observations show that there is no obvious influence on the configurations of He bubbles whether appmHe/dpa is low or high in Ti_3AlC_2. This may have some relationship with high resistance to irradiation damage in this material.

In Ti_3AlC_2, the formation energy of anti-site defect between Ti and Al is low, only 3.13 eV[9]. Ion irradiation could be prone to produce a large number of anti-site defects (Ti_{Al} or Al_{Ti})[3,10,11], causing the distribution of Ti and Al atoms in each layer, which is also responsible for the structural transformation. Some of the C atoms which occupied the octahedral holes between the Ti layers in the virgin compound are displaced and move to the new octahedral holes between the original Ti and Si (or Al) layers[10,11]. Thus the formation of anti-site defects of cations and disorder of anions provide an alternative way to accommodate the defects from irradiation damage cascades, which is similar with the cases of complex oxides[12]. It is reasonable to assume that the most of vacancies created by initial Fe-ion irradiation are quickly annihilated or transform anti-site defects, so that only a minority of vacancies survive before the following He-ion implantation. Actually, up to now there are hardly any reports on cavities in ion irradiated MAX materials even with high damage level. Therefore, the environment with low appmHe/dpa may do not imply the more vacancies (or cavities) than high appmHe/dpa in the ion irradiated Ti_3AlC_2. Note that He bubbles still present spherical shape, indicating that surface free energy dominates during their formation process[13].

In summary, we study the characters of defects and He bubbles in high damage environment in Ti_3AlC_2, which was created by 3.5 MeV Fe-ion irradiation and 500 keV He-ion implantation successively. Compared with single Fe-ion irradiation, (Fe+He) irradiation enhances damage dramatically, creating more serious structural distortion. However, Ti_3AlC_2 still retains the crystalline structure, without amorphization. A large number of He bubbles with mean radius about 0.62 nm appear in He depositional region. It seems that the relative low appmHe/dpa doesn't make an obvious influence on the growth of He bubbles compared with the high appmHe/dpa. However, the following He-ion implantation influences in part the pre-created defect configurations.

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4 - 6 Environmental Residual Radiological Impact Assessment of the Proton Accelerator of China Initiative Accelerator Driven System

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China Initiative Accelerator Driven System (CiADS) is the first integrated ADS facility designed to study the safety disposal of nuclear waste, which will be constructed by Institute of Modern Physics, CAS. CiADS is consisted of a proton accelerator, a spallation target and a sub-critical nuclear reactor. As a nuclear facility, it will cause environmental radiological impact during the operation[1−3]. So, the environmental impact assessment of CiADS is not only significant to public health, but also offers significant guides to the shielding design of CiADS. Induced

radioactivity in earth, pebbles and groundwater around the proton accelerator of CiADS has been studied using both experimental and simulation methods to provide important information for the environmental radiological impact assessment of the CiADS.

Pebble samplings were collected and irradiated by a ^{241}Am-Be neutron source. Based on the γ-spectrum measured by a HPGe detector before and after the neutron irradiation, the specific activities of induced-nuclides ^{24}Na, ^{54}Mn, ^{56}Mn and ^{27}Mg in these samples were analyzed and compared with the Monte-Carlo simulation values obtained with the Geant4 toolkit. The comparison between the experimental and simulated results indicates that Geant4 toolkit is feasible for radiation impact assessment of nuclear facilities, such as the proton accelerator of CiADS (Fig. 1).

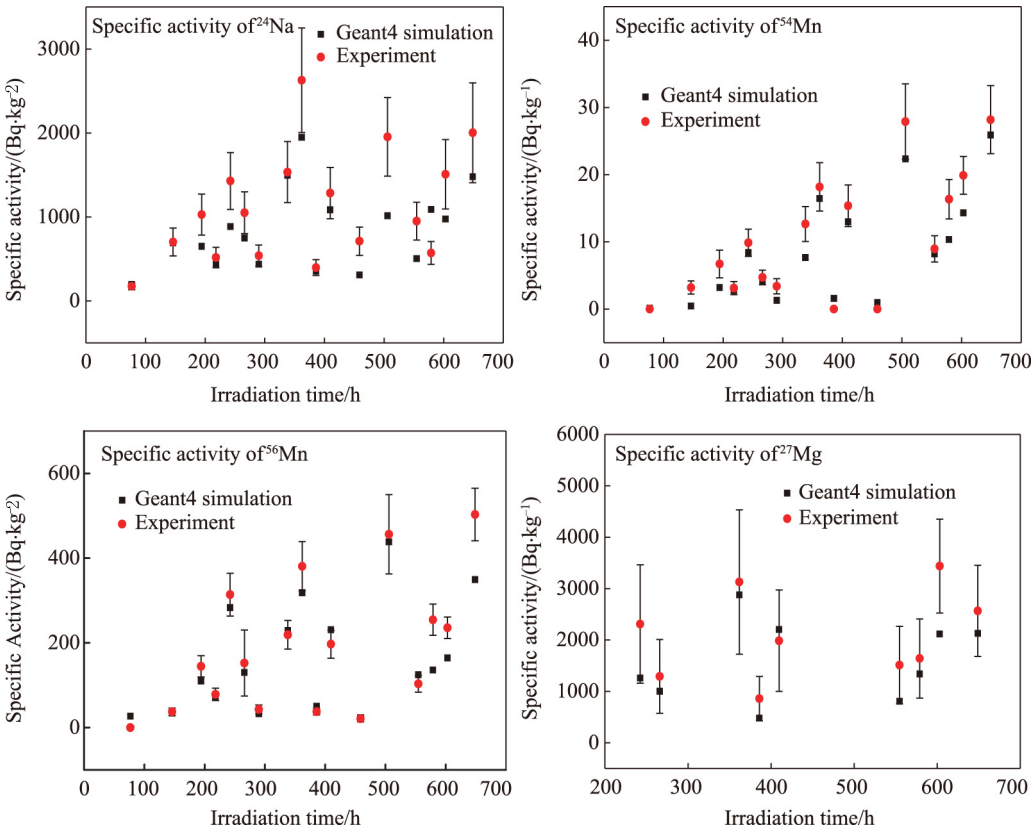

Fig. 1 (color online) The specific activities of induced-nuclides ^{24}Na, ^{54}Mn, ^{56}Mn and ^{27}Mg in pebble samples.

The neutron spectrum and induced-nuclides in the environmental media surrounding the proton accelerator (500 MeV, 600 MeV and 1.2 GeV) have been predicted using Geant4. The results show that the saturation activities of induced-nuclides in surrounding media outside theshielding of the proton accelerator are much lower than their exemption values[4]. The environmental radiological impact can be ignored if they fix in the environmental media.

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