Remote-controlled compact gamma camera “Gammavisor” for control of radioactive sources/contamination

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Abstract

For activities on rehabilitation of the RRC KI the new version of the gamma imaging device - “Gammavisor” was developed. The device consists of a gamma radiation detection unit enclosed in a lead shielding with a detachable double-cone collimator for registration a gamma image and a color video camera mounted on the shielding case. The shielding case is fastened to a rotator mounted on a stand (tripod). The detection unit consists of a CsI(Tl) scintillation crystal; a scaling fiber optics taper (FOT); a microchannel plate light amplifier; and a digital video camera with a lens for reading and recording an image in a computer. The instrument is connected to compact computer fastened to a rotator too. The instrument and rotator are controlled by operator from computer connected with system via wireless Wi-Fi line or by twisted-pair cable. The device is used for control of position radioactive sources, sorting radwaste, mapping of radioactive contamination of installation and rooms.

1. Introduction

The works on preparation for a decommissioning of research reactor MR are spent in RRC «Kurchatov institute». Reactor MR was shutdown in 1992. It works is continuation by works on rehabilitation of objects in RRC «Kurchatov institute» site begun in 2003. In the period from 2003 to 2006 the activities have been spent on liquidation of the historical radwaste storages and rehabilitation of a site of their placing [1]. At carrying out of these works there were various non-standard problems in the field of radiating measurements. Some new devices have been developed for carrying out of such measurements [2-4]. The results received at application of new devices developed for use in rehabilitation works, have shown their efficiency at the decision of non-standard problems.

The research complex “Reactor MR” includes research reactor MR with nine pipelines installations, various systems and the equipment, placed in a set of buildings and premises. Reactor MR was used mainly for test of fuel assemblies and materials for new nuclear power installations.

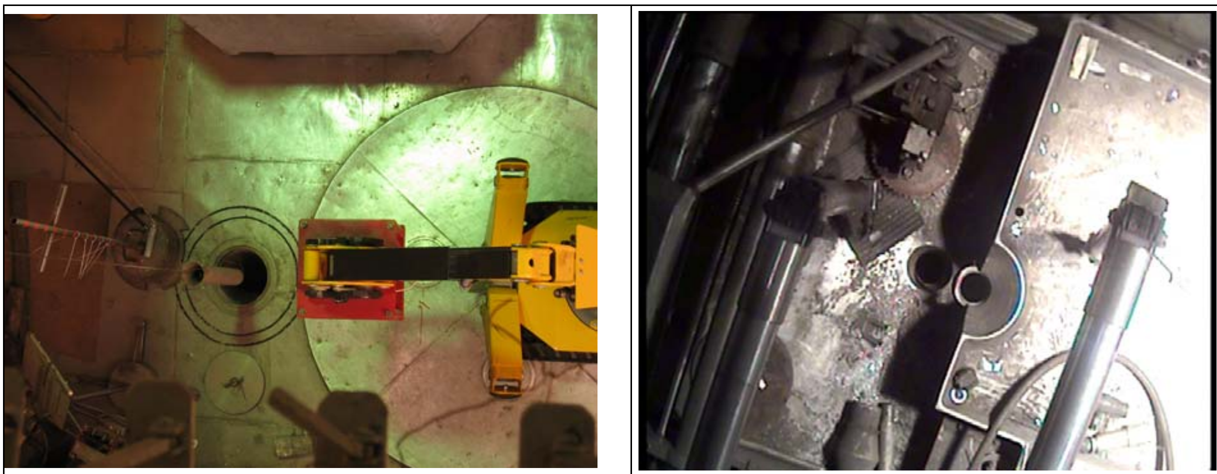
Main objective of works for a decommissioning of research reactor MR is:

- dismantle of the equipment of primary contour and loopback installations of reactor MR,
- removal of the formed radioactive waste from RCC Kurchatov Institute site,
- the subsequent rehabilitation of buildings and constructions of reactor MR taking into account the further use of these objects.

2. Instrumentation for radiological inspection

The important stage of preliminary works for a decommissioning of research reactor MP is the carrying out of radiological inspection. One of the most contaminated premises is a hot cell of the reactor which was used for post irradiation examination of reactor fuel.

