NATIONAL INSTITUTE FOR LASERS, PLASMA AND RADIATION PHYSICS
Atomiștilor 409, 077125 Măgurele, Ilfov, ROMÂNIA
Phone: +40 21 457-4489, Fax: +40 21 457-4243, http://www.inflpr.ro

Test Summary Report

Customer: Pro Optica S.A.
Str. Gheorghe Petrașcu, nr. 67
Cod poștal 031593
Sector 3, București

Contract nr.: 4/10.06.2019
Contract duration: 10 June – 31 December 2019
Name of product/ service: *"Laser induced damage test of reflective coatings by femtosecond laser beam at 800 nm, below 50 fs"*

Date: 20/12/2019
Approved by: Marian ZAMFIRESCU, Head of CETAL/ INFLPR

1. Samples:

Series of broad band reflective coatings HR @ 800 nm
16 samples: PO_1.1; PO_1.2; PO_1.3; PO_1.4; PO_2.1 .... PO_4.4
Substrate: ∅1", quartz

2. Preparation for LIDT test

Cleaning procedure: blowing with Green clean aerosol
Mounting of test specimen: Kinematic mount, vertical position, 45^{O} (+/- 2^{O}) incident angle
Test environment: clean filtered air; Temperature: 23-25 °C ± 1, °C; Humidity: 8 - 35 %
Typical 50x, 200x, and 500x Nomarski picture of the sample after cleaning, before tests.

Laser parameters for test:
Wavelength: 800 nm; Pulse repetition frequency: 10 Hz;
Output energy: Adjustable, up to 5 mJ;
Polarization state: Linear, totally polarized, horizontal;
Pulse duration - FWHM: 45 fs;

Devices measurement:
Pulse energy real time monitored with type J-10MT-10 kHz detector. Manufacturer: Coherent, Inc. ;
Temporal diagnosis: SPIDER APE-Berlin;
Spatial diagnosis: Beam profiler: Ophir-Spiricon, type GRAS20;
Temporal profile and spatial profile are recorded before test.

