

A software tool for Quality Assurance of Computed / Digital Radiography (CR/DR) systems

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ABSTRACT

The recommended methods to test the performance of computed radiography (CR) systems have been established by The American Association of Physicists in Medicine, Report No. 93, "Acceptance Testing and Quality Control of Photostimulable Storage Phosphor Imaging Systems".¹ The quality assurance tests are categorized by how frequently they need to be performed. Quality assurance of CR systems is the responsibility of the facility that performs the exam and is governed by the state in which the facility is located. For Example, the New York State Department of Health has established a guide which lists the tests that a CR facility must perform for quality assurance.² This study aims at educating the reader about the new quality assurance requirements defined by the state. It further demonstrates an easy to use software tool, henceforth referred to as the Digital Physicist, developed to aid a radiologic facility in conforming with state guidelines and monitoring quality assurance of CR/DR imaging systems. The Digital Physicist provides a vendor independent procedure for quality assurance of CR/DR systems. Further it, generates a PDF report with a brief description of these tests and the obtained results.

Keywords: Quality Assurance, Quality Control, AAPM, New York State Guide

1. INTRODUCTION

Quality assurance of CR systems is the responsibility of the facility that performs the exam and is governed by the state in which the facility is located. For Example, the New York State Department of Health has established a guide which lists the tests that a CR facility must perform for quality assurance.² Current state guides are developed based on the acceptance evaluation plan, detailed in AAPM Report No. 93 section 8.3. The acceptance evaluation plan consists of dark noise, uniformity, laser beam function, spatial resolution, low contrast resolution, spatial accuracy, artifact examination, contrast/noise, laser jitter, exposure indicator accuracy and few others. Each state guide instructs the CR facility to conform with the standards set by the state and to maintain records for atleast three years. The exact tests performed may vary from manufacturer to manufacturer but must include those quality control checks specified by the manufacturer and be modeled after the program in the state guidelines.

The Digital Physicist is a Java based framework developed as a paradigm of the acceptance evaluation plan detailed in the AAPM report No. 93. It uses ImageJ, an open source image manipulation software developed by the NIH, as a reference library for some mathematical manipulation. The Digital Physicist provides an intuitive and easy to use graphical user interface (GUI) to perform quality assurance tests, namely - Dark Noise, Linearity, Uniformity, Laser Jitter, Spatial Resolution, Erasure Thoroughness and Noise/Low Contrast Resolution. It offers wizard-like work flow to guide the user with instructions for image acquisition and test execution for each test. The Digital Physicist is modularized and each test is represented as a separate module. The architecture of the software allows for the addition of more test modules. The Digital Physicist also provides storage and retrieval functionality for test results. Comparison modules to compare the saved results are provided for a few tests. The Digital Physicist also provides a reporting module which enables the user to choose from the saved results of these tests and write PDF reports indicating pass/fail criteria for each test. The report generated is a paradigm of the QC records that the CR facility maintains to conform with the state guidelines.

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The Digital Physicist aids medical physicists, radiologic technologists, service engineering, and manufacturer service representatives in performing these tests. The software is vendor neutral in the sense that it enables the user to perform these tests on images acquired from CR/DR systems of any vendor. The acceptable image formats for the Digital Physicist are ‘.dcm’ and ‘.tiff’. The software will further provide vendor neutral quantitative acceptance criteria for all tests, based on the information gathered from the user. This will help facilities without a service contract for their CR systems to comply with the state guidelines.

2. METHODS

Table 1, shown below, lists all the tests of the state guide,² categorized by how frequently they need to be performed.

Daily Test	Quarterly Tests	Annual Tests
Image Artifact Test	Dark Noise Test	IP Dark Noise Test
	Resolution	IP Uniformity
	Contrast/Noise	System Linearity
	Laser Jitter	System Autoranging
	Exposure Indicator Accuracy	Image Geometric Uniformity
	Image Plate Cleaning	Spatial Resolution
	Retake Images	

We used the iCRco CR3600(iCRco, Inc, Torrance, CA 90505) with standard image acquisition software to obtain the images required for these tests. These images can be imported to our software for further analysis and test execution. A detailed description of all the tests listed in Table 1 is detailed in several documents.^{1,3} The emphasis of the paper is to describe the developed software and a detailed description of these tests is beyond the scope of this paper. We provide a brief description of the test and a table containing test parameters applied to the CR3600.

