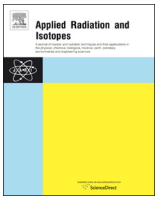
Applied Radiation and Isotopes 137 (2018) 129–138

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Shielding design of a target station and radiation dose level investigation of proton linac for a compact accelerator-driven neutron source applied at industrial sites

Baolong Ma[a], Yoshie Otake[b,a], Sheng Wang[a,b,*], Hideyuki Sunaga[b,a], Yutaka Yamagata[b], Atsushi Taketani[b], Huasi Hu[a], Qinggang Jia[a], Guang Hu[a], Unico Bautista[c,b,d]

[a] Xi'an Jiaotong University, No. 28, Xianning West Road, Xi'an 710049 Shaanxi, China
[b] RIKEN Center for Advanced Photonics, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
[c] University of Tokyo, Shirane 2-22, Shirakata, Tokai-mura, Naka-gun, Ibaraki 319-1188, Japan
[d] Department of Science and Technology, Philippine Nuclear Research Institute, Quezon City 1101, Philippines

HIGHLIGHTS

- Shielding material was optimized by GA algorithm coupled with Monte Carlo code.
- A multi-layer shielding structure was adopted and showed significant advantages.
- Materials of bellow for CANS proton linac were studied from a new perspective.

ARTICLE INFO

Keywords:
CANS
Shielding design
Genetic algorithm
Bellows
Industrial site

ABSTRACT

The shielding design for a compact accelerator-driven neutron source (CANS) that is applied in industries was studied using both theoretical simulations and experimental measurements. Neutron shielding material composition for CANS was optimized by coupling the genetic algorithm with the Monte Carlo code. A multi-layer shielding structure was developed and successfully applied to a CANS target station. The high radiation dose of CANS proton linac was investigated in detail on the basis of experimental measurements, and the radiation dose was significantly reduced by replacing the material of its bellow pipes.

1. Introduction

Neutrons are the fundamental particles with many unique properties. They are weakly interacting neutral particles with a strong penetration power; they can also provide high contrast for light elements in the presence of heavy elements because of their large scattering cross-section with light atoms. Furthermore, neutrons have a magnetic moment and a magnetic cross-section. The excellent intrinsic attributes of neutrons enable a wide range of objects to be imaged, ranging from large-scale structures to magnetic structures. Therefore, neutron imaging can be highly complementary to X-ray imaging.

High neutron beam fluxes are provided by large-scale neutron facilities: (1) reactor neutron sources and (2) large accelerator-based neutron sources. Nuclear reactors use fission reactions to produce neutrons, e.g., HFR (Carlile, 2006), JRR3 (Sakurai et al., 2002), HANARO (S.M.C. et al., 2007), FRM-II (Trinks et al., 2000), OPAL (Kennedy, 2006), CARR (Han et al., 2013). Neutrons can also be produced by the spallation reaction, including ISIS (Wilson, 1995), ESS (Clausen, 2000), LANL (Saunders et al., 2013), SNS (Mason et al., 2006), J-PARC (Ikeda, 2005), CSNS (under construction) (Wei et al., 2009). These large-scale neutron source facilities play important roles in fundamental science. However, there is little opportunity for industrial users to utilize these facilities because user proposals are usually screened based on their scientific value, instead of their application value; moreover, a high cost is also needed to keep the experimental results confidential. Therefore, there are urgent demands for neutron beam in industrial fields. The Compact Accelerator-driven Neutron Source (CANS) (Otake par.auth. et al., 2015), which has modest scale and cost, has emerged to compensate for the shortcomings of large-scale neutron facilities in industrial applications.

Table 1 shows five main CANS facilities in the world. All of them are designed for the purpose of basic research and education except for

---

[*] Corresponding author at: Xi'an Jiaotong University, No. 28, Xianning West Road, Xi'an 710049, Shaanxi, China.
E-mail address: shengwang@mail.xjtu.edu.cn (S. Wang).

https://doi.org/10.1016/j.apradiso.2018.03.015
Received 19 October 2017; Received in revised form 10 March 2018; Accepted 18 March 2018

Table 1
Main CANS facilities in the world.

Name	Type	Particle	Energy	Current	Reaction	Intensity	Moderator
Hokkaido University Neutron Source (HUNS)	Linac	Electron	33 MeV	90 μA	(e, X), (X, n)	~ 1.6×10^{12} n/s	Solid methane coupled with premoderator: polyethylene
Low Energy Neutron Source (LENS)	RFQ + 2 Linac sections	Proton	7 or 13 MeV	25 mA	Be (p, n)	~ 5×10^{10} n/s	Cryogenic methane
RIKEN Accelerator-driven Neutron Source (RANS)	Linac	Proton	7 MeV	100 μA	Be (p, n)	~ 10^{12} n/s	Polyethylene
Compact Pulsed Hadron Source (CPHS)	Linac (RFQ + DTL)	Proton	3 or 13 MeV	1.25 mA	Be (p, n)	~ 5×10^{13} n/s	Stage 1: polythene Stage 2: solid methane
Peking University Neutron Imaging Facility (PKUNIFTY)	RFQ linac	Deuteron	2 MeV	40 mA	Be (d, n)	~ 3×10^{12} n/s	Polyethylene and light water