The hot cell is located in a reactor hall. The top overlapping of the hot cell is at floor level a reactor hall. The sizes of the hot cell 3.5x5m, height – 3m, a thickness of the top overlapping 2m. The investigated samples pull down to the hot cell through its top hatch leaving in a reactors hall by means of remote mechanisms. In the hot cell the equipment for a fragmentation of investigated samples for the subsequent analysis is established. As a result of spent works there was a radioactive contamination of the hot cell. On fig. 1 photos a reactors hall and the hot cell used for a fragmentation of investigated samples are presented.



a) b)

Fig. 1. a) Photo of reactor hall with top hatch of the hot sell on floor reactor. b) Photo of mechanisms for a fragmentation of investigated samples in the hot cell.

For the remote radiation inspection of the hot cell, a new version of the remote-controlled compact gamma camera “Gammavisor” was developed.

The device consists of a gamma radiation detection unit enclosed in a lead shielding and a color video camera mounted on the shielding case. The lead shielding is 20-mm thick.

The detecting block consists from scintillating crystal CsI(Tl) (thickness of 3 mm and Ø40 mm); a scaling fiber-optical plate; two MCP image amplifiers and a CCD camera with an lens for reading and recording an image in a computer.

Gamma-imaging is based on using of conical collimator or coded mask. Digitized video images are used for identification of the radioactive objects.

The set of replaceable two-cone collimators was made. Using these collimators it is possible to change the field of view and a spatial resolution of the device. Replaceable collimators are made from tungsten alloy (density 17.2 g/cm^3) and have the dimensions ∅18 mm x 20 mm, angles of view 30^0, 45^0, 60^0, diameters of collimator’s waist are 1.8 mm, 5 mm, 2.2 mm correspondingly.

The front part of shielding is made as a set of the leaden rings. Changing a position of rings, it is possible to establish different replaceable collimators without disassembling of the device. The installation of a coded mask is provided also. The application of coded masks allows to increase sensitivity of the device [3]. The hexagonal URA coded mask of 9-th rank is made. Mask is made from tantalum, the thickness of mask is 4 mm, angle of view of the device with mask - 25 degrees. The design of device and photo of collimators and coded mask is given in Fig. 2.

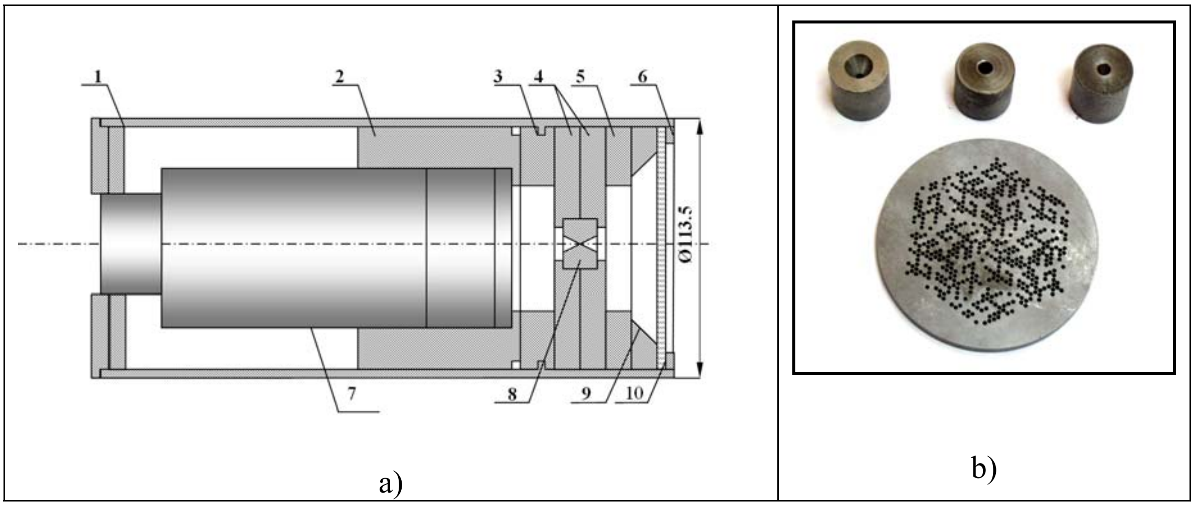
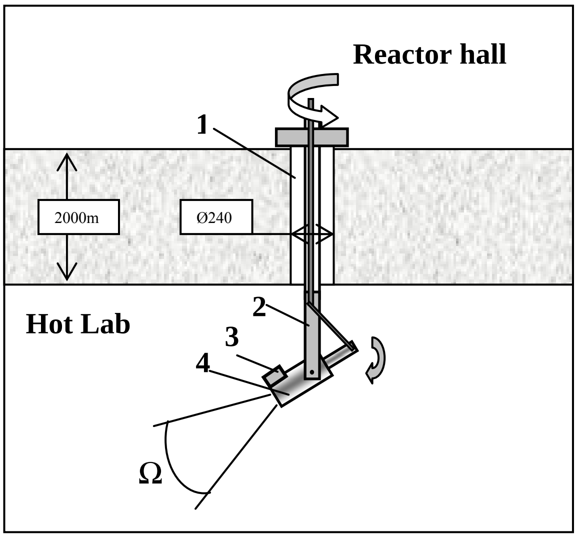


