THE DESIGN OF NEUTRON RADIOGRAPHY FACILITY AND ITS APPLICATION IN SPRR-300

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Abstract: The neutron radiography is one of non destructive test technologies. The neutron radiography facility has been designed in SPRR-300 to check the inner structure of some components. The facility is made up of collimator system (including the shutter), the table for sample, the imaging system, the controlling system and so on. In the collimator system, The graphite is used as a moderator, and the bismuth as a gamma filter and the material made of lead, boron, polyethylene and cadmium as the diaphragm. The interior structure of the collimator is like a labyrinth in order to reduce its weight and absorb effectively scattered neutrons. For improving the shielding performance and the controlling precision of the exposure time, a shutter is used. The table for sample is used to modify the tested part and orientation of the sample. There are two methods of neutron radiography in SPRR-300, one using films (including direct imaging and indirect imaging) and the other using CCD camera. The converters are Gd foil and Gd_2O_2S foil for direct imaging, and In foil, Dy foil for indirect imaging, and NNU-2(^{6}LiFZnS(Ag)) for CCD imaging. To improve Signal-to-Noise in CCD imaging system, the double thermocouple refrigeration is used. To improve resolution power, the lens with small visual angle is used. To improve dynamic range, the image grabbing, processing and analyzing technology of 14bit data is used. In the controlling system, PLC(Programmable Logic Control) is used to improve the facility automation and the radiation shielding of researchers and instruments. The neutron radiography has been utilized in recent years to detect internal structures or defects of some components in SPRR-300, and some good effects were obtained.

Introduction: Neutron radiography is an imaging method that the objects are penetrated by neutron and information is obtained about the inner structure (non-destructive) .Its principle is the same as X-ray Radiography. But compared with X-ray radiography, because of the difference of the interaction with a atom neutron radiography has some merits which X-ray radiography has not, such as penetrating some dense materials , for example lead, bismuth, uranium and so on and getting high contrast of light materials enveloped in these dense materials, distinguishing between elements of similar atomic weight and isotopes of the same element and avoiding the interference of gamma radiation of the irradiated materials by using the indirect imaging method, so neutron radiography is a only available non destructive method in some situations[1, 2]

SPRR-300 is a Swimming Pool Research Reactor(3.5MW). It is a light-water moderated and cooled, graphite and beryllium reflected thermal reactor. The maximal thermal neutron flux in the core of SPRR-300 is about 6.5×10^{13} $n.cm^{-2}.s^{-1}$[3]. Neutron radiography has been developed in the reactor since 1980s, but with a stagnation of a long period. Now, neutron radiography has been re-developed during these years, and a new neutron radiography facility has been designed and set up in SPRR-300. There are two methods of neutron radiography: a method of using films and a method using CCD. The former has better power resolution and lower time response, and more difficulty to be digitaled and the later is contrary.

