THERMAL SHRINKAGE AND GAS VOID FORMATION OF WAXY CRUDE OIL – FLOW LOOP DEVELOPMENT

by

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ABSTRACT

The objective of this research is to design a flow loop to study the compressibility of waxy crude oil under thermal shrinkage and gas void formations. Fields are producing crude oil with high wax content (longer carbon chains) have trouble in transporting the waxy crude oil. This problem occurs when the wax starts to form from static cooling and clogs up the pipe. Two main important temperatures in the problem occurrence is the wax appearance temperature and the pour point temperature. At these temperatures, the wax will form and harden to clog up the pipeline. However, this gel are slight compressible because of the gas voids that are formed. The restart pressure of the pipe (to regain flow) is always over predicted as it does not include the compressibility characteristics. This project focuses on creating a flow loop to experimentally simulate the conditions where the crude oil goes through while being transported. The test section of the flow loop will then be scanned under a MRI Scanner to detect the gas voids formed. For this project, a test run has been done using the MRI Scanner, where a tube of gel is scanned and images can clearly see the gas voids formed. In addition, the flow loop has been finalized and under fabrication. The flow loop is designed to duplicate the conditions at sea bed (sea bed temperature), and later on, the test section will be tested under a MRI Scanner to study the gas void formations and compose the compressibility of the gel formed.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Many fields are producing crude oil that has high wax content (waxy crude oil) which usually consist of intermediate to light hydrocarbons, waxy components (higher value of carbon chain hydrocarbons) and a variety of organic, but non-hydrocarbon compounds. The transportation of waxy crude oil causes many problems when the waxy crude oil gels up. When the wax forms from static cooling, the main issue is to re-start the flow of the crude oil.

The restart or "start-up" from the gelled up crude oil, depends on the evaluation of the lowest pressure needed at the pipe inlet to restart the flow. According to Guillaume Vinay et al. (2009), the conventional restart pressure prediction uses the conservative relation of:

$$\Delta p = 4\tau_y L / D$$

where, τ_y is the yield stress needed to break the gel,
L is the pipe length,
D is the pipe diameter.

However, this is an over prediction, because the compressibility of the gelled up crude oil is not taken into account. Of course many more characteristics are not taken into consideration which could lead to the change in pressure to have a different value. However, for this project we are focused mainly on the compressibility of crude oil.

1.2 Problem Statement

Precisely predicting the restart pressure will need a thorough study on the compressibility of the gelled up crude oil.

1.2.1 Problem Identification

When the temperature of the pipeline decreases below the "wax appreance temperature" (WAT) and the "pour point", the gel structure in the crude clusters together and the crude undergoes thermal shrinkage (Guillaume

Vinay et al. 2009). The new formation is now more drastically more compressible then the original crude oil. However, the conventional equation used nowadays does not consider the slightly compressible characteristics of gelled up crude oil. The ignorance causes much wastage in producing excess pressure during the restart process.

Figure 1: Part of wax plug retrieved from Statfjord B (Sept 01)- taken from "Pigging of Pipes with High Wax Content" by Alf Tordal (2006)

1.2.2 Significance of the Project

Studying the compressibility of the gelled up crude oil would further enhance the prediction of the restart pressure, avoiding any unnecessary excess in spending (reduces CAPEX) and guaranteeing flow of crude oil (G.-P. Borghi el al. 2003). Besides that, precise calculations would avoid any unneeded redevelopments offshore.

1.3 Objectives

The objective of this research is to design a flow loop to study the compressibility of waxy crude oil under thermal shrinkage and gas void formations.

1.4 Scope of Study

For this project, the main characteristic of the waxy crude oil that is studied is the compressibility of the crude oil. To do so, a flow loop will be designed to duplicate the conditions at sea bed (sea bed temperature), and the test section will be tested under a MRI Scanner to study the gas void formations and compose the compressibility of the gel formed.