2.1 IP Dark Noise

Dark Noise is the noise produced in a photo-detector when the photo-cathode is shielded from all external optical Radiation and operating voltages are applied. The test involves analyzing the average signal intensity in 80% of the image obtained from an unexposed detector. The Dark Noise test, measures the erasure efficiency of the Imaging Plate (IP) and the CR system. To perform this test, the user selects an IP from the inventory. The IP is erased without making an X-ray exposure. The user scans this erased IP to obtain an image. This image is evaluated for criteria listed in Table 2. This test is performed on all the IPs in the inventory and the IPs failing this test need to be quarantined for use.

Exposure Condition	No exposure
IP Processing	None
Image Post Processing	None
Measurements	PV (Pixel Value), PVSD (Pixel Value Standard Deviation)
Qualitative Criteria	Artifact free and uniform image, there can be some profile bands in IP direction
Quantitative Criteria	PV > 64000, PVSD < 4000*

*The CR3600 produces 16-bit images, criteria are modified accordingly

2.2 System Linearity

This test measures the uniformity of the detector response, exposed to the varying dose. It determines the response of the detector and the readout systems to at least three decades of exposure variation (1000 times difference).¹ The test involves exposing an imaging plate or a digital detector to approximately 0.1, 1 and 10mR dose, details of which are listed in the Table 3. A linear-log plot of the average signal intensity in 80% of the image and exposure should result in a straight line.

Table 3. Testing and Acceptance Criteria for Linearity

Exposure Condition	0.1, 1.0 and 10 mR incident exposures at 80 kVp, 180 SID, 0.5 mm Cu and 1 mm Al filtration. A time delay of 10 minutes between exposure and readout
IP Processing	None
Image Post Processing	None
Measurements	Mean pixel value (PV) within 80% of image area. Slope, intercept and correlation coefficient(CC) of a linear fit to PV vs log(E) plots
Qualitative Criteria	The plot of EI and PV vs exposure on a linear log scale should result in straight lines
Quantitative Criteria	Slopes/1000+1 > ± 0.1 , CCs < -0.95

2.3 System Uniformity

This test measures the uniformity of the detector response, exposed to the same dose. The test involves exposing three different imaging plates or digital detectors to the same dose, details of which are listed in the Table 4, and analyzing the standard deviation in 80% of the image area of the acquired images.

Table 4. Testing and Acceptance Criteria for Uniformity

Exposure Condition	10 mR incident exposures at 80 kVp, 180 SID, 0.5 mm Cu and 1 mm Al filtration. A time delay of 10 minutes between exposure and readout
IP Processing	None
Image Post Processing	None
Measurements	Average pixel value and its standard deviation (PVSD) in 80% of the image area
Qualitative Criteria	Uniform image without any artifacts
Quantitative Criteria	PVSD < 400 (Single Screen), PVSDs < 400

2.4 Laser Jitter

Laser beam jitter (inconsistent gray-level output caused by timing errors with the location of the beam or synchronization with the ADC) is evaluated by examining the edge of the ruler on the image. Ruler edges should be straight and continuous over the full length of the hard-copy or soft-copy image. Scan lines in light to dark transitions along the ruler edge that do not form the linear ruler edge indicate a timing error, or laser beam modulation problem. Table 5 summarizes the test and the parameters measured.

Table 5. Testing and Acceptance Criteria for Laser Jitter

Exposure Condition	Test Object : Steel Ruler, 5mR entrance exposure using 60 kVp, Filtration : none
IP Processing	None
Image Post Processing	None
Measurements	If any jitter present, jitter dimension using measurement tool
Qualitative Criteria	Ruler edges should be straight and continuous
Quantitative Criteria	There should not be more than ± 1 jitters

2.5 Spatial Resolution

Spatial resolution tests include measurement of the central and peripheral limiting resolution for each IP size and type (standard and high resolution) along the scan and sub-scan directions. Table 6 summarizes the test and the parameters measured.