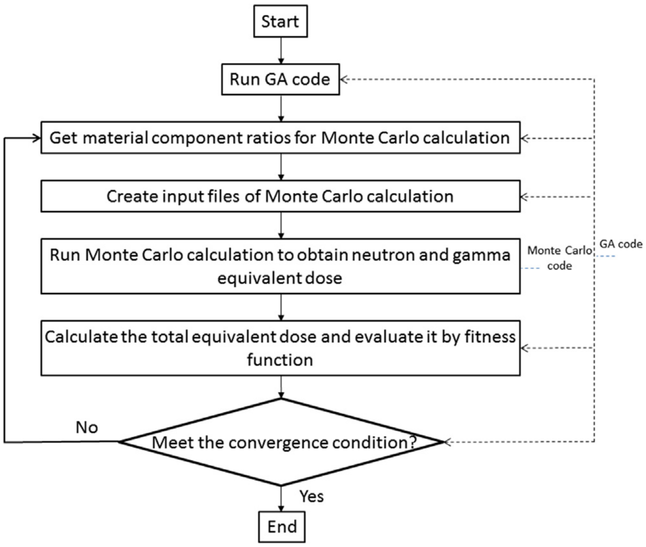


Fig. 1. Flow chart of shielding material optimization by GA coupled with Monte Carlo code.

RIKEN Accelerator-driven Neutron Source (RANS) (Otake et al., 2017; Yamagata et al., 2015). RANS is constructed for industrial applications such as non-destructive inspection of corroded steel (Taketani et al., 2017), neutron engineering diffraction (Ikeda et al., 2016), investigation of concrete durability under chlorine salt erosion, and so on (Seki et al., 2017).

Among the various aspects of CANS design, shielding design is one of the key factors to make industrial use on site possible and to avoid radiation exposure to the public and operators under the complex

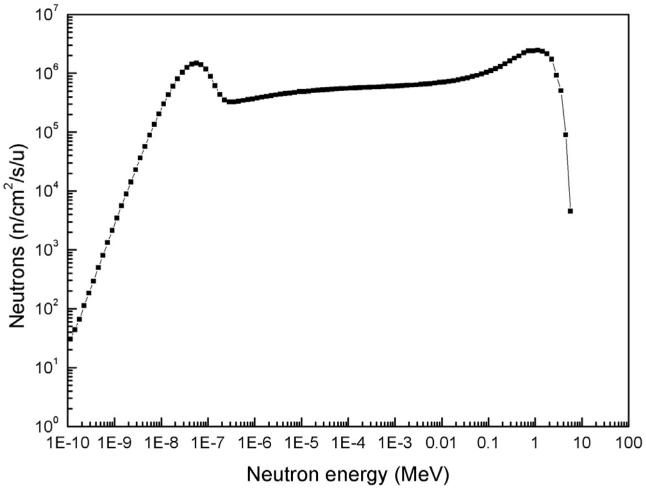


Fig. 3. Neutron energy spectrum at RANS reflector.

Table 2
M concentration ratios for each BPE (%).

	^{1}H	^{10}B	^{11}B	^{12}C	^{16}O
Model 1	64.36	0.303	1.130	32.18	2.152
Model 2	61.836	0.535	1.989	30.918	3.786
Model 3	61.442	0.655	2.442	30.811	4.649
Model 4	58.289	1.062	3.962	29.145	7.541
Model 5	52.768	1.758	6.557	26.384	12.532
Optimal one	63.43	0.41	1.53	31.72	2.91

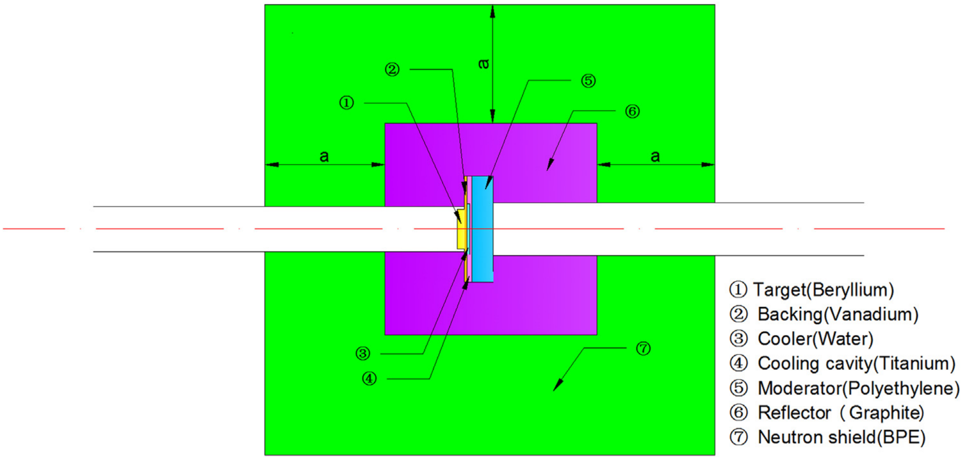


Fig. 2. Geometrical configuration for the shielding effect evaluation of BPE.