses a pulse to pile, a high temperature airs cooled pile or a small-integrated water-cooled reactor and so on.

The pulse piles in the world has running 1,000 piles·years of experience. It uses the uranium-hydrogenation zircaloy as the fuel, combining to transformation system of the felon Rankin of low temperature and low pressure, has good security, good performance on the fission-product containment, compact structure, long life, mature on the technology and so on [4]. Small pulse pile which may be used to equip 2,000-ton-level conventional submarines has Canadian ESC group 1,000 kW utility AMPS1000 and so on, AMPS – 1 [4] developed together by the American general atomic energy company and the Canadian ESC group, which is equipped on the seabed surveying submarine, also belongs to this kind of pile.

The high temperature air cooled pile uses the entire ceramics fuel element, the graphite as moderator and the structural material, with the hydrogen, the helium or other gas substitute pressing water coolant, it is one kind of secure efficient and advanced reactor. Because of merit of the high temperature air cooled pile is obvious, many countries in the world have all given the high attention to the development of high temperature air cooled pile, already had South African SKOM high temperature air cooled pile (PBMR); Japanese small high temperature air cooled pile (HTTR); France's Magnox air cooled pile; American 40MW Peach Bottom experiment high temperature air cooled pile; Chinese HTR-10 high temperature air cooled pile.

The small integrated water-cooled reactor usually contains a reactor vessel, a steam generator, a gas turbine, a generator and it’s part in the ball shell pressure vessel of titanium alloy. Its structure is compact. The core adopts the coolant to cool calculatedly, the stop rod composes the control rod system and the reactivity control rod, the core was still in condition to be submerged in the dehydration accident situation, the installment is secure. Such as using in 150kW-power DRX small reactor which is installed in the deep-sea scuba made in Japan.

### 2.2. Equipment Characteristics of Reactors used in the Conventional Submarine

When constructing a conventional submarine equipped with the small reactor AIP system, the small reactor is generally required to form a movable installing module. When the traditional hull block construction method is adopted in building conventional submarines, the detachable board is taken apart above the hull reactor compartment and the small reactor module is hoisted into the AIP bay section to be installed. When the block method of hull construction is adopted in building conventional submarines, the small reactor modules are moved in parallel into the AIP bay section for installment. To facilitate the decommissioning and dismantlement of the small reactor, the detachable board structure should be installed above the hull AIP cabin in designing.

### 2.3. Radioactive Process Systems Grouping Together

Conventional submarines equipped with the small reactor AIP system are generally characterized by grouping radioactive process systems together. The small reactor AIP system is equipped with radioactive devices. Its pipeline is installed in the AIP bay section with a negative pressure system and a capacity as small as possible to handle enough pressure. The first and second screening as well as partial screening are set up so that the dose from an operation is far lower than one tenth of the allowable value of the annual dose (5mSv) to make sure the small reactor AIP possesses ideal nuclear safeguard.

## 3 Decommission and Decontamination of Small Reactor AIP Submarines

### 3.1. Basic Principles Decommission Should Follow

Based on the practice of most countries the International Atomic Energy Agency (IAEA) divides the decommissioning of general reactors into three levels:

I level – After reactors are closed permanently, cleaning up, classifying, handling or temporary storing of the radioactivity are carried into execution, the decontamination of the scene and the system are carried by the numbers, the moderate seal depositing with an effective surveillance to the reactor is adopted.

II level – Radioactivity item beyond the biological shield (or security shell) is thoroughly decontaminated to the permission level or dismantled, each kind of radioactivity item processes and handles, to leaves behind the radioactive substance implements shield isolation, regular or the non-periodical monitor are carried to the scene.

III level - dismantling completely the reactor facility to make the field site decontaminate to be unlimited used again.

According to the characteristics of the combination power propulsion system in conventional submarine equipped the small reactor power, its reactor retirement may be definitely implemented as III level, its retired designation and the basic principle to implement as follows:

(1) According to the international convention, when designing the conventional submarine equipped with small reactor AIP, we should consider its decommissioning process. About five years before the anticipated lifetime terminates the running unit submits the decommissioning plan to the management departments of the countries concerned;

(2) To be based on general survey about the radiation dose and the nucleons analysis to the reactor cubicle and the reactor, according to the radiant field intensity and the polluted nucleons type, we divide the region of the reactor cubicle and the reactor, its dismantlement is carried in the principle order "the non - restricted sector - restricted sector -forbidden area";

(3) The formulation of retirement plan and the selection of retirement measurement should emphasize to reduce the quantity and rank of radioactive waste, and should be clear about where the radioactive waste is put;

(4) Clear about using standard of retirement, take the effective actions, reduce the radiation field intensity of the working place as far as possible, reduce the operating personal and the public radiation dose;

(5) Before each stage starts, we should propose the analysis report on safe and the detailed program regulation, and carry on the secure appraisal to the preceding stage;

(6) The retirement funds should be used reasonably.