Fig. 2. a) The design of device. 1- case of the device, 2 – lead shielding , 3,4,5,9 – lead rings, 6 - nut, 7 – detector, 8 - collimator, 10 -input window. b) The photo a set of collimators and coded mask.

In a result of laboratory tests the following basic parameters of portable gamma camera are determined:

- energy range : 60-1500 кeV;
- field of view of the gamma camera with different collimators : 30^o, 45^o, 60^o;
- angular resolution : 1^o, 2^o, 2.5^o;
- field of view of the video camera : 70^{o}x58^o;
- sensitivity : visualization of a ^{137}Cs point source with activity 6×10^8Bq, located on distance 10 m from the device, at a normal background dose rate (0.15μSv/h), during imaging time 15 min and signal/noise ratio 5:1.

For reading of the image from screen of MCP image intensifier two types of CCD cameras (VS-CTT-075 and VS-205-USB) are used.
In the first variant of the device (with VS-CTT-075 CCD camera) the signal from the detector is transferred on a cable to the computer of the operator.
A special portable computer is used for control all gamma camera sub-systems by operator, for processing of gamma images, storage and displaying and for operation with images. Standard distance between detecting head and computer is 50 meters.
The given variant of the device has the smaller sizes and will be used for carrying out of measurements in hard-to-reach places in premises including the hot sell. For remote-controlled compact gamma camera “Gammavisor” the VS-205-USB CCD is used. The shielding case is fastened to a rotator mounted on a stand (tripod). The instrument is connected to compact computer fastened to a rotator too. The instrument and rotator are controlled by operator from computer connected with system via wireless Wi-Fi line or by twisted-pair cable. The device is used for control of position radioactive sources, sorting radwaste, mapping of radioactive contamination of installation and rooms.
For the remote radiation inspection of the hot cell the special device has been made. The device consists of a metal bar to which on the rotary hinge fastens the gamma camera with a video camera. It’s measuring system pull down to the hot cell through its top hatch by means of remote mechanisms. The vertical and horizontal turning of the measuring system is carried out by means of a manual driver. The signal from the detector is transferred to a special portable computer. The scheme of measurements in the hot cell with the gamma camera and photo a measuring system is shown on fig. 3.



a)

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Fig. 3. a) The scheme of measurements in the hot cell with the gamma camera. 1 - top hatch of the hot sell, 2 – a measuring system for the remote radiation inspection, 3 – gamma camera, 4 – a video camera, Ω - field of view of the device. b) Photo a measuring system for the remote radiation inspection

3. Conclusions

A new version of the remote-controlled compact gamma camera “Gammavisor” for visualisation of radioactive sources was developed and made. For the remote radiation inspection of the hot cell with used gamma camera the special a measuring system has been made.
The device can be established on the rotary device operated from the computer of the operator too. In this case the instrument and rotator are controlled by operator from computer connected with system via wireless Wi-Fi line or by twisted-pair cable. The device is used for control of position radioactive sources, sorting radwaste, mapping of radioactive contamination of installation and rooms.
Now the hot cell is used for a fragmentation of a highly active waste, their packing in cases, etc. Application of the new device for inspection of the hot cell will allow to define the most active sources of radiation, to define sequence of works on cell clearing, to supervise a course of these works and by that to raise their efficiency.

