Radiation Protection Experience at The One-Megawatt Pool Reactor THOR and its Affiliated Facilities

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(Received March 4, 1970)

In an eight-year period of operating THOR and its affiliated facilities, since it went to critical on April 13, 1961, twenty incidents involving more or less serious radiation exposure or reactor hazards were recorded. Some of these incidents are described in this paper. The incidents described here were chosen to give a representative picture of what could be expected in the operation of a reactor facility of similar design and similar purpose under similar operating conditions. The difficulties which exist or have existed in the radiation protection work were reviewed, and the possible solutions were suggested and practiced.

I. INTRODUCTION

The possession of some unique major facilities such as the 1 MW research nuclear reactor, THOR (Tsing Hua Open-pool Reactor), 3 MeV Van de Graaff accelerator, hot cell of 10,000 Ci ^{60}Co equivalent gamma capacity, and the radioisotope production laboratories in which 20 kinds of short-lived isotopes are produced and supplied to domestic users have made National Tsing Hua University, in addition to its regular academic programs, emerge to become a national laboratory and center of studies in the field of nuclear science and engineering. A detailed description of the first research reactor in Taiwan, THOR, is given elsewhere.¹⁾ Radiation protection experiences gained with this reactor since it went to critical on April 13, 1961 and with its affiliated facilities will be described hereinafter from the point of view of a health physicist.

II. UNPLANNED EXPOSURE

In an eight-year period 20 significant accidents were recorded at THOR and its affiliated facilities.

Some of the representative accidents will be described below in the hope that our experience will be shared with health physicists and reactor operators in the operation of similar facilities under similar conditions.

The first accident occurred at 10:20 a. m. on May 2, 1962 at the radioisotope production laboratory while ^{35}S was being processed. A glass beaker filled with irradiated KCl was broken when heated with an electric heater. Some of ^{35}S spilled on the electric heater and became vaporized. The window of a fume hood in which ^{35}S was treated had been broken for some days and the radioactive vapor coming out from the hood thus triggered the area monitor. Smear test was taken inside and outside the hood; the result indicated the hood was contaminated with counting rates in the range of $10^4 \sim 10^5$ cpm. The decontamination work took 5 people working for a full day.

On August 9, 1962 another ^{35}S contamination occurred at the same place due to poor encapsulation while irradiated in the irradiation basket around the reactor core. The irradiated sample was wrapped with a piece of polyvinyl chloride and then encapsulated in an aluminum can. When the aluminum can was opened in the hood, water was found in the can. The polyvinyl chloride

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wrapper had already been broken; some of the ^{35}S fell on the floor of the hood. A contamination of $10^4 \sim 10^5$ cpm was detected in the hood, floor, and the right hand sleeve of the experimenter.

During August 13 till September 8 in 1962 two film badges had the records of 3,440 mrad and 564 mrad respectively due to betas alone. The inquiry of the badge holders revealed the fact that they did repair a broken ion exchange column used for ^{35}S treatment inside a hood on August 31.

One experimenter irradiated molybdenum in beam port W-1, while other experimenter irradiated cobalt in beam port W-2. After irradiation these two samples were stored temporarily in a lead shield that was located in the reactor bay. Warning sign was attached to each sample respectively on March 5, 1963. However, one of the two experimenters took cobalt for molybdenum on March 13. When he opened the lead container, he realized the sample was wrong but had received some external exposure while examining the sample.

On September 14, 1964 ^{82}Br was sprayed in the isotope production laboratory while being shaken due to mechanical failure of the shaker. At the same time next door the fume hood was contaminated with ^{82}Br when the irradiated sample was opened for treatment due to the malfunction of the opening tool.

A dose rate of 5,000 mR/hr was detected in the reactor bay when the reactor operators opened the shutter of beam port E-2 on January 27, 1965. An indication light above the beam port was supposed to be observed when the shutter was opened in order to assure that the reactor core had already been removed from the high-power pool section to the low-power section. The reactor operators presumed the electric circuits for the light had been out of order.

The first accident in the hot cell happened on August 9, 1965 when ^{60}Co rods were re-distributed and packed. The hot cell was badly contaminated with ^{60}Co powder, and four persons involved received more or less over exposure ranging from 110 to 920 mrem whole body irradiation.

The routine urinalysis during September 22 through 24, 1965 revealed that one of the urine samples reached a counting rate of 2110cpm/250 ml urine while the background counting rate was 1 cpm. The isotope production laboratory people

tried to improve the ^{131}I production process by means of mechanical hands in a junior cave. However, the mechanical hands did not function properly and the off-gas system of the fume hood was not working; the handling of ^{131}I had thus to rely on direct manipulation of the experimenter without adequate shielding and remote control.