Table 6. Testing and Acceptance Criteria for Spatial Resolution

Exposure Condition	Place three line-pair patterns, two in orthogonal directions and one at 45° angle, Exposure : 60 kVp and 5mR dose, Filtration : none
IP Processing	None
Image Post Processing	None
Measurements	Maximum discernible spatial frequencies in the three directions (R_{hor} , R_{ver} , R_{45}) using a magnified (>10x) narrowly windowed presentation of the images
Qualitative Criteria	Wire mesh image should be uniform without any blurring
Quantitative Criteria	$R_{hor}/f_{Nyquist} > 0.9$, $R_{ver}/f_{Nyquist} > 0.9$, $R_{45}/1.41f_{Nyquist} > 0.9$

2.6 Erasure Thoroughness

The ability to reuse the IP without residual signals from previous overexposures is important, and the erasure test evaluates the ability of the read/erase cycle to remove ghosting artifacts under severe exposure conditions. Table 7 summarizes the test and the parameters measured.

Table 7. Testing and Acceptance Criteria for Erasure Thoroughness

Exposure Condition	Test object : thick lead block, Exposure : 60kVp at 50mR, read the screen. Expose same screen the second time, Test object : none and Exposure : 60kVp at 1mR. For a quantitative test reread the screen after second exposure without exposing.
IP Processing	None
Image Post Processing	None
Measurements	Average pixel value (PV) and standard deviation (PVSD) within 80% of the reread/unexposed image
Qualitative Criteria	Absence of a ghost image of the lead block from the first exposure in the re-exposed image
Quantitative Criteria	$PV > 54800$, $PVSD < 400$

2.7 Noise/Low Contrast Resolution

Contrast resolution should be limited by quantum statistics (random variations in the number of x-rays absorbed in the IP) in a well-designed system. This test ensures that the contrast detail threshold should be proportionately lower at higher exposures. Table 8 summarizes the test and the parameters measured.

Table 8. Testing and Acceptance Criteria for Noise/Low Contrast Resolution

Exposure Condition	Test Object : Low contrast phantom (e.g:Leeds TO.12), Exposure : 75 kVp at 0.5, 1.0, and 5.0mR, Filtration : 1 mm Cu
IP Processing	None
Image Post Processing	None
Measurements	Minimum discernible contrast for each object size (contrast detail threshold)
Qualitative Criteria	Contrast detail threshold should be proportionately lower at higher exposures
Quantitative Criteria	none

3. RESULTS AND DISCUSSION

3.1 Digital Physicist Overview

Figure 1(a) shows the user interface of the Digital Physicist. The user can choose to perform new test or view previous results, as indicated in the figure. Selecting the ‘Tests’ option shown in Figure 1(a) takes the user to the list of tests as shown in Figure 1(b). As mentioned in Section 1, the architecture of the Digital Physicist is designed to be modularized and the tests are implemented in the software following a Strategy Pattern⁴ to facilitate addition of new tests. The platform independence of Java allows for each test to be provided as a plugin, to utilize the test functionality in a different framework. For example, each of these tests modules can be executed from an ImageJ framework. The Digital Physicist has a wizard work-flow. The user selects the test he wants to perform from the list of tests as shown in Figure 1(b). The user is guided through each step of the test with detailed instructions and minimal functionality adequate to perform each test. This is explained in further detail in Section 3.2 using the dark noise test as an example.

The configuration button, shown in Figure 1(a), gives the user options to add image analysis tools shown in Figure 1(c), if additional functionality is desired. These consist of window/level, zoom, pan, rotate image and view histogram and help the user analyze images during test execution. At the end of each test we display the results of the test performed. The user can choose to save the result, as shown in Figure 3(b), or discard it. However, to generate a report for the desired test results, the user needs to save the test results as explained in Section 3.9.

3.2 IP Dark Noise

To begin performing this test, the user selects the test name from the list of tests, shown in Figure 1(b), represented as an ‘Abstract Button’ in the software. The user is directed to the test area of the software, shown in Figure 2(a). The test area is divided into test steps, test instructions, navigation, image acquisition and previous images. Test steps are listed as a graphic time-line and informs the user about the progress of the test. Test instructions, implemented as a JTextArea in Java, guides the user through each step. The instructions are updated at each step of the test. The navigation bar enables the user to navigate through each test. There are two modes of image acquisition, ‘Scan’ or ‘Disk’. The ‘Scan’ option is custom designed to acquire images using a CR3600. The ‘Disk’ option enables the user to select images stored on the hard-disk or storage device, to perform the test. This feature makes the Digital Physicist a vendor neutral quality control suite. The images used during each session of the software are added to the ‘Previous Images’ list shown in Figure 2(a). The graphic shown in the bottom right of Figure 2(a) gives the user details of image acquisition.