To simulate the piping that transports the waxy crude from offshore, the Reynolds number will be the main guideline to obtain the closest possible conditions to what is faced in the real industrial scenarios.

Besides that, this project will look into the possibility of assisting the addition of a compressibility factor in the conventional method of calculating the restart pressure ($\Delta p = 4\tau_y L / D$).

1.5 Feasibility of the Project within the Time Frame

To assist the progress of the project, it will be divided into two main checkpoints.

Checkpoint 1 would require the precise calculation and designing of a flow loop that is able to simulate the offshore conditions as well as able to be scanned by a MRI Scanner. This flow loop will then be fabricated.

Checkpoint 2 is about running the flow loop with the crude oil obtained from the Sepat Field. The crude will be left running and the test area will be scanned under the MRI Scanner. The results will be studied for the gas voids created and will be related to the compressibility of the crude oil.

CHAPTER 2

LITERATURE REVIEW

During shutdown or ill-timed cooling, waxy crude oil tends to gel up and hinders the transportation and/or production of petroleum products, especially from offshore platforms (I. Henaut et al. 1999, G.Cazaux 1998). The originally, incompressible waxy crude oil then undergoes thermal shrinkage when the pipeline temperature drops below the pour point of the temperature. Major apprehensions arise during the restart of flow from the blocked pipeline due to the gelled up crude oil (Michele Margarone et al. 2010, G.-P. Borghi et al. 2003).

For flow to restart, a certain pressure has to be applied at the pipe inlet. However, reliable methods of predicting the necessary restart pressure needed to start up the flow are not available, there is a probability that the piping system that has gelled up crude oil might be at risk (Michele Margarone et al. 2010). A proper prediction of restart pressure is needed to avoid the risk of losing huge sums of money from piping replacements. Besides that, proper study of the characteristics of the gelled up crude oil is important to reduce the Capital Expenditure Cost (CAPEX Cost) as well as guaranteeing a constant flow of crude (G. –P. Borghi et al. 2003). Most models used to predict the start up pressure, assumes that the gelled up crude acts like an incompressible, high viscous fluid.

However, because the conventional method of predicting the needed applied pressure for restart only includes the yield stress of the gel, over-predictions tend to occur. One of the important characteristics that is avoided during the calculation of the restart pressure is the compressibility of the gelled up crude oil. According to G. Vinay et al. (2006), the compressibility characteristics leads to strong pressure drop at the upstream of a pipe. This statement further proves the over-prediction currently used to calculate the restart pressure.

THEORY

WHAT IS CRUDE OIL?

The oil that is produced from below the earth surface is called crude oil. Crude oil is a mixture of hydrocarbons with different lengths of carbon chains. The longer the carbon chain, the heavier the molecule is. Heavier molecules tend to appear as solid or liquid while molecules with much lesser carbon appear to be in gaseous form.

According to McCain (1990), these petroleum deposits are composed of multiple organic chemicals. When majority of this chemical mixture is composed of smaller molecules, this would lead to the presence of hydrocarbon gaseous at normal temperatures and pressures. However, when the mixture contains large molecules, it would appear as liquid hydrocarbon at normal pressures and temperatures.

A typical crude oil contains thousands of different chemical compounds. Crude oil is usually separated into fractions according to the range of the boiling points. It would not be practical to separate each and every component of the thousands of different chemical compounds in the crude oil.

McCain (1990) writes that, crude oils are divided according to the larger molecule structures in the mixture. The classifications are of paraffins, napthenes, aromatics and aspaltics. Liquids from the reservoir always appear differently at different wells. Some may appear to be black, heavy and thick, while others are brown with low specific gravity.

In this case of crude oil from the Sepat platform, since the wax appreence temperature is high (approximately 35^{o}C), the crude oil here is assumed to be of heavier characteristics. This crude oil is also known to gel up at lower temperatures which would cause problems of transporting the crude oil to shore.