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HOT CELL CRASH TESTS AND ACCIDENT LOADING STUDIES ON NUCLEAR FUEL RODS

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ABSTRACT

The highest mechanical stress for spent fuel assemblies transported in a cask after intermediate storage occurs in case of a hypothetical transport accident. The release of activity and dose output depend on the mechanic load capacity of the cask, whereas the compliance of criticality safety is mainly determined by the amount of spent fuel released into the cask due to rod breakage. Accordingly, the mechanical behaviour of the irradiated rod plays a major role in evaluating the criticality safety. The aim of this investigation was to quantify the amount of fuel released per rod breakage. A device simulating fuel rupture events under transient impact load has been developed and a campaign of impact tests on irradiated UO_2 fuel segments covering a burn-up range from 20 to 73 GWd/tHM has been successfully performed. The overall mechanic behaviour was similar for all fuels investigated in spite of the differences in burn-up and material properties. Without exception the fuel amount released per breakage did not exceed 2 g, definitely less than the mass of a single fuel pellet. The analysis of the particle size of the released fuel yielded a maximum size of about 3 mm.

1. Introduction

To guarantee international transport regulations the cask inventory has to comply with criticality safety requirements even in case of a transport accident. So far the behaviour of spent fuel rods at various burn-up levels under accidental load conditions is not well-known. As a consequence of a transport accident, spent fuel rods can break and fuel can be released into the cask. Additionally, assuming the ingress of water into the cask during an accident, the fuel release from all rod breakages must not endanger the criticality safety even in the worst case of reconfiguration and accumulation of the released fuel. Goal of this investigation was to measure the amount of fuel released per rod breakage dependent on the burn-up level. For this purpose, a device simulating fuel rupture events under transient impact load has been developed and a campaign of impact tests has been successfully performed in a hot cell at the Institute for Transuranium Elements (ITU). Results were obtained on 3 PWR and 1 BWR UO_2 representative fuel segments covering a burn-up range from 20 to 73 GWd/tHM.

2. Experimental set-up

The rupture and fuel release behaviour of representative fuel rod segments under calculated accidental loading conditions has been experimentally studied using the device shown in Fig.1 and 2.