Once the user selects an image, he/she proceeds to the next step of the test shown in 2(b). For the dark noise test, the user needs to analyze the obtained image for any artifacts, as detailed in Table 2. The user is provided with functionality to window/level the image using the mouse, to analyze the image for artifacts. Sample images of common artifacts observed for this test, are provided to facilitate the user in identifying them. The user proceeds to the next step of this test shown in Figure 3(a). The test result is decided based on quantitative criterion obtained from the image and the qualitative criterion provided by the user. The result can be saved by providing the information listed in Figure 3(b). The saved results are added to the table in the ‘Sessions’ section of the software, shown in Figure 3(a).

3.3 System Linearity

The user obtains three images for this test as detailed in Table 3. The software guides the user in analyzing each of the images. The results of this test are shown in Figure 4.

3.4 System Uniformity

The user obtains three images for this test as detailed in Table 4. The software guides the user in analyzing each of the images. The results of this test are shown in Figure 5.



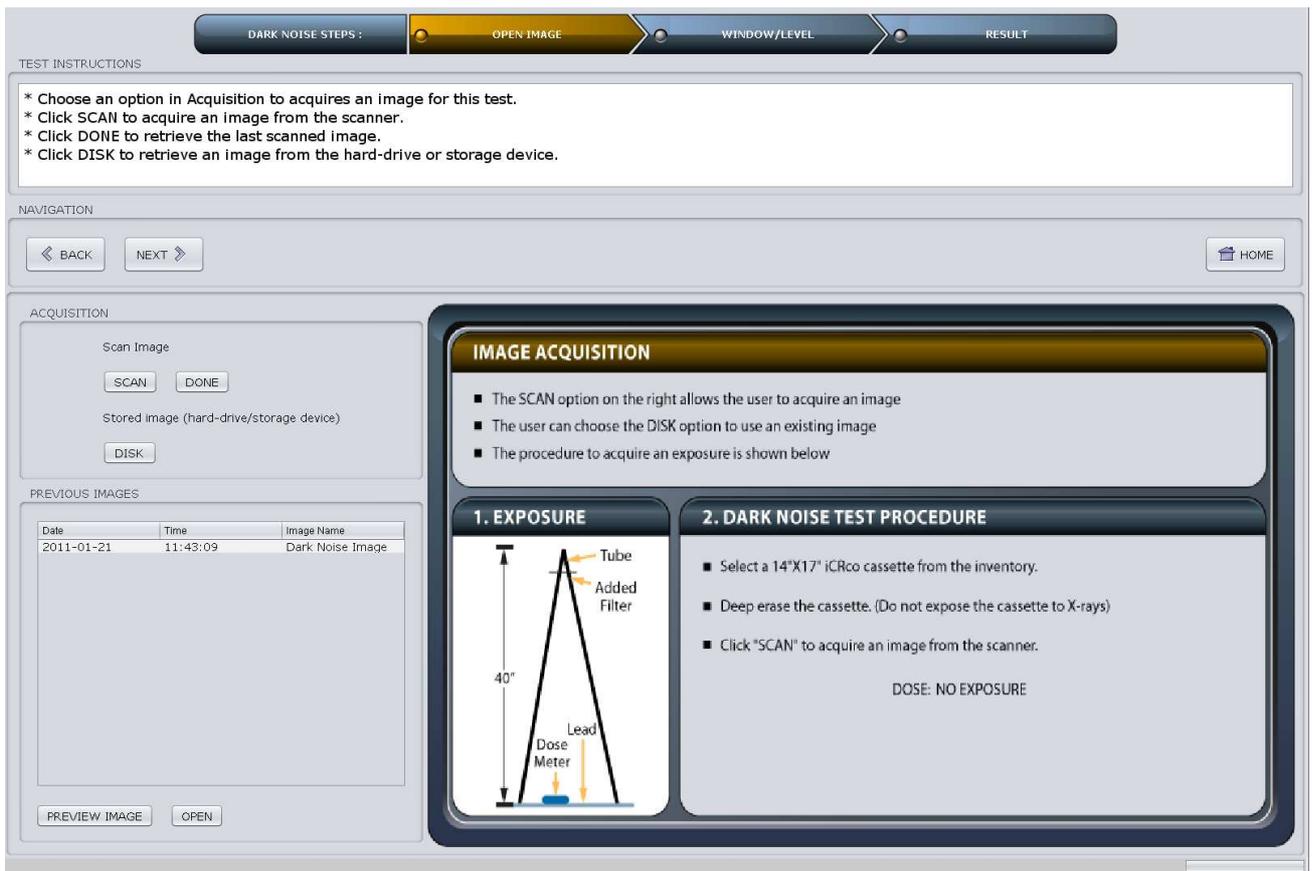
(a)