Results: The structure of the neutron radiography facility in SPRR-300 is showed in Fig.1[2]. The neutron for neutron radiography is drawn from a radial thermal neutron channel, which diameter is 150mm. The 55mm lead plate in front of the channel is used to filter γ -rays from the reactor core. Graphite plug is placed in front of the channel to moderate neutron. The value of cadmium ratio (Rcd) obtained for gold foil on the orifice of the channel may adjusted from 4 to 150 if the length of graphite plug is changed from 0cm to 100cm. An interior collimator like a taper after the graphite plug is used to prevent the divergence of neutron flux. The interior structure of the interior collimator is like a labyrinth. On the one hand, the structure can reduce the weight of the collimator, and on the other hand, it can more effectively absorb scattered neutrons and γ -rays. The diameter of the diaphragm of the interior collimator can be changed between 10mm, 30mm and 50mm. Another bismuth plate of 45mm thickness in front of the inter collimator is used to stop γ -rays again. To increase collimation ratio, an exterior collimator like a taper is used, and collimation ratio can vary between 50 and 660 with the change of the diameter of the diaphragm and the length of the exterior collimator. The diaphragm of the interior collimator is composed of borated plastics, metal gadolinium or cadmium rings, and the inner surface of the interior and exterior collimator is lined by lead foil and boron carbonide to decrease scattered neutron and γ -rays. A shutter made up of water, lead and steel box is used to control the exposure time and enhance the shielding. The sample table is driven by three motors, and it can move left and right, up and down and round and round to adjust the angle and region of a sample, and it can be driven forward and backward by hand to adjust collimation ratio. There are two methods of neutron radiography in SPRR-300, a method using films (including direct imaging and indirect imaging) and a method using CCD, including Intensified CCD (I-CCD) and Cooled CCD (C-CCD). The former has better spatial resolution(about 50 μ m), but requires more time for developing films, and the information of a photograph is more difficultly converted to digital data. The latter has characteristics opposite to those of the filming method. The indirect imaging (the transfer imaging) is the method that a converter is activated by neutron and is moved into dark box to make the film exposure, so It can avoid the interference of gamma radiation of the irradiated materials. The I-CCD system is often called the Real-time radiography, and its maximal frame speed is about 25frames/s, and the spatial resolution is about 200 μ m. The C-CCD system with about 100 μ m spatial resolution is also called the high resolution static system, and it takes about 0.5s~1800s to get a neutron radiograph according to the sample material and the neutron flux. To improve Signal-to-Noise in C-CCD imaging system, the double thermocouple refrigeration is used to cool CCD below -25□. To improve resolution power, the high quality of the lens with small visual angle is used to cover 10cm×10cm (f: 188.7mm, f/D: 1.45) or 3cm×3cm (f: 225.7mm, f/D: 1.6). To improve dynamic range, the image grabbing, processing and analyzing technology of 14bit (16383) gray-data is used. The pixel array format of the C-CCD chip is 1024×1024 pixels with a pixel size of 24×24μm. The quantum efficiency of the C-CCD is in the range of 80~90% for wavelengths from 350 to 800nm. A 10mm thick glass coated with Al and TiO_2 as the protecting layer is used, and it has the high reflectivity (more than 90%) for the light emitted by the scintillator, generation of few γ -rays and no-lasting activation of the material. A light shielded box which material is Al to avoid long term activation is used. The converters used in SPRR-300 reactor are Gd foil, Gd_2O_2S foil for direct imaging, and Dy foil for indirect imaging, and NNU-2($^6LiFZnS(Ag)$) for CCD imaging.