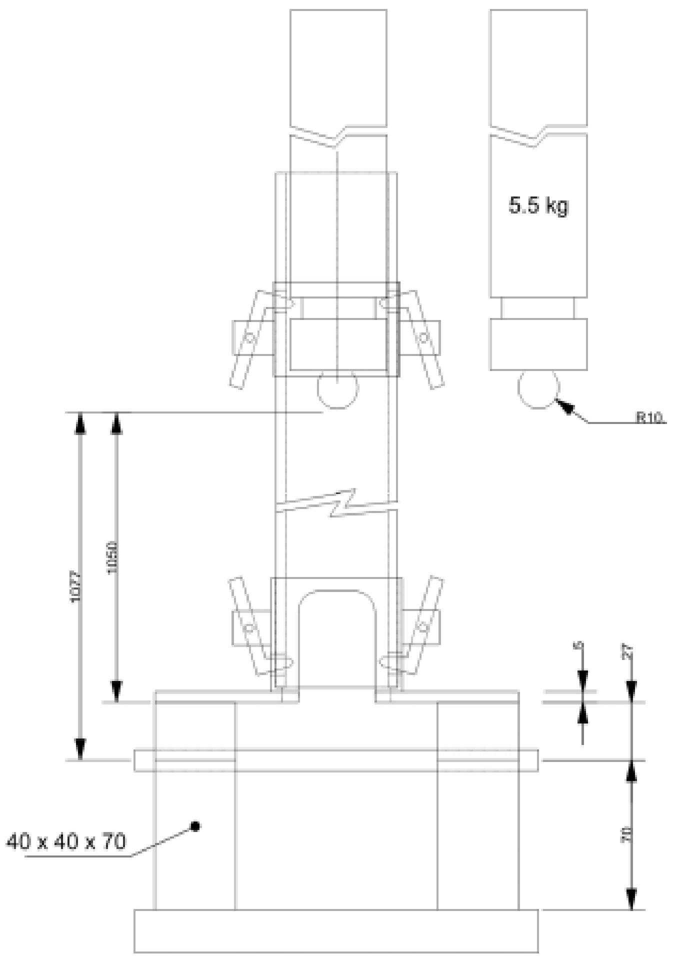

Fig. 1. Schematic presentation and main dimensions of the crash test device

The test setup consists of releasing a free falling corpus (hammer) through a vertical guiding tube (column) placed perpendicularly to a fuel rodlet (sample). The hammer is held (clamped) at and released from the top end of the column. The height of the column and the mass of the hammer determine the load on the sample. The sample is fixed on a stable metallic block near the column bottom end. In order to prevent repeated impacts of the hammer bouncing onto the sample, after its first impact the hammer is captured by clamps placed at the bottom end of the column. The experiment is recorded by a high speed camera, placed outside the hot cell. To determine the amount of fuel released during the impact, the fuel rodlets were weighed before and after each test.

For the present test campaign, a 5.5 kg hammer was used; the column was made of a Plexiglas tube with outer diameter Ø 6 cm and height 105.0 cm; the distance between the hammer's start position and the sample was 107.7 cm; the high speed camera was capable of capturing 5000 frames/s.

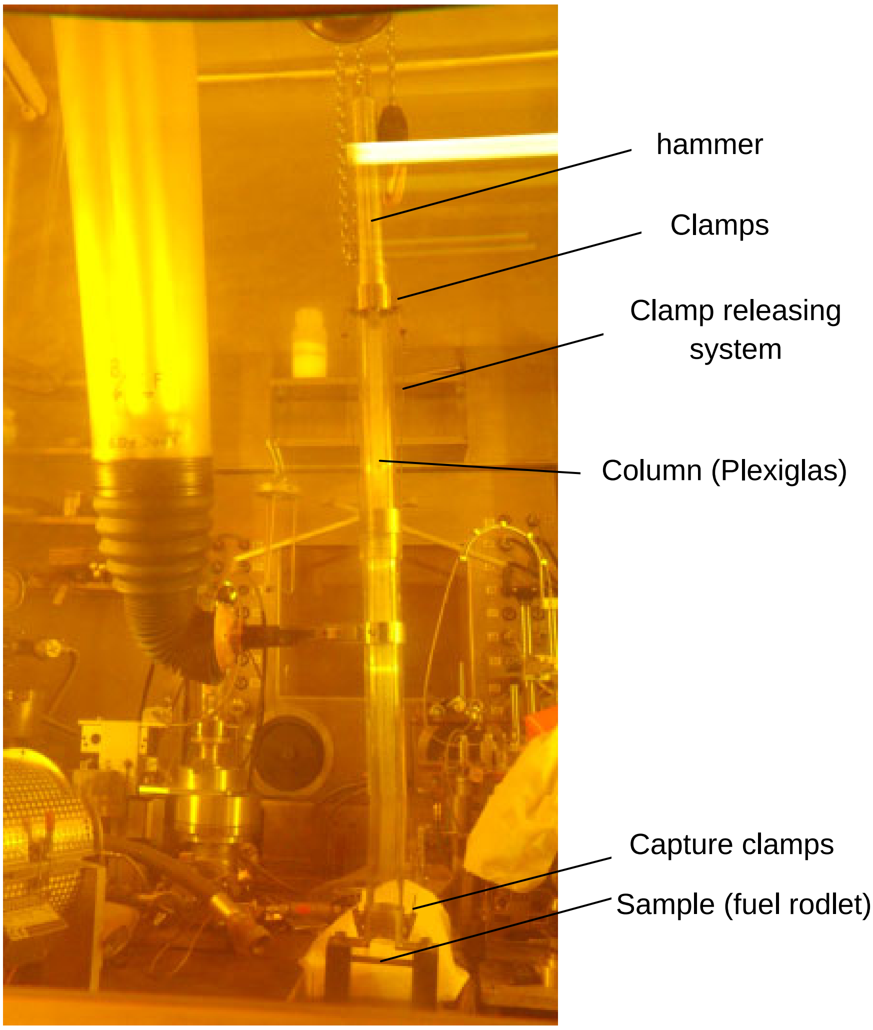

Fig. 2. The test device installed in a hot cell

3. Results and Discussion

Tests were performed on rodlets (samples) cut from 3 PWR and 1 BWR irradiated fuel pins. Table 1 summarizes the main properties of the tested samples. Cladding and fuel of the selected rods had been extensively studied in the frame of previous post irradiation examinations programmes in ITU.