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3. Measurements

Operator: Laurentiu RUSEN

<table>
<tr><th>Sample number</th><th>Test results</th><th>Extrapolated 0 % LIDT for N = 10^8 pulses energy density and power density for measured data</th></tr>
<tr><td>Sample PO1.1</td><td>
<table>
<tr><td colspan="10">Measured 0 % and 50 % threshold energy density</td></tr>
<tr><td>Number of pulses</td><td>1</td><td>2</td><td>5</td><td>10</td><td>20</td><td>50</td><td>100</td><td>200</td><td>500</td></tr>
<tr><td>$H_0(N)$ (J/cm^2)</td><td>0.33</td><td>0.32</td><td>0.32</td><td>0.32</td><td>0.32</td><td>0.30</td><td>0.30</td><td>0.31</td><td>0.28</td></tr>
<tr><td>$H_{50}(N)$ (J/cm^2)</td><td>0.48</td><td>0.47</td><td>0.46</td><td>0.46</td><td>0.46</td><td>0.45</td><td>0.45</td><td>0.43</td><td>0.42</td></tr>
</table>
</td><td>$H_0(10^8)$ = 0.22 J/cm^2</td></tr>
<tr><td>Sample PO1.2</td><td>
<table>
<tr><td colspan="10">Measured 0 % and 50 % threshold energy density</td></tr>
<tr><td>Number of pulses</td><td>1</td><td>2</td><td>5</td><td>10</td><td>20</td><td>50</td><td>100</td><td>200</td><td>500</td></tr>
<tr><td>$H_0(N)$ (J/cm^2)</td><td>0.87</td><td>0.85</td><td>0.85</td><td>0.84</td><td>0.82</td><td>0.80</td><td>0.76</td><td>0.72</td><td>0.72</td></tr>
<tr><td>$H_{50}(N)$ (J/cm^2)</td><td>1.14</td><td>1.14</td><td>1.10</td><td>1.07</td><td>1.06</td><td>1.03</td><td>0.96</td><td>0.92</td><td>0.90</td></tr>
</table>
</td><td>$H_0(10^8)$ = 0.5 J/cm^2</td></tr>
<tr><td>Sample PO1.3</td><td>
<table>
<tr><td colspan="10">Measured 0 % and 50 % threshold energy density</td></tr>
<tr><td>Number of pulses</td><td>1</td><td>2</td><td>5</td><td>10</td><td>20</td><td>50</td><td>100</td><td>200</td><td>500</td></tr>
<tr><td>$H_0(N)$ (J/cm^2)</td><td>0.78</td><td>0.78</td><td>0.76</td><td>0.76</td><td>0.76</td><td>0.75</td><td>0.76</td><td>0.67</td><td>0.66</td></tr>
<tr><td>$H_{50}(N)$ (J/cm^2)</td><td>1.08</td><td>1.03</td><td>1.02</td><td>1.01</td><td>1.00</td><td>0.97</td><td>0.94</td><td>0.91</td><td>0.87</td></tr>
</table>
</td><td>$H_0(10^8)$ = 0.5 J/cm^2;</td></tr>
<tr><td>Sample PO1.4</td><td>
<table>
<tr><td colspan="10">Measured 0 % and 50 % threshold energy density</td></tr>
<tr><td>Number of pulses</td><td>1</td><td>2</td><td>5</td><td>10</td><td>20</td><td>50</td><td>100</td><td>200</td><td>500</td></tr>
<tr><td>$H_0(N)$ (J/cm^2)</td><td>0.27</td><td>0.26</td><td>0.251</td><td>0.25</td><td>0.25</td><td>0.24</td><td>0.23</td><td>0.23</td><td>0.23</td></tr>
<tr><td>$H_{50}(N)$ (J/cm^2)</td><td>0.43</td><td>0.42</td><td>0.42</td><td>0.42</td><td>0.42</td><td>0.41</td><td>0.41</td><td>0.41</td><td>0.37</td></tr>
</table>
</td><td>$H_0(10^8)$ = 0.21 J/cm^2</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Sample PO2.1</td><td>
<table>
<tr><td colspan="10">Measured 0 % and 50 % threshold energy density</td></tr>
<tr><td>Number of pulses</td><td>1</td><td>2</td><td>5</td><td>10</td><td>20</td><td>50</td><td>100</td><td>200</td><td>500</td></tr>
<tr><td>$H_0(N)$ (J/cm^2)</td><td>0.65</td><td>0.61</td><td>0.60</td><td>0.59</td><td>0.58</td><td>0.60</td><td>0.58</td><td>0.46</td><td>0.35</td></tr>
<tr><td>$H_{50}(N)$ (J/cm^2)</td><td>0.79</td><td>0.77</td><td>0.76</td><td>0.75</td><td>0.74</td><td>0.70</td><td>0.68</td><td>0.61</td><td>0.54</td></tr>
</table>
</td><td>$H_0(10^8)$ = 0.18 J/cm^2;</td></tr>
</table>

Sample PO2.2

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.23	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.19
$H_{50}(N)$ (J/cm²)	0.31	0.29	0.28	0.28	0.28	0.28	0.28	0.27	0.27

$H_0(10^8)$ = 0.19 J/cm²;

Sample PO2.3

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.63	0.63	0.61	0.61	0.61	0.59	0.55	0.46	0.43
$H_{50}(N)$ (J/cm²)	1.00	0.98	0.97	0.95	0.95	0.91	0.86	0.80	0.76

$H_0(10^8)$ = 0.26 J/cm²;

Sample PO2.4

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.53	0.52	0.53	0.53	0.53	0.52	0.51	0.50	0.49
$H_{50}(N)$ (J/cm²)	0.71	0.70	0.68	0.68	0.67	0.67	0.65	0.64	0.63

$H_0(10^8)$ = 0.43 J/cm²;

Sample PO3.1

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.43	0.43	0.47	0.47	0.46	0.30	0.29	0.27	0.25
$H_{50}(N)$ (J/cm²)	0.63	0.61	0.60	0.59	0.59	0.54	0.53	0.49	0.45