### 3.2. Formulation about Retirement Plan and Project

When retirement plan is formulated, the management structure, the working routine, the technical standard to use and the funds safeguards should be clear. According to characteristics of the conventional submarine equipped the small reactor power unit, the basic principle of retirement and the advanced degree of remote-control dismounted technology, the foundational plan of retirements of a conventional submarine equipped the small reactor power unit to be supposed: the surplus nuclear fuel on the submarine is dismounted by the local ship-breaker yard-reactor cubicle and the system is decontaminated-the small reactor overall module is dismantled-then the entire submarine is dismantled; the small reactor overall module is dismantled and transported to handling storehouse which constructs special shield to radiation for seal 3~5 years-remote-control dismounted technology is applied in partial dismantlement and decontamination after being dismantled-reactor core is buried.

The technical standard on retirement of conventional submarine equipped the small reactor power unit should carry the international standard of limiting value inequality on the compound illumination effective dose which occupation emission staff irradiated inside and outside, it is commended by International Atomic Energy Agency [6]. Occupation radiation dose of retirement staff monitored in Table 1, in retirement working period the dosage burden, which personally will create to the public should not surpass Table 2.

Table 1. List of Operating Personnel Radiation Dose Limits

| Item | Radioactive dose (mSv) |
|---|---|
| Annual meaningful effective dose in Continuously 5 year | ＜20 |
| Effective dose in any year | ＜50 |
| Equivalent dosage entered crystalline in a year | ＜150 |
| Equivalent dosage entered limbs or skins crystalline in a year | ＜500 |

Table 2. List of Population Radiation Dose Limits

| Item | Radioactive dose (mSv) |
|---|---|
| Annual mean effective dose in Continuously 5 year | <5 |
| Effective dose in any year | <1 |
| Equivalent dosage entered crystalline in a year | <15 |
| Equivalent dosage entered limbs or skins crystalline in a year | <50 |
| Effective dose creating by radioactive discharges in a year | <0.25 |

### 3.3. Choice of Physics and Chemistry Method in Decontamination

The decontamination removes the loose and the radioactive deposit on object surface, to reduce the occupation radiation in the next working procedure of clean process. The decontamination cannot thoroughly annihilate radio-nuclides, but changes of existence form or the position of the nuclide can be caused only, in order to manage radiation safety; The decontamination may cause the partial establishment, the equipment and the material to be used limitedly and unlimitedly. The decontamination includes system decontamination before dismantling and dismantlement decontamination of dismantling process. The decontamination of retirement of conventional submarine equipped the small reactor power unit mainly refer the system decontamination about the reactor cubicle before dismantling the small reactor overall module and the dismantlement decontamination in dismantling the small reactor process. It is different from retirement and decontamination of ordinary nuclear facility, retirement's decontamination of the conventional submarine equipped the small reactor power unit can be regarded as the final decontamination, the decontamination coefficient hoped is high as far as possible, it is generally requests DF > 20. The method of decontamination mainly has physics and chemistry method [7].

The common physical method of decontamination has cleaning, the surface striping, spurt-pill and so on, at present, many concrete implementations methods in view of the different decontaminated objects has already been developed in international [8], several main physical decontamination methods are seen in the Table 3.

Chemical decontamination is to use chemical solvent (organic solvent, acid liquor, complex compound solution, salt brine and so on) to clean the contaminated area, facility and so on [9-11], several main chemical decontaminated methods are seen in the Table 4.

Table 3. Main Physics Method of Decontamination

| number | designation | principle or method | adaptive decontamination object |
|---|---|---|---|
| 1 | volatility/lowly warms coming off | The nitrogen or other gases heated up ( not higher than 350 □) carries off the volatile organic matter through the heater scrubbing system, the organic matter is processed and reclaimed. | Eliminating organic matter in mud, also adapts in the ignitable waste. |
| 2 | Light or flame ablation | After the certain frequency light is absorbed transforms as the heat energy or with the high temperature flame, instantaneous causes the pollution layer to hot decomposition. | Apply to elimination substrate surface coating or organic pollutant. |
| 3 | microwave thickly carves | Shells the surface of the concrete polluted with the certain frequency microwave, brokenly causes the surface to become the detritus, then collects it with a vacuum system. | It is suitable for decontamination of the concrete surface, is ill to decontamination of the metal surface. It is few that dust produced by, the surface does not need to be moist, and thus the handling expense is reduced. |
| 4 | press water decontaminat-ion | With the clean water(grinding compound) in a low pressure (≤ 7Mpa), a high pressure (7～140MPa), a ultrahigh voltage (140～300MPa), washes out the elimination surface pollutant. | Using in to eliminate the pollutant of object surface, decontamination effect concerns with the pressure, the velocity of flow, the spray nozzle structure, the distance between purification and the surface, and the traveling speed. |
| 5 | spurt carbon dioxide pill (dry ice) | Preparing the liquid state carbon dioxide to do a consistent specification of pill, accelerated it by compressed air, and it go through a spray nozzle to the object surface, dry ice in a certain kinetic energy which bursts produces permeate substrate of material, its superficial pollutant are caused to fall off. | It is effective To clean the surface pollutant of plastic, ceramic, the compound material and the stainless steel. Maximum allowable concentration in the operational site is 5000 mg/L, The natural environment aeration airiness condition must be provided. |
| 6 | supercritical extract and supercritical water | The carbon dioxide is heated up 32.3□ and its pressure surpasses 8Mpa to dissolve the organic pollutant; Using the water above 357 □ and 22.1Mpa in pressure to do treatment the object polluted, the organic matter is oxidized into the small molecular gas, the organic-metal transforms for the ordinary water metallic ion able to dissolve. | It uses in to dissolve the virulent component or withdraws the organic matter from the material. |
| 7 | PIG method | The clean material, which is made by the oxygen ester, it are special shape like bullet, its contraction is strong, by the system composed by a PIG launcher, a receiver, a detector system, a power supply and the impetus medium, pass the pipeline, clean pollutant. | It is used in to eliminate attachment dirt on the tube wall. |
| 8 | decontaminat-ion by Air blast | Using the special air chamber structure of the air operated ball, which the energy is stored in the compressed air will release instantly, it will cause the environmental media to become looseness and break with forming a air wave. | It is used in clearing silt, removing dirty stuff, fragmentation; it has the extremely remarkable effect for the decontamination in the pipeline, the accumulator tank, the trench, the canal and so on. |