Fuel type	Burn-up GWd/tHM	Cladding type	Outer diameter mm	Cladding thickness mm	Average clad. outer corrosion thickness µm	Cladding hydrogen concentration ppm
PWR	19.0	duplex Zry-4	10.75	0.725	<50	<200
	42.6					
	73.6					
BWR	53.0	Zry-2	10.05	0.605		<100

Table 1. Characteristics of the fuel rod samples selected for the impact tests

Despite the differences in burn-up and other properties (Table 1), similar overall behaviour was observed for all samples. With the exception of the lowest burn up (19.0 GWd/tM), all other tested samples were cracked at 3 positions, in the middle and at the two fixing ends and cleaved into four pieces. The sample with the lowest burn-up (test 1) was not fractured completely but showed 3 deep cracks after the hammer impact. This outcome was similar to that of preliminary "cold" tests on non irradiated specimen (Zry-4 tubes filled with Al_2O_3 pellets) performed just before installing the impact device in the hot cell.

A video film of each test has been recorded by the high speed camera. Some photos from test 2 performed on the 73.6 GWd/tHM PWR rodlet are shown in Fig.3. The brittle outer corrosion layer is fragmented explosively by the first hammer contact and very early elastic sample deformation occurs. In the following stages the sample breaks up at the centre region first (and fuel is released) and, subsequently, at the sample fixing positions of the holding block.