$H_0(10^8)$ = 0.11 J/cm²;

Sample PO3.2

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.12
$H_{50}(N)$ (J/cm²)	0.28	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.24

$H_0(10^8)$ = 0.09 J/cm²;

Sample PO3.3

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.38	0.35	0.35	0.35	0.34	0.35	0.35	0.34	0.32
$H_{50}(N)$ (J/cm²)	0.49	0.49	0.49	0.49	0.48	0.46	0.45	0.448	0.41

$H_0(10^8)$ = 0.31 J/cm²;

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Sample PO3.4

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.32	0.33	0.33	0.31	0.32	0.32	0.34	0.33	0.29
$H_{50}(N)$ (J/cm²)	0.71	0.64	0.64	0.64	0.61	0.58	0.55	0.53	0.48

$H_0(10^8)$ = 0.29 J/cm²;

Sample PO4.1

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.59	0.59	0.59	0.57	0.57	0.57	0.56	0.52	0.45
$H_{50}(N)$ (J/cm²)	0.94	0.87	0.87	0.84	0.83	0.82	0.81	0.72	0.66

$H_0(10^8)$ = 0.31 J/cm²;

Sample PO4.2

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.41	0.41	0.41	0.41	0.40	0.39	0.39	0.31	0.29
$H_{50}(N)$ (J/cm²)	0.59	0.59	0.58	0.56	0.55	0.53	0.52	0.502	0.46

$H_0(10^8)$ = 0.19 J/cm²;

Sample PO4.3

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.27	0.26	0.259	0.26	0.26	0.25	0.25	0.26	0.26
$H_{50}(N)$ (J/cm²)	0.39	0.38	0.381	0.38	0.38	0.37	0.38	0.36	0.36

$H_0(10^8)$ = 0.25 J/cm²;

Sample PO4.4

Measured 0 % and 50 % threshold energy density

Number of pulses	1	2	5	10	20	50	100	200	500
$H_0(N)$ (J/cm²)	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15
$H_{50}(N)$ (J/cm²)	0.28	0.28	0.269	0.2626	0.26	0.26	0.25	0.25	0.24

$H_0(10^8)$ = 0.12 J/cm²;

4. Comments

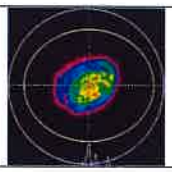
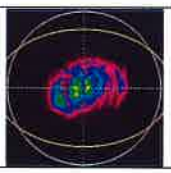
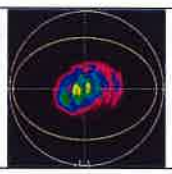
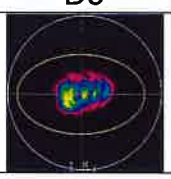
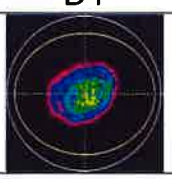
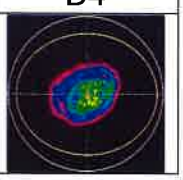
Because the samples were tested in different days, the measurement conditions could slightly vary. Samples from the same batch were blind tested in different days. Measurements of similar samples from the same batch are compared below. As it can be observed, there are some batches for which the LIDT varies from 0.2 to 0.5 J/cm^2. The presumed source of these variations is the amount of the error on correct estimation of beam diameter, caused by the very elliptic beam as well as the non-uniform beam profile for some measurements.
When LIDT values are compared between samples of the same batch and the beam profile are verified for each sample, it results that the beam profile measured on Days D4 and D5 give more trustable LIDT value.