WAX APPREANCE & POUR POINT TEMPERATURE

Majority of crude oil contains waxes that will precipitate at lower pressure and temperature, which causes the crude oil to gel up.

The Wax Appearance Temperature (WAT) is the specific temperature at which wax develops within the liquid crude oil. According to Mustafa V. Kok et al. (1996), WAT is the temperature when crystallization is visible. The WAT point is determined by the concentration and molecular weight (properties) of the waxes and the chemical properties of the hydrocarbon matrix.

Mustafa V. Kok et al. (1996) also defined pour point as the point where a lattice leading to the solidification of the crude oil. As the amount of wax increases, crystals grow with the dropping temperature. When the crude is solidified (unable to flow) the point at which it happened is called the pour point temperature.

REYNOLDS NUMBER & ENTRANCE LENGTH

To properly develop the flow loop, the Reynolds Number has to be considered. Reynolds Number (Re) is the ratio of inertial forces to viscous forces of a particular fluid. According to Cengel and Cimbala (2006), for a circular pipe, Re is expressed as:

$$\text{Reynolds Number, Re} = \frac{Inertial\ forces}{Viscous\ forces} = \frac{\rho\, V_{avg}\, D}{\mu}$$

Where V_{avg} is the average flow velocity (m/s), D is the diameter of the pipe (m), $\frac{\rho}{\mu}$ is the kinematic viscosity of the fluid (m^2/s). Since the units of the nominator and denominator cancel out each other (and Re being a ratio), Re is dimensionless.

When a fluid enters a circular pipe at a velocity, the fluid particles which are in contact with the surface of the pipe goes under no-slip condition. This condition makes the fluid particles (which are in contact with the surface of the pipe) come to a complete stop. In addition, this would cause a gradual slow down of the fluid which are adjacent to the layer in contact to the surface from the effects of friction. The fluid at the middle of the pipe then tries to make up for the loss of velocity because it has to keep a constant mass flow rate though the pipe. A velocity profile develops from this phenomenon.

Reynolds number is important to calculate the entry length needed for a fully developed flow in a pipe. Cengel and Cimbala (2006) defined entry length as the distance from the entrance of the pipe to within 2% of the fully developed value of wall shear stress. A fully developed flow has a parabolic velocity profile. It is important to achieve a fully developed flow for the flow loop because pipelines transporting crude oil from the platforms are hundreds of kilometers long. Having that kind of length would create a fully developed flow. So hence in this case, we need a fully developed flow to experimentally simulate the flow loop.

The graph below explains further on the development of the flow from entrance region to the fully developed region.