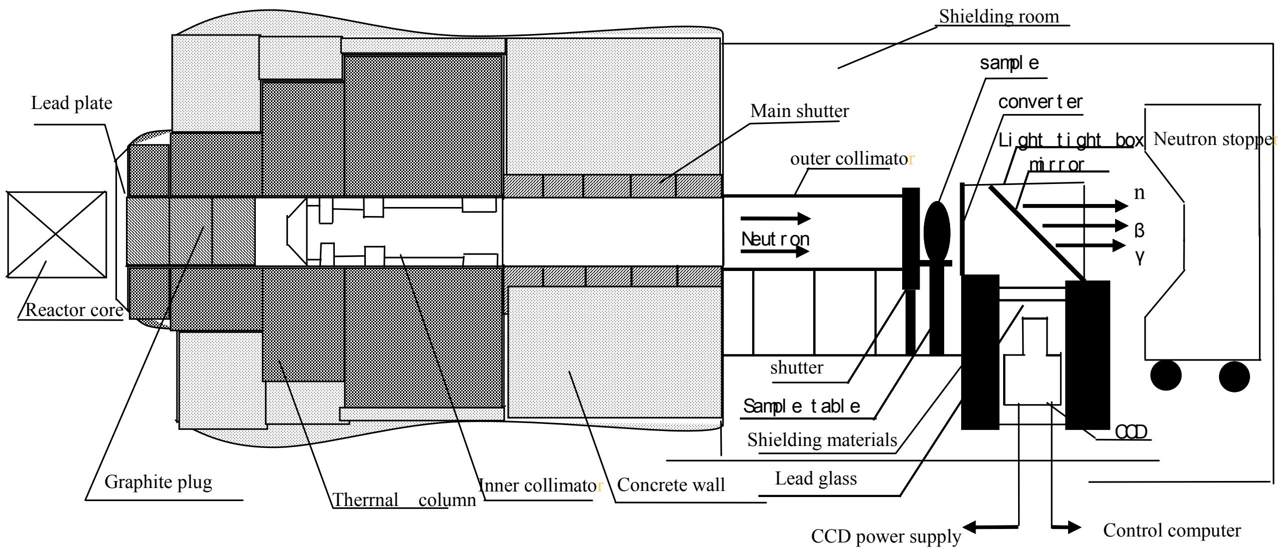

Fig. 1 The structure of neutron radiography facility in SPRR-300

The characteristics of neutron radiography facility in SPRR-300:

a) The maximal flux on sample:$4\times10^{7}\cdot cm^{2}\cdot s^{-1}$.

b) Cd-ratio : 4□150 (Adjustable).

c) Collimator ratio: 60□660 (Adjustable)□

d) neutron-gamma ratio: $2.70\times10^{10} n.cm^{-2}.Sv^{-1}$.

e) ASTM-86 indicator parameters (Cd-ratio is 15): NC-62.14%, S-0.95%, v-0.71%, P-1.79%, H-8, G-7. Imaging: quality: the second grade.

The application of neutron radiography in SPRR-300

a) Detecting parts including explosive

Neutron radiography particular advantage is to detect the explosive state in a metal conduit, such as a fuse, a explosive network, a bolt, and a detonator, etc. The explosive density and foreign materials can be detected. A explosive network was determined in SPRR-300, and a minimum space defect of 0.02mm has been observed in it by the film imaging method.

b) Inspecting nuclear fuel elements

For raising fuel burn-up, different amount of Gd_2O_3 as burnable poison is doped into nuclear fuel elements with cosine distribution. It has important significance to control fuel element quality. The content, distribution and grain-size of Gd_2O_3 in the element have clearly been detected in SPRR-300. In addition, two components of UO_2 fuel with magnesium powders as disperser were inspected. The different gaps between both fuel parts, the Mg-grains and their distribution have clearly been seen.

C)quality control of heavy metal component

Non destructive testing (NDT) of Heavy metal components is difficult to be done by X-rays radiography because X-rays are uneasy to penetrate them. However, neutron radiography has good result to inspect them. A heavy metal component made of plumbum, stannum and antimony was detected in SPRR-300, and air holes, which diameter is more than 0.5mm, and some organic impurity, which diameter is more than 0.2mm , were found. Now, neutron radiography has been an important method of quality control of the heavy metal component.

d) Electronic Device Testing,

Neutron radiography can be used to check a electronic device, such as on-off switches, and relays, especially for the hydride in it.

Some neutron radiographs are shown below, and among these a, b, c and d are got by C-CCD imaging system, but f and g are got by film imaging method.

Discussion[4,5]: With the development of CCD technology, there are more and more neutron radiography facilities which use CCD method. According to my knowledge, there are two key questions which must be thought about The first is how to improve further the resolution power of CCD imaging system to arrive at the level of film method if possible. The second is how to improve the ability of anti-irradiation of CCD to prolong CCD life and how to remove the white dots which are produced because of neutron and gamma irradiation to improve image quality. To resolve the first question, a small imaging area(30×30mm^2) lens and a big array CCD chip (1024×1024 pixels) was used□but the resolution power still need to improve comparing with film method. Perhaps, the principle of scintillator converter should be changed as metal converter such as Gd converter which has only one uncertainty. Now, the scintillator converter such as ^{6}LiFZnS(Ag) has two uncertainties. A ^{6}Li atom absorb a neutron to convert to an alpha particle, then an alpha particle make ZnS(Ag) material shining. Another factor that the diameter of a ^{6}LiFZnS(Ag) grain is about 4~6μm maybe debase the resolution power. Consequently, we are trying to develop a new nanometer converter made of Dy nanometer crystal which can absorb a neutron to emit light and has only one uncertainty. To resolve the second question, an astronomy-grade CCD chip shall be used and shall be shielded severely against gamma and neutron irradiation, and a median filter arithmetic shall be used also, which means the value of the middle pixel is replaced by the average of surrounding pixels.