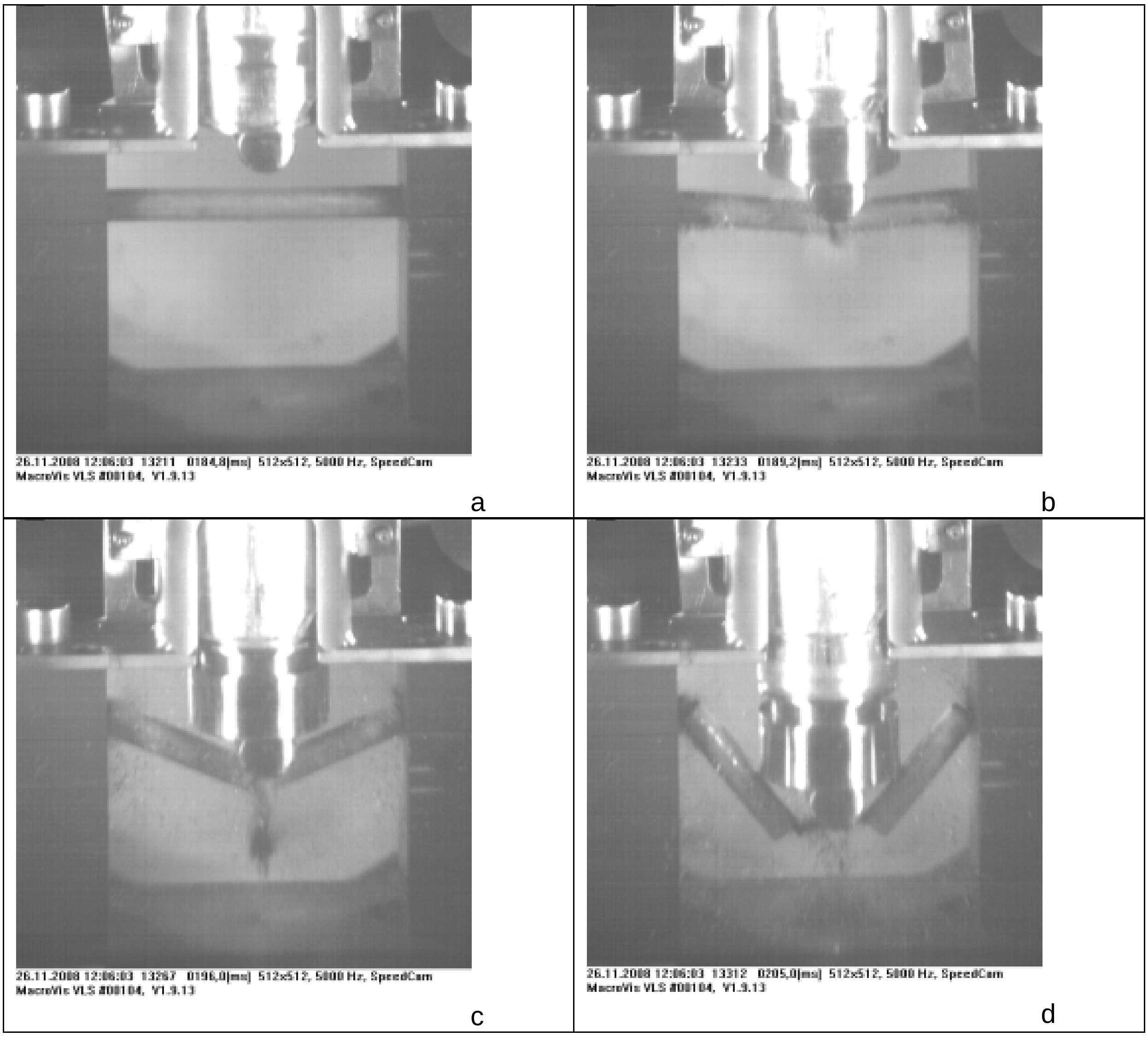

Fig. 3. Details of the hammer impacting on the 73.6 GWd/tHM PWR) sample (test 3) as observed with the high speed camera (sequence a-d).

Fig. 4 illustrates the outcome of the impact tests. In the left image of Fig. 4 the cladding region with removed outer corrosion layer in the vicinity to the rupture position can be clearly seen. Even in the case of test 1, where the low burn-up rodlet was not broken through, the amount of fuel released (shown in the right photograph of Fig.4) is comparable to that released from the other samples. In all tests the collected released fuel is a mixture of powder and fine fragments with a maximum size of about 3 mm. Particle size distribution analysis is currently ongoing and some preliminary results are presented in the next section.

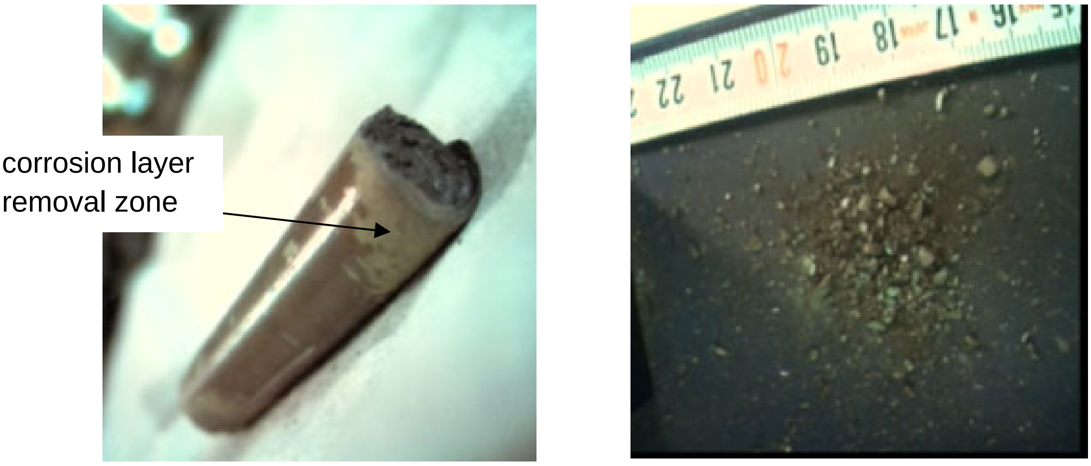

Fig. 4. A broken 73.6 GWd/tHM PWR fuel rodlet (left); collected fuel fragments released during the test on the 19.0 GWd/tHM PWR sample (right). The arrow on the left picture indicates the region where the outer clad corrosion layer was removed after the impact test.