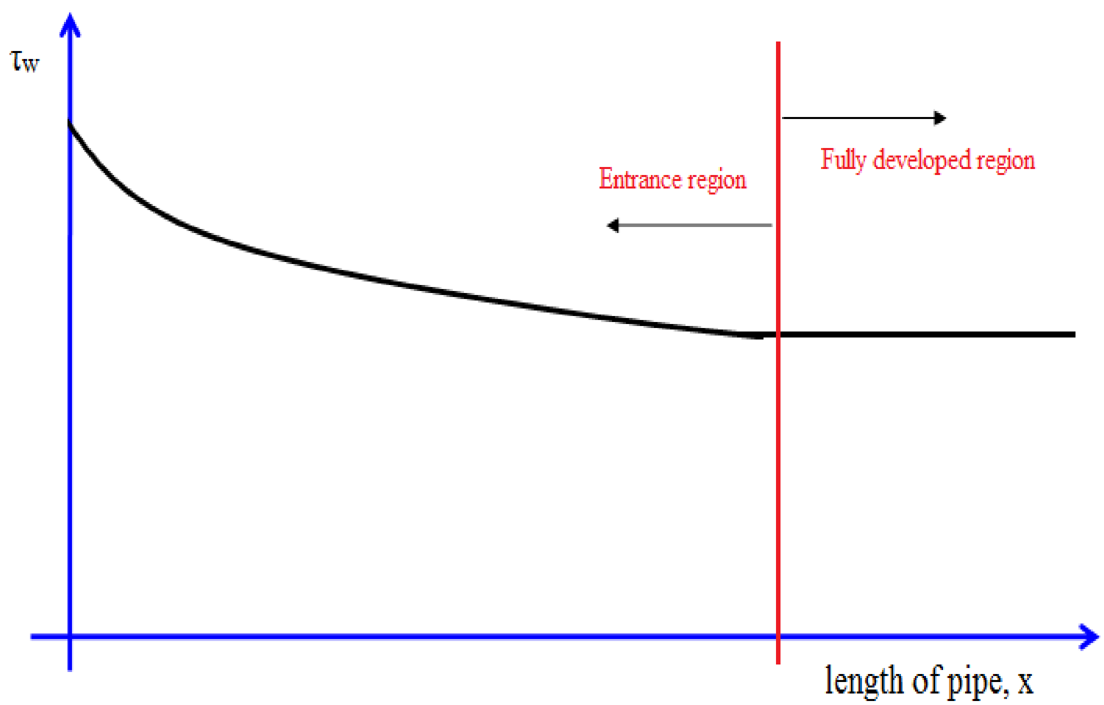


Figure 2: The fully developed region starts after the entrance region

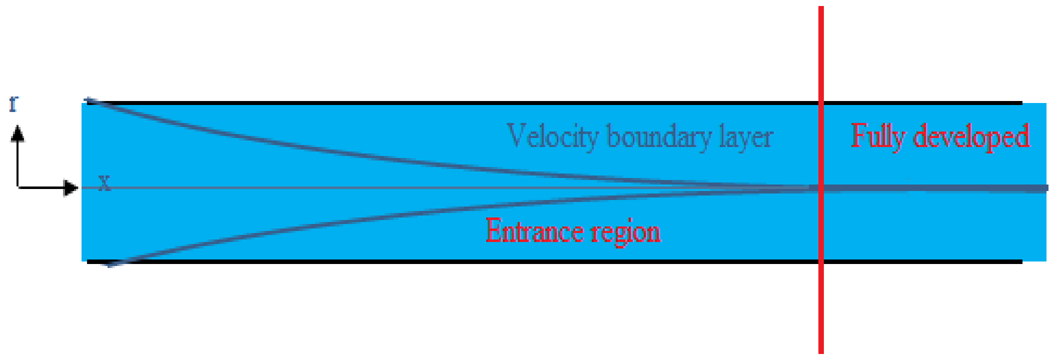


Figure 3: The r during the entrance region within a cylindrical pipe

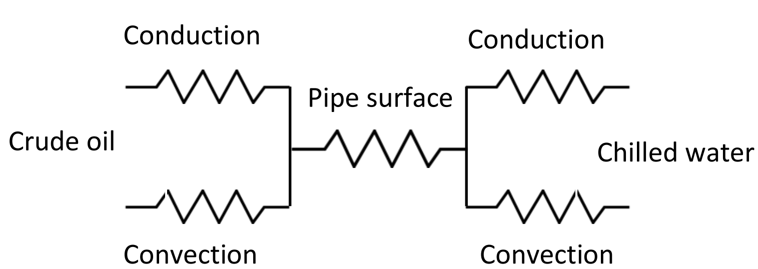
To calculate the entrance length, L_h, the flow has to be predetermined if it is a laminar or turbulent flow. To calculate the entrance length:

$$L_{h,laminar} \approx 0.05\ (Re)\ (D)$$

$$L_{h,\ turbulent} \approx 1.359\ (D)\ (Re_D^{1/4})$$

After the entrance length is determined, the test section of the flow loop is built after the length of the L_h. This is to ensure that when heat transfer across the boundary of the pipes and cools the crude down, the flow of the crude will at a fully developed flow. The exchange of heat that occurs within the pipeline is from conduction and convection mechanisms. The crude transfers the heat to the surface of the pipe, which is then transferred to the chilled water.