On December 2, 1965 one irradiated telluric acid sample was electrolyzed and adsorbed by platinum foil during ^{131}I production process. Next morning the telluric acid was found leaking out due to a crack of the electrolysis cell. The contaminated area inside the junior cave where the electrolysis cell was located reached a dose rate of 600mR/hr, even outside the lead shield the dose rate was 100mR/hr. The isotope production personnel proceeded to do the decontamination work immediately for 40 minutes with a result of whole body irradiation 70 mrem, hand irradiation 140 mrem (gamma) and 75 mrem (beta). The urinalysis revealed that he had received an internal exposure of 2090 cpm/250 ml urine on December 4 and 1240 cpm/250 ml urine on December 8, while the background reading was 1cpm.

The break of a plastic vial in the pneumatic tube caused an unexpected accident on December 27, 1966. Gold foil was encapsulated in a plastic vial and sent into the pneumatic tube for four-hour irradiation. After being irradiated, the vial did not come out to the rabbit station. The reactor operator suspected that this vial should have been stuck somewhere, so he sent in another vial in order to force the first vial out from the pneumatic tube. However, it did not work at all. The reactor was shutdown on December 19. The pneumatic tube system was thoroughly checked and finally the blower for the pneumatic tube was disassembled; a few pieces of vial fragments were found but not the gold foil. One end of a vial was taped with adhesive tape (adhesive side out) and it was led through the pneumatic tube again and the gold foil stuck to the tape and came out with the vial. During this search for gold foil and broken vial, all people involved were exposed more or less to radiation.

Over exposure was recorded while working in an environment without proper shielding. One happened on February 28, 1967 when ^{59}Fe was processed. The experimenter received 2,810mrem (gamma) and 190mrem (beta) whole body irradiation. Later on April 6 and 7, one worker

received 3,250 mrem (gamma) and 190 mrem (beta) while repairing a ^{60}Co radiography equipment without notifying the health physics man.

The internal exposure often happened to ^{131}I production people due to the volatility of ^{131}I itself. On April 26, 1967 two newly hired workers electrolyzed ^{131}I outside the hood instead of inside the hood and the air in the laboratory was contaminated.

Another accident involved ^{131}I occurred on August 5, 1967 in the reactor bay. Some irradiated telluric acid powder fell in the bay area while it was taken out from the beam port due to the falling of its capsule cap. A dose rate of 500 mR/hr was recorded in the bay area. Slight internal and external exposure were received by the decontamination group.

A whole body irradiation of 8,800 mrem was received overnight by a graduate student who used a 270 Ci ^{60}Co source for his thesis experiment. He entered the hot cell without putting the ^{60}Co source into a lead container first because he was tired and weary for working late till 3 a. m. in the morning.

The very recent accident occurred on July 25, 1969 when an untrained worker tried to use the manipulators to hoist a 400 Ci ^{60}Co source from a lead container in the hot cell. The door of the hot cell was opened but shielded with lead bricks and concrete blocks with an opening that would let the gamma beam to come out for an experiment set-up. The source suddenly fell off and was out of sight. It caused an environment of 2~3 mR/hr extending to most of the isotope production laboratories. Fortunately it was close to 9:30 p. m. and no one stayed late in the laboratories. Six people from the Health Physics Section were called immediately to add more shielding material to and around the opening and to reduce the dose rate to a permissible level for the nearby laboratories. All people who worked for putting up shielding received some external exposure that night. The source was located next morning and was put back inside the lead container.

The last incident of 1969 happened in the Modern Physics Laboratory where two seniors from Physics Department received 10 rems each on October 12 while they were engaged in an experiment on X-ray radiography. At the same time the laboratory next door was contaminated with ^{32}P .

III. PROBLEMS

During this eight year period the accidents did occur regardless of the strict rules and regulations that have been imposed on the ionization radiation workers. Some particular and unique problems remain unsolved in a developing country engaging in the atomic energy work. These problems have been reviewed and analyzed by Borthwick²¹. As the field operating health physicists in a nuclear science center and national laboratory, we would like to take a more perspective view on the existing radiation protection problems of our own.

1. Budgetary Limitations

Tsing Hua is an educational institution but undertakes the duty of a national laboratory concurrently. Within the frame of limited budget available for atomic energy development, only a few per cent of budget is available for radiation protection. It is not easy for a health physicist to achieve international accepted standards of safety under these circumstances.

2. Manpower

It is a fact that there is an acute shortage of scientific manpower in most developing countries. Recently the brain drain phenomenon makes this problem more serious. Radiation protection is a branch of science that most people do not appreciate its importance and existence. It is thus difficult to attract top graduates of college or technical school to enter this field.