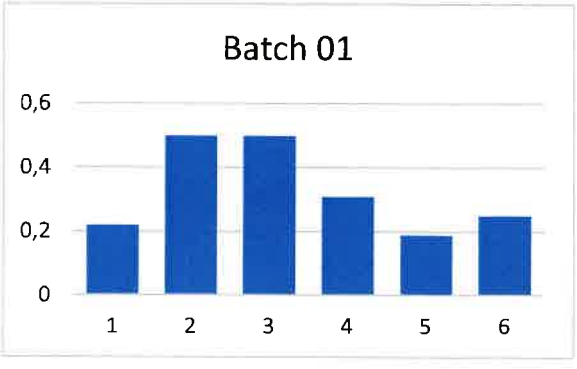
Within such premises, after removable of the values more affected by the beam profile quality, the classification of the LIDT evaluated for 10^8 pulses is the following:

Batch 5: 0,30 J/cm^2
Batch 1: 0,26 J/cm^2
Batch 2: 0,21 J/cm^2
Batch 3: 0,19 J/cm^2
Batch 4: 0,107 J/cm^2

Recommendation:
For the best samples, a new series of measurement from a similar batch with the same deposition parameters is recommended for a better statistics and verification of deposition reproducibility.

Batch 01

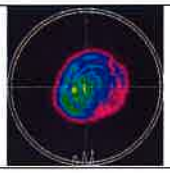
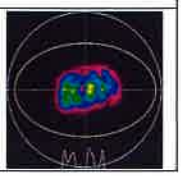
	PO_1.1	PO_1.2	PO_1.2	PO_4.1	PO_4.2	PO_4.3
$H_0(10^8)$ [J/cm^2]	0.22	0.5	0.5	0.31	0.19	0.25
Day	D5	D1	D2	D3	D4	D4
Beam profile						



Comments: The extreme values of LIDT obtained for PO_1.2, PO_1.2 and PO_4.2 are eliminated from statistics.
The average are calculated from values measured on samples PO_1.1, PO_4.1 and PO_4.3.

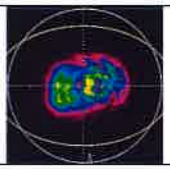
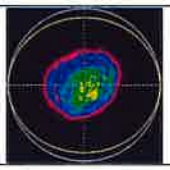
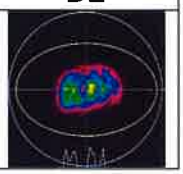
Average LIDT: 0,26 J/cm^2.

Batch 02

	PO_1.4	PO_2.4
$H_0(10^8)$ [J/cm^2]	0.21	0.43
Day	D1	D2
Beam profile		

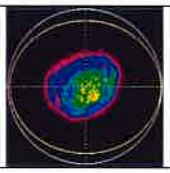
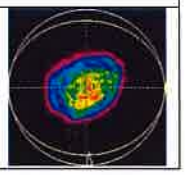
Comment: PO_2.4 is eliminated from measurements because the laser profile on the sample is very non-uniform and could affect the estimation of de LIDT. LIDT: 0,21 J/cm^2.

Batch 03

	PO_2.1	PO_2.2	PO_2.3
$H_0(10^8)$ [J/cm^2]	0.18	0.19	0.26
Day	D2	D5	D2
Beam profile			

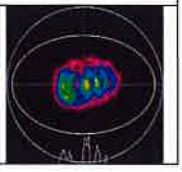
Comment: PO_2.3 is eliminated from measurements because of large difference of the LIDT value relative to other two samples from the same batch. Also, the laser profile on the sample PO_2.3 is very non-uniform and could affect the estimation of de LIDT. Average LIDT: 0,19 J/cm^2.

Batch 04

	PO_3.1	PO_3.2	PO_4.4
$H_0(10^8)$ [J/cm^2]	0.11	0.09	0.12
Day	D3	D5	D4
Beam profile			

Average LIDT: 0,107 J/cm^2.

Batch 05

	PO_3.3	PO_3.4
$H_0(10^8)$ [J/cm^2]	0.31	0.29
Day	D4	D3
Beam profile		

Average LIDT: 0,30 J/cm^2.