The figure below is a graphic representation of the mechanisms of heat transfer for this case.



Both conduction and convection occur when the heat is transferred from the crude to the chilled water, through the walls of the pipes. Conduction occurs when heat is transferred by the movement of energy of motion between adjacent molecules. Heat can be conducted thought solids, liquids and gases. Convection, on the other hand, usually occurs when a solid and a fluid exchange energy. Warmer fluid which is next to the solid surface would develop a circulation from the difference in density because of the temperature dissimilarity within the fluid itself.

MRI SCANNER

Next, the test section will be scanned under a MRI Scanner. A MRI Scanner is a short form for Magnetic Resonance Imaging Scanner. It's a new technique that has been used in the medical field since the beginning of the 1980s. This scanner utilizes magnetic radio waves and has no radiation damage.

MRI Scanners are usually used in the medical field where patients lay inside the scanner which can be assumed to be a large cylindrical shaped magnet. Strong radio waves are then sent through the scanned body. Since the body has atoms, it forces the nuclei of the atoms into a slightly different position. As these nuclei move back into their original space, radio waves are sent out from the nuclei. A sensor then picks up the radio waves and sends the signals to a computer which interprets the results to form a picture. The picture is developed and different parts are shown differently based on the strength and location of the signal that was detected by the MRI Scanner.

From a medical point of view, an MRI Scanner is able to plot pictures of almost all the tissues in a human body. Darker parts of the produced picture have tissues that has the least hydrogen atoms (for example, bones), while the brighter parts of the picture are from tissues that contain much more hydrogen atoms (such as fatty tissue). The different types of tissues present can be identified by varying the time period of the radiowave pulses. Since the scanner is able to provide clear pictures of different parts of the human body that are surrounded by different types of tissue,

There are three types of images that can be produced by the MRI Scanner. Those types are T_1, T_2, and Proton Density. These three types of images are based on different parameters and produce slight different images.

The first type of image is the T_1 weighted image. T_1 is the longitudinal relaxation time. T_1 shows the period of time for the scanned substance to become magnetized after being positioned in a magnetic field. It can also be defined as the necessary time to regain longitudinal magnetization after a radio frequency pulse. The thermal interactions of the resonating protons and magnetic nuclei within the magnetic environment determine the T_1.

According to W.G.Bradley (nd), molecules are always in motions due to vibration, rotation and translation. Molecules which are smaller in size (for example: water molecules) tends to generally move relatively more rapidly, resulting in relatively higher natural frequencies. However, larger molecules (for example: protein molecules) move relatively slower than smaller molecules, resulting in a relatively lower natural frequency. The T_1 image reflects on the relationship of the frequency of these molecules in motions as well as the frequency. The smaller the molecules in size, the higher the T_1 relaxation time and vice versa.

For the T_1 weighted image, the contrast within the images depends on the differences of the proton density and the T_1 relaxation properties of the part that is scanned by the MRI Scanner. The shorter the T_1 relaxation time, the stronger the signal. Hence, the pixel will appear brighter in the picture. Taking an example, fat appears brighter than water in the T_1 weighted images.

The second type of MRI images available is the T_2 image. T_2 is the transverse relaxation time. W.G.Bradley (nd) also states that, it is a measure of how long a transverse magnetization would last in a uniform external magnetic field. In other words, it measures the period of time for the resonating protons to remain coherent or rotate in a phase after a 90^{o} radio frequency pulse. The magnetic interactions relationship between two or more spinning protons would cause the T_2 to decay.

Besides that, T_2 relaxation varies depending on the internal static field of a substance which is usually due to protons from relatively large molecules. The slow fluctuating magnetic fields make regions with increased or decreased magnetic fields. Bones, tendons, and teeth tend to have a shorter T_2 and don't produce lasting signals (decays quickly).