(b)

(c)

Figure 1. (a) Screen-shot of features of the Digital Physicist, (b) Test selection GUI and (c) Image manipulation tools



(a)



(b)

Figure 2. (a) Dark Noise test image selection step and (b) Artifact evaluation step

RESULT ACTIONS

Save

Clear Result

Save JPEG

SESSION ACTIONS

Load Session

Add Result

Delete Session

RESULT

Average Pixel Value in 80% of the Image (> 64000): 64735.0

Was the image analyzed in the previous step artifact free? YES NO

Test Result : PASS

SESSIONS

Date	Time	Study Name	Description
2010-10-14	09-42-38	DN Result 1	Demo 1
2010-12-08	09-40-21	DN Result1	Demo1

(a)

Save

Result Name: DN TEST

Study Description: Please enter Description here

OK Cancel

(b)

Figure 3. (a) Dark Noise test result and (b) Saving the obtained result

RESULT

Slope/1000 - 0.1 ($\leq \pm 0.1$): -0.10000011081154042

Is the plot a straight line? YES NO

Test Result : PASS

SESSIONS

Date	Time	Study Name
2010-10-14	11-47-25	Lin Result1

Figure 4. Linearity test result

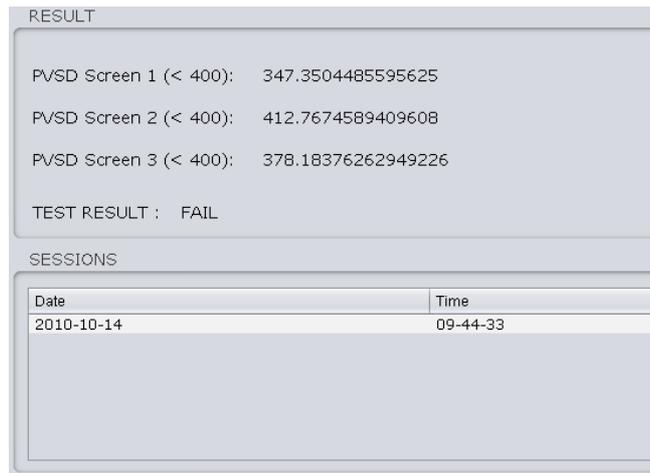


Figure 5. Uniformity test result

3.5 Laser Jitter

The user obtains one image for this test as detailed in Table 5. The software guides the user in analyzing the image. The results of this test are shown in Figure 6.

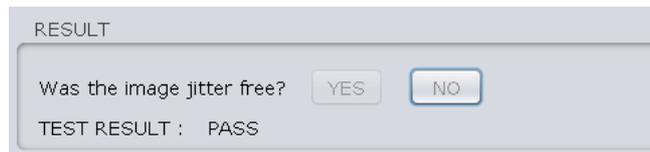


Figure 6. Laser Jitter test result

3.6 Spatial Resolution

The user obtains one image for this test as detailed in Table 6. The software guides the user in analyzing the image. The results of this test are shown in Figure 7.



Figure 7. Spatial Resolution test result

3.7 Erasure Thoroughness

The user obtains two images for this test as detailed in Table 7. The software guides the user in analyzing each of the images. The results of this test are shown in Figure 8.



Figure 8. Erasure Thoroughness test result

3.8 Noise/Low Contrast Resolution

The user obtains two images for this test as detailed in Table 8. The software guides the user in analyzing each of the images. The results of this test are shown in Figure 9.