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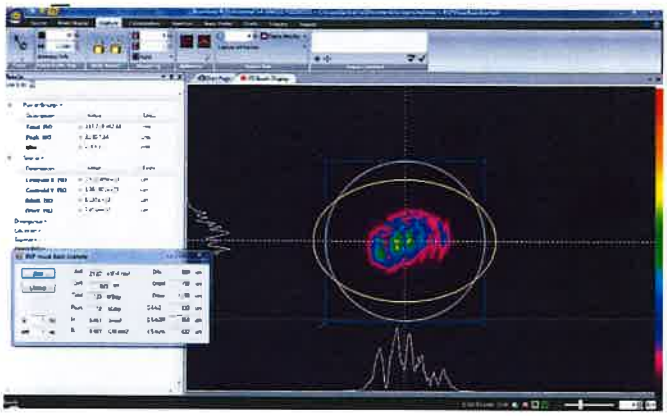
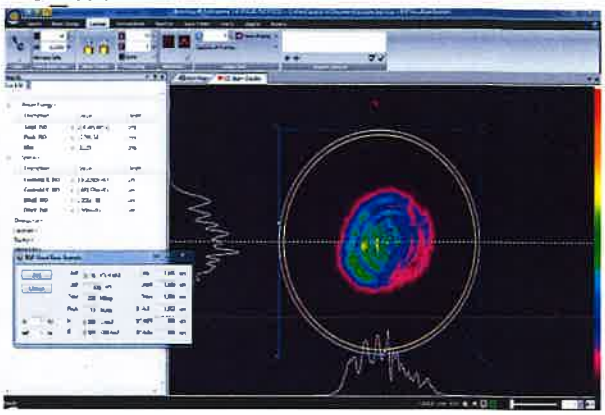
Day 1