3. Facilities and Equipment

From the accidents mentioned above one can easily find that some of the accidents were attributed to the poor quality of isotope handling tools, chemicals, containers, and glassware. The delays and difficulties in the provision of laboratory space and essential equipment have naturally affected the radiation protection work.

4. Technical Assistance and Advice

In Far East countries the development of atomic energy is similar and almost the same except Japan. The regional cooperation would not be of much help as far as technical assistance or advice is concerned. The International Atomic Energy Agency (IAEA) is virtually the only source to get technical assistance. However, IAEA's resources are not unlimited. The radiation protection man will have to explore other possibilities for assistance. It is by no means

easy.

5. Language and Information

The bulk of the health physics information is written in English, a little is in Japanese; the effect of this is principally noticeable for the junior radiation protection personnel. They find literature studies difficult and their ability to work on their own is handicapped. Even a health physicist with advanced degree will feel isolated not being accessed to the health physics information in a developing country.

6. Climate

The prolonged periods of high humidities at high temperature which exist on a semi-tropical island rapidly spoil unprotected electronic equipment. Tube characteristics change, insulators deteriorate through moisture absorption and chemical change, and damaging fungus even appears at vital places.

7. Training

The lack of experience as operating health physicists presents obvious difficulties. No appropriate textbook or reference book on radiation protection written in our own language presents another problem. The newly recruited staff with science or technology background are taught and trained in the laboratories as one kind of on-the-job training. After working for two years, they may be sent to study abroad for an advanced degree or on-the-job training. However, the lack of scientific manpower and the rapid development of peaceful uses of atomic energy in Taiwan have made the training not fast and sufficient enough to meet the requirement.

IV. POSSIBLE SOLUTIONS

Our domestic problems suggest profitable lines of research and development and lead to investigation on some particular areas. We have attempted to review the problems being faced and have sought the possible solutions as listed below.

1. Health Physics Research

Health physics research is an important aspect in every health and safety program even in a situation of shortage of experienced staff and available fund. Only through research the standards of safety at a high level can be maintained. The research program will attract and keep competent people, solve the safety problems, and provide incentive and stimulation to staff. A few topics listed below are appropriate for our

health physics man to work on and in fact these subjects are being studied.

- a. Study on the adsorption properties of local soils and clays for liquid radioactive waste disposal.
- b. Investigation into the design and construction of suitable small incinerators for combustible radioactive wastes.
- c. Investigation of the production ^{41}Ar in the THOR beam ports.
- d. Study on the deposition and accumulation of radionuclides in the environments.

2. Removal of Language Barrier

Some efforts should be made to translate the basic and necessary documents, texts, literature, and information from foreign language into Chinese. The staff are encouraged to take English or Japanese lessons of their own. The IAEA's Basic Standards for Radiation Protection and Health Physics Addendum-Safe Handling of Radioisotopes have already been translated and next will be the Argonne National Laboratory's Radiation Safety Technician Training Manual. The translation of Plutonium Safety Manual and the Radioactive Contamination of the External Environment are scheduled to be finished by next year.

3. Training

One three-credit course on radiation protection is offered to senior and graduate students at Tsing Hua every year. In this course laboratory experiments, field operation, and class instructions receive the same attention. The first two lectures of the following courses-reactor experiment, radiation measurement, modern physics laboratory, nuclear chemistry laboratory-must reserve for health physics lectures. In these two lectures, laboratory rules are emphatically stressed. Every new staff member of Health Physics Section should receive a three-month period on-the-job training and attend the radiation protection class or read the assigned texts.

4. Financial Support

Our research program has become very active since 1967. In such a short period of time ten seniors and four graduate students have involved in our research activities. We hope the results of our research will not only solve our safety problem, but will also give us an opportunity to ask for financial support from National Science Council and other similar foundations.

Our first contract with IAEA on radioactive waste treatment was approved in September 1968.

5. Technical Advice

Due to geographical convenience we have attempted to start a cooperation program on health physics with Japan and seeked its technical advice if necessary. The first approach is the exchange of technical personnel, to participate in its Health Physics Society, and to publish some technical papers in Japanese journal. This approach has been quite successful so far. The technical advice on plutonium safety and bio-assay was given by Japanese health physics group.

V. CONCLUSION

Our experience on radiation protection for a one-MW pool type research reactor and our views and comments on attacking the existing problems

are by no means complete. All views expressed in this paper are personal ones which are not necessarily the official views of the University. We feel that through intense research and investigation one can solve many problems on radiation protection in a research reactor facility of a developing country.