Figure 9. Noise/Low Contrast Resolution test result

3.9 Report Generation

The user can generate a report of the saved test results using the Digital Physicist. This module enables the user to retrieve saved results in a certain date range as shown in Figure 10(a). The user selects the desired results from the table to be included in the report. The module is presently configured to include only one result of each test. The generated report is shown in Figure 10(b).

4. CONCLUSION

This software provides the community with essential tests like dark noise, linearity, uniformity, laser jitter, spatial resolution, erasure thoroughness, noise/low contrast resolution and artifact examination to monitor their CR performance. We present a software which helps medical physicists, radiologic technologists, in-house engineering, and manufacturer service representatives perform all the quality assurance test, listed by the New York State guide² and the AAPM Report No. 93,¹ collectively and document the results. This software would help CR facilities monitor their CR systems better and ensure radiation protection to their patients.

5. FUTURE DIRECTION

Laser jitter, spatial resolution and noise/low contrast resolution tests presently have no quantitative evaluation to monitor test results. We are working on these modules further to come up with better test objects and quantitative evaluations. We are further working to make the reporting module more customizable. Lastly, we are also working to design a phantom which allows the user to perform some of these tests with a single image of this phantom.

ACKNOWLEDGMENTS

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REFERENCES

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Select the date range to retrieve stored results

FROM DATE : TO DATE :

STUDY TYPE	DATE	TIME	STUDY NAME	DESCRIPTION
DarkNoise	2010-10-14	09-42-38	DN Result 1	Demo 1
DarkNoise	2010-12-08	09-40-21	DN Result1	Demo1
Linearity	2010-10-14	11-49-25	Ln Result1	Demo 1
Uniformity	2010-10-14	09-44-33	Unj Result 1	Demo 1
LaserJitter	2010-10-14	09-46-01	LJ Result 1	Demo 1
SpatialResolution	2010-10-14	09-46-43	SR Result 1	Demo 1
ErasureThoroughness	2010-10-14	17-36-55	ET Result 1	Demo 1
NoiseAndContrast	2010-10-14	16-23-58	Noise 1	Demo 1

Institution Name :

Tests performed by :

State License Number :

(a)

Radiation Safety/Quality Assurance Test Report

Facility / Institution Name : icr
 Date : Wed Dec 08 09:46:40 PST 2010
 Report generated by : sdfgdsfg
 State License Number : dfgsdfghs

TEST NUMBER	TEST	RESULTS	PASS / FAIL
1	DARK NOISE TEST : Each IP in the Inventory was erased. The image obtained from the erase was analyzed for artifacts. The Average Pixel Value was recorded in 80% of the image	PV : 64735.0	PASS
2	LINEARITY TEST : Three images were obtained using 0.1, 1 and 10mR exposure respectively at 80kVp with 0.5mm Cu filtration. These images were used to plot PV vs Exposure on a linear-log scale	Slope of the plot : -0.1	PASS
3	UNIFORMITY TEST : Three images were obtained using 10mR exposure at 80kVp with 0.5 mm Cu filtration. Average pixel value was recorded in 80% of the three images.	PVSD 1 : 347.35 PVSD 2 : 347.35 PVSD 3 : 347.35	PASS
4	LASER JITTER Test : An image of a steel ruler was obtained using 5mR exposure at 60kVp. The image was analyzed for pixel bleeds.	QUALITATIVE	PASS
5	SPATIAL RESOLUTION TEST : Three images of the line-pair phantom were obtained in horizontal, vertical and 45-degree orientation using 5mR exposure at 60kVp.	QUALITATIVE	PASS
6	ERASURE THOROUGHNESS TEST : Each IP in the Inventory was deep erased. The image obtained after the erase was analyzed for ghost images.	PV : 64735.54 PVSD : 186.3	PASS
7	NOISE / LOW CONTRAST TEST : Images of the DIN test phantom were obtained using 0.5, 1.0 and 5.0 mR exposure at 75kVp. The images were analyzed for decrease in contrast detail at higher exposures.	QUALITATIVE	PASS

Report Generated using  **DIGITAL PHYSICIST™**
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(b)

Figure 10. (a) Digital Physicist report generation GUI and (b) Saved PDF of the generated report