PO_1.2

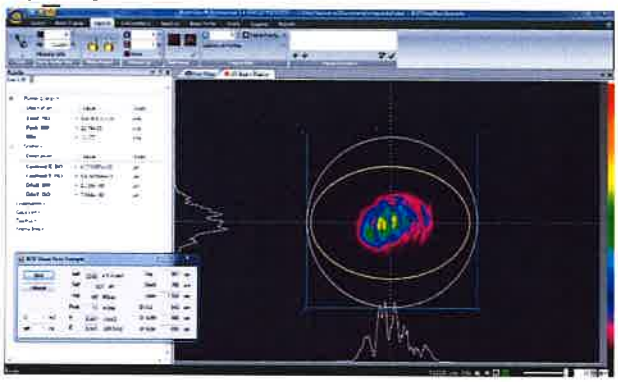


PO_1.4

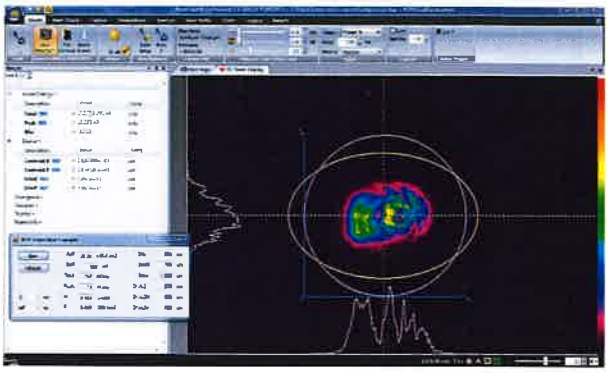


Day 2

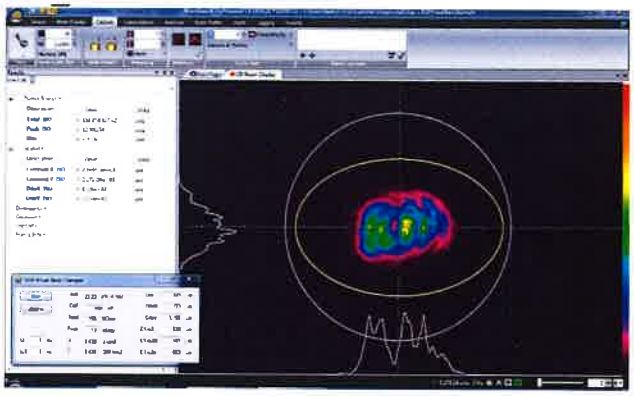
PO_1.3



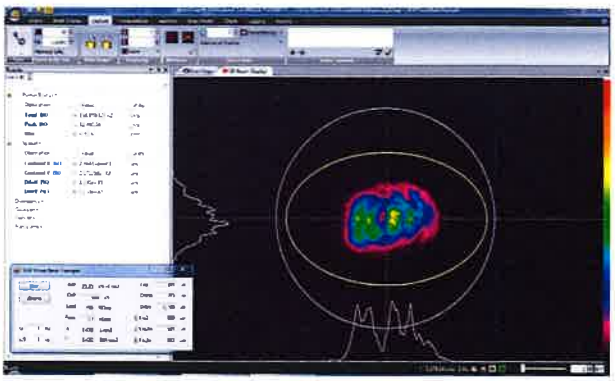
PO_2.1



PO_2.3



PO_2.4



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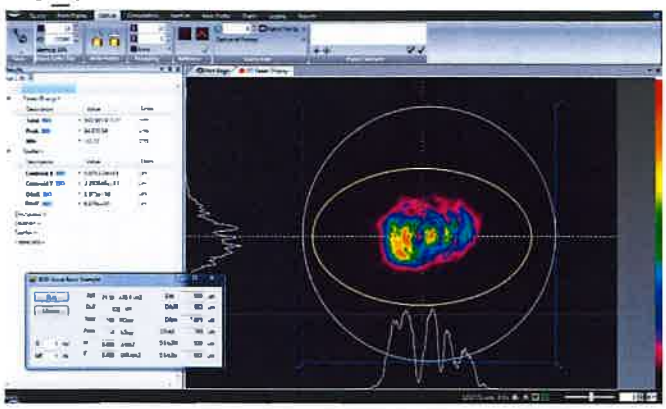
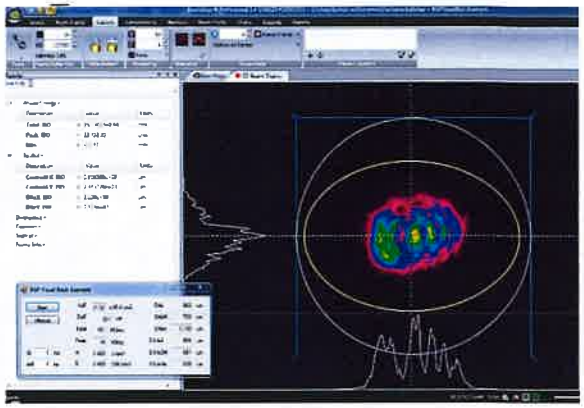
Day 3