For a T_2 weighted image, the contrast between the tissues in the images solely depends on the differences in the proton density and the T_2 relaxation properties of the tissues in the parts that are being scanned. Basically, the longer the T_2 relaxation time, the stronger the signal produced. Hence, this would lead to a brighter pixel in the image that has been produced.

The last image that can be produced is the proton density image. Also known as the spin density, this weighted scans differentiate the signals from the amount of available spins (hydrogen nuclei in water).

To sum it up, according to Gemma Steadman (2003), the T_1 weighted scans are basic scans, particularly to differentiate fat from water. Water would appear darker while fat would appear brighter. This weighted image can be increased by improving its contrast. The T_1 images are usually used to highlight fat deposition within a patient. On the other hand, T_2 weighted images shows water with a brighter shade, while fat with a darker one. T_2 is also a basic scan type available for this project. Proton density scanning on the other hand shows the concentration of proton in an area.

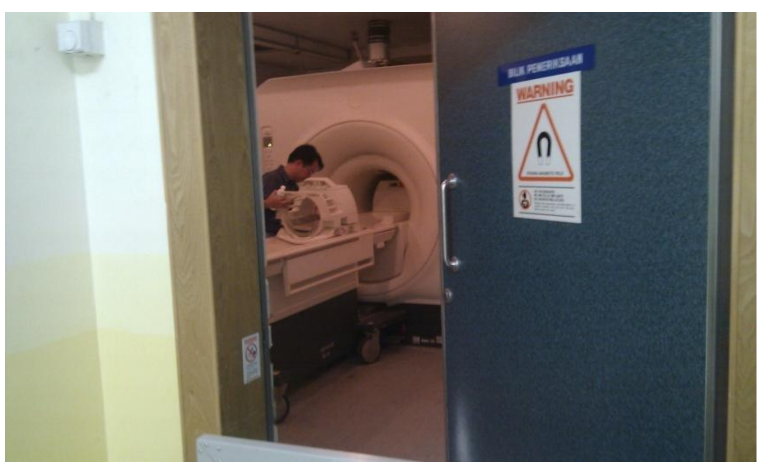


Figure 4: The MRI Scanner that will be used for the scanning of the flow loop in Hospital Universiti Sains Malaysia, Kelantan.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

To begin the project, a thorough research through books and previous technical paper is done to ensure the objectives of this project are met.

Next will be the flow loop designing for the experimental simulation. A flow loop will be designed to experimentally simulate the real life conditions (focusing more on the similarity of temperature and flow rate using Reynolds Number as a guide). The flow loop will consist of a heated “reservoir” where the crude oil is heated up to reservoir temperatures, a test area (where the pipe is submerged under chilled water) and a piping to loop the whole system. A flow chart representation of this flow loop is included in the next page.

The design of the flow loop will take into account the flow of the crude oil. The entrance length will be calculated to ensure that the experimental simulation is proper. Besides that, the test section has to be easily removed from the main flow loop to be scanned.

The flow loop will be filled with crude supplied from the Sepat field. The flow loop will then be left running in a constant heating and cooling circle until the waxy crude oil gels up at the test area completely. The test area is then tested under the MRI Scanner. The images produced from the scanning of the test section will reveal differently shaded areas that will indicate the gas voids that are formed in the test section. The compressibility of the gel can then be studied through the gas voids formations which were analyzed from the scanning of the images taken.

The flow loop is capable to investigate the gas voids formation under dynamic (as well as static) cooling. Since the flow loop enables flow while cooling the test section, future test on dynamic cooling can be done. The flow loop also is able to follow the Reynolds number of the flow in the real application.

The flow loop is limited to only the cooling and flow characteristics of the real industry. Other criteria that are faced by pipelines in the real industry are not included in this