Test	**Sample**	**Burn up GWd/tHM**	**Number of break positions**	**Amount of released fuel**	**Remark**
1	PWR	19.0	3	3.905 g	The sample did not fully brake, manipulators were used to break all 3 positions
2	PWR	46.2	3	4.799 g	
3	PWR	76.3	3	5.620 g	
4	BWR	53.0	3	4.724 g	

Table 2. List and amount of released fuel of the performed impact tests

In Table 2 are reported the amounts of fuel released in all tests. Considering the measurement accuracy, the slight increase with burn up (it must be also considered that the BWR is smaller in diameter, see Table 1) can be practically neglected. Especially, the development of the "rim-structured" layer, with its characteristic sub-micron grain population, beyond a burn-up of about 60 GWd/tHM does not play a prominent role. In all cases the released fuel per breakage did not exceed 2 g, i.e. an amount which is definitely less than the mass of a single fuel pellet.

4. **Grain sizes of the released fuel**

The released fuels from were collected and kept in aluminium containers. It has been attempted a coarse separation between big and smaller fuel grains. For this purpose a sieve with 1 mm squared openings has been used and the separated amounts of grains larger or smaller than 1 mm are given in Table 3. Obviously, since frequent opening and handling of the stored material took place, a part of it got "lost" and therefore the total mass of the larger and smaller grains is not equal to that of Table 2.

	Released Fuel	
Test	**Grains > 1 mm**	**Grains < 1 mm**
1	1.4 g	2.1 g
3	1.8 g	2.8 g

Table 3. Total mass of larger and smaller grains of the released fuel

Periscope photographs of the fuel grains are given in Fig.5. Known reference shapes (squares of known sizes) were placed close to the fuel grains for the necessary calibration of the photos magnification. Unfortunately, during handling works, some brush hairs (whose weight was not taken into account) have tainted the material. In the left photographs of Fig. 5 no grain bigger than 3 mm is observed. It is expected that aerosols and undersized grains are just a very small part of the total released mass.

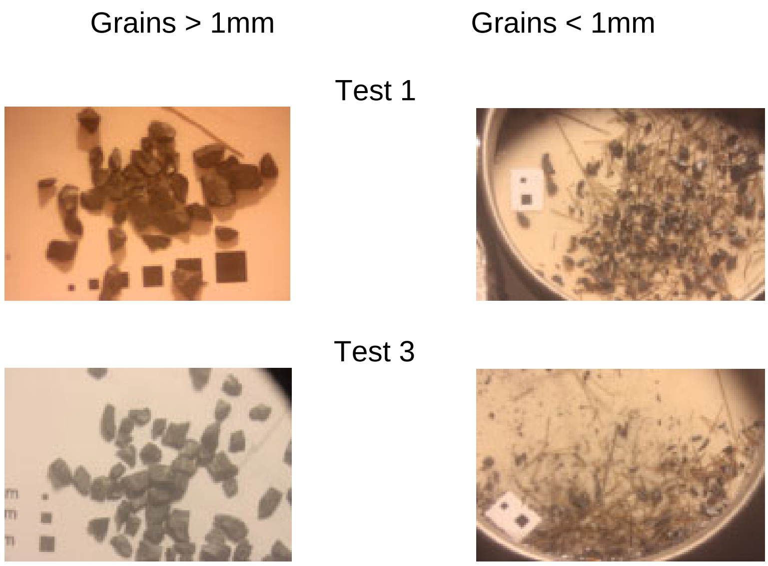

Fig. 5. Periscope photographs of the separated grains of the released fuel.

5. Conclusion

A series of impact tests on irradiated fuel segments were successfully carried out with a simple device installed in a hot cell. The results of these experiments reflect directly on safety issues regarding transports of nuclear spent fuel rods. Similar overall behaviour was observed for all samples, in spite of the differences in burn-up and other properties. The fixed specimens are hit by a falling corpus (hammer) and ruptured at 3 positions releasing fuel. Even in the case of the low burn-up (19 Gwd/tHM) rodlet which was not completely broken through, the amount of fuel released is comparable to that released from the other samples. In all tests the released fuel is a mixture of powder and fine fragments with a maximum size of about 3 mm and never exceeded 2 g per breakage, which is an amount definitely less than the mass of a single fuel pellet.

Acknowledgments

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