REFERENCES

1. C. H. Cheng; "One and a Half Year's Experience with Tsing Hua Open-pool Reactor (THOR) and its Utilization," IAEA Proceedings of a Study Group Meeting on Utilization of Research Reactors, Bangkok, 17-21 December (1962).
2. R. A. Borthwick; "Problems of Health Physics Development in S. E. Asian Countries," IAEA Regional Study Group Meeting, Manila, 9-12 December (1963).

「会 員 の 頁」 投 稿 案 内

「保健物理」は会員皆様の雑誌です。編集委員会では次のようないくつかのカラムを作って、皆様の寄稿をお待ちしています。ふるって御投稿下さい。

1. 諸案内などのカラム

文献・アイデアを求む、研究会の開催、職員募集、その他会員のための案内など。400字以内。

2. 随想などのカラム

保健物理または関係あることについての随想など写真などの分を含めて1,800字（刷り上り1ページ）以内。

3. 新技術などの紹介のカラム

保健物理または関連分野の新しい技術・製品・装置あるいは用語などの紹介や解説。写真などの分を含めて850字（刷り上り1/2ページ）以内。

4. 事業所便りのカラム

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5. 意見などのカラム

本誌、本会あるいは保健物理全般についての意見や希望など。850字以内。

原稿送り先 茨城県那珂郡東海村 日本原子力研究所
保健物理安全管理部内、保健物理編集委員会
〒319-11

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原稿用紙 1行が25字あるいは20字の横書きのもの。
その他 氏名、勤務先、連絡先（住所、電話）を必ず書いて下さい（意見などのカラムでは誌上匿名を認めます）。氏名等のないものは掲載しませんので御注意下さい。なお採否は編集委員会に一任下さい。

5 巻 2 号掲載論文「個人用塵埃サンプルの特性試験」について（質問）

（東芝総研） 近 藤 昇

いま私供のところでも、個人エアサンプラを購入する計画があって、どのメーカーの製品がよいかと選択にまよっていた時に、たまたま標題の論文が掲載され、大変に参考になりました。個人エアサンプラの性能上必要な条件は、十分な吸引流量がとれて、低抗増大や電源電圧の多少の変動があっても（勿論なくとも）長時間吸引流量が不変であることでしょう。この流量の変動に関与する因子をパラメータとした実験データは大いに私共にとって参考となりました。そこで最も決定的な特性をあらわしている Fig. 7「供給電圧と流量との関係」をみますと、Casella が 5.5V 以上で約 2.6 l/min の一定流量を

しめしており、これはモータにガバナが装置されているためであるとして、著者等は高く評価しておられます。しかしここで疑問は、この実験が無負荷時のものであることで、実際の使用状態においては、Casella の流量は（ミリボア・フィルタ AA）1.5 l/min (340 mmH₂O) であることが同論文 Fig. 5 でしめされております。そうだとすれば、実際の使用状態においては、このガバナの効果はあまり意味がないのではないかと思います。論文の実験データは性能評価上よく理解できましたが、「実用的である」という結論には、ちょっと疑問が生じたので、御教示頂ければ幸いです。

御 質 問 に 対 し て

（原研、東海） 大 畑 勉

御質問の内容は、

- (1) 負荷時におけるガバナの効果
- (2) 実用性

の 2 点を含んでいると考えられます。

そこで、(1) については、Casella の場合についても Fig. 9 に示す様な特性図を作っていないため、負荷がどの程度増加したら、ガバナの効果にどの程度影響をもたらすかは、はっきり断定しかねます。

しかし、以下のことは申し上げられると思います。負荷が増加するにしたがって、沪指からダイヤフラムまでの負圧の増加、それによるモーターの消費電力の増加、つまり電池電圧の降下を引き起こす結果となります。しかし、Casella の場合、Fig. 6 に示す様に負荷が増加しても、モーターの消費電力が最も低いこと、および Fig.

3 の試験結果から電池容量が他の 2 機種と比較して、最も安定していること。以上のことから、負荷が増加することによりおこる電池電圧の降下は他の 2 種と比較してより遅いと考えられます。したがって、電池電圧が約 5.5V まで、しかもある程度の負荷の範囲であれば、ガバナを装着してある効果はあると言えるのではないでしようか。

(2) の実用的であると判断した理由は、この種のサンプラを使用して得られた空気中濃度値をより正確に評価しえることが必要なわけです。そこで、重要なことはサンプラの吸引性能が高いことだけでは、実用的であるとは言えません。その点、Casella の場合は、他の 2 種と比較して、(1) で述べた利点をもつことからより実用的であると判断した訳です。