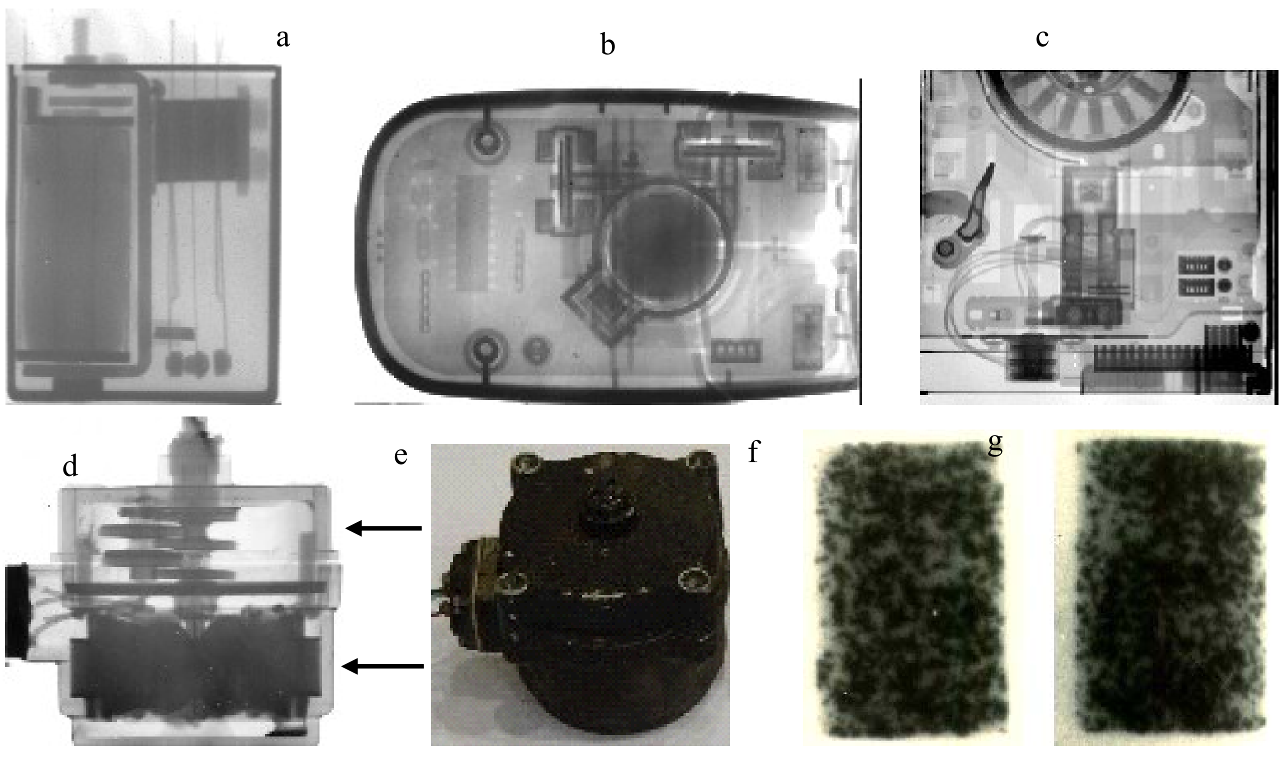

Fig 2 Some neutron radiographs got in SPRR-300. a: relay, b: a mouse, c: a floppy d and e: a motor and its practicality image, f and g: UO_2 fuel pieces (a black dot is a Gd_2O_3 grain):

Conclusions: The neutron radiography facility has some disadvantages because of various reasons, we will continually develop neutron radiography including neutron computer tomography to improve it. Presently, the use of neutron radiography is not quite universal in China because neutron sources are irremovable, expensive and so on, and neutron radiography is developed in few research institutes. But I think the status may be changed with the development of small removable neutron sources. We also wish to cooperate and exchange each other with all colleagues in the world!

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