As what we can know from Table 3 and 4, each kind of decontamination technology has certain limitation. The different decontaminated object needs to have the different decontaminated method. In order to aim at safty, saving time and money, we must select the reasonable decontaminating craft and method. Regarding to retirement and decontamination of the conventional submarine equipped the small reactor power unit, considering system decontamination, we may implement chemical decontamination to the radioactive return routing decontamination, we may use the high-pressured water decontamination to the reactor cubicle decontamination.

Table 4 Main Chemical Method of Decontamination

| number | designation | principle or method | adaptive decontamination object |
|---|---|---|---|
| 1 | Froth decont-amination | The froth produced by the surface active takes as the carrier of chemistry decontamination. | Uses in clean and decontamination of each kind of metal surface and the complex equipment part superficial. The second time wastes produced is few, the technology is mature, but the decontamination coefficient is low. |
| 2 | Chemistry gelatin decontaminat-ion | The gelatin is sprayed or spread to the part surface. After coagulation wash and strips processing are carried on. | The pollutants that may delete are removed Effectively, the second time wastes produced is few, the coefficient of decontamination is high, but the technology is complex. |
| 3 | Organic acid processing | Using the weak acid characteristic of the organic acid (oxalic acid, citric acid, amino-sulfuric acid), it mix each other or mix with inorganic acid to use. | Oxalic acid - hydrogen peroxide processing dioxide plutonium pollutant; The amino-sulfuric acid is effective detergent on the carbon steel and stainless steel; The petroleum - sulfuric acid carries on the ground decontamination to be good effect. |
| 4 | Inorganic acid processing | Using the strong acid characteristic of the inorganic acid (hydrochloric acid, sulfuric acid, nitric acid, phosphoric acid), it are applied alone or added the slows-down corrosive to use. | Hydrochloric acid may use in to eliminate pollution on the boiler and the pipeline, radioactive cobalt-60 on stainless steel surface and few fission product; Sulfuric acid may remove the deposit not to contain the calcium compound; The phosphoric acid uses in the carbon steel fast to escape the membrane and the decontamination. |
| 5 | Oxidation deoxidization processing | With the oxidized characteristic of potassium permanganate, potassium dichromate, hydrogen peroxide, it mix each other or mix with inorganic acid to use to dissolved pollutant. | Uses in processing and elimination of oxide compound on metal surface, attaching fission product, and each chemistry commodity |
| 6 | Complexing processing | To apply the complexing agent may selectivity combine certain ion production to complex compounds, it often mix to use with the detergent, the oxidant or the acid | Uses in to dissolve uranium dioxide of pollutant surface and so on. |
| 7 | Electro-chemistry decontaminat-ion | To apply principles of electro-dialysis, electricity swim and electrolysis to remove the pollutant. | To apply electro-dialysis or electricity swim to elimination virulent harmful heavy metal in soil; To apply electrolysis to eliminate virulent harmful pollutant the metal surface. |
| 8 | microorganism degenerative oxidizing | Microorganism coating to pollutant surface, after it consumes by the pollutant, to apply the detergent or the solvent to wash, to be dry, heated up, again to apply the fresh solvent to wash off the residual contamination. | Uses to the mineral oil in the sludge pond, the cabin goes and so on. |

The dismantlement decontamination focuses on recycling of superficial polluted material and reduces quantity of the retirement waste by treatment and handling, the dismantlement decontamination may emphatically consider to use the electrochemical decontaminating technology.

## 4. Conclusion

Equipping conventional submarines with the small reactor AIP system, deemed as a real power revolution of conventional submarines, represents power development of conventional submarines in the 21st century. Navies in the various countries will pay close attention to it. Its quantity will be increasing. The decommissioning will also become a significant problem worldwide. Therefore, decommissioning the conventional submarine equipped with small reactor power devices is not only a problem that appears beyond the lifetime of the small reactor nuclear devices, but also the problem involving the entire process of design,

construction, running and closure. This article only proposes this kind of question. It is certain that related international rules as well as the optimized methods ways in decommissioning and decontamination processes will be available.

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