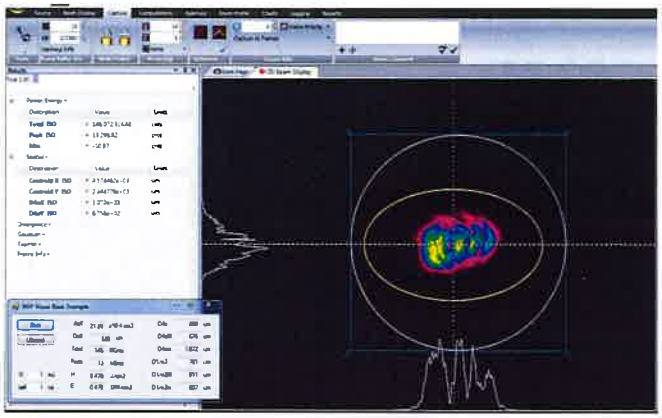
PO_3.1



PO_3.4



PO_4.1



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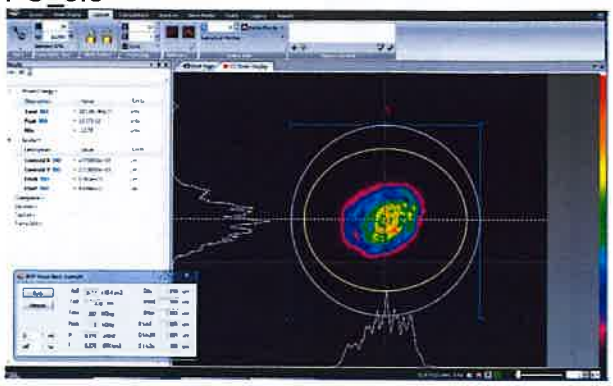
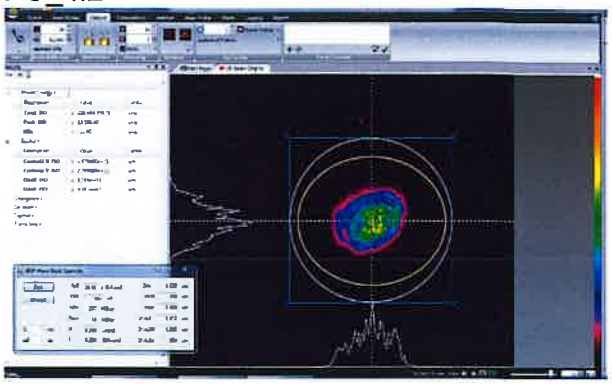
Day 4

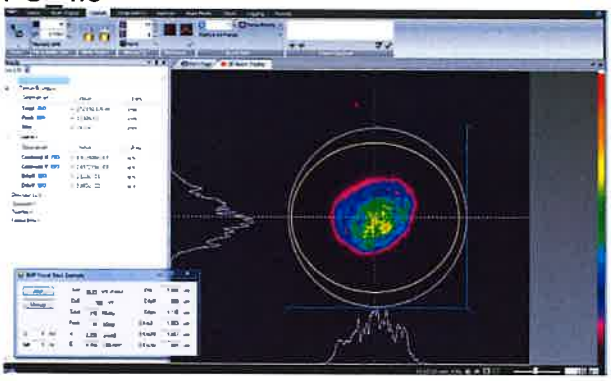
PO_3.3



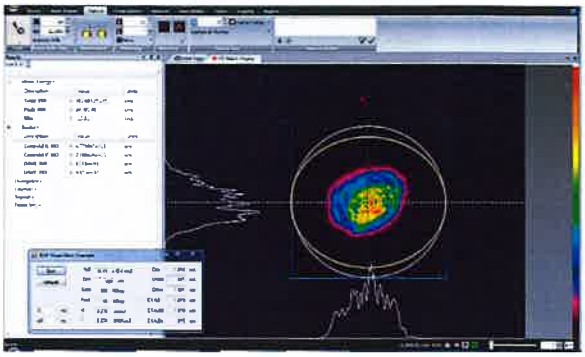
PO_4.2



PO_4.3



PO_4.4



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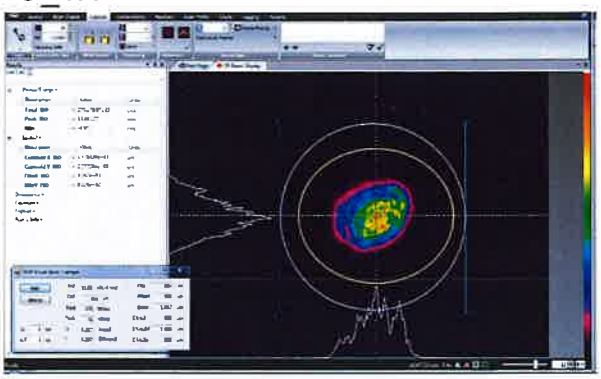
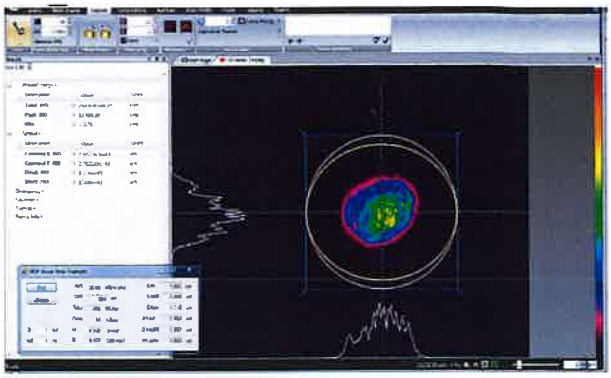
Day 5

PO_1.1



PO_2.2



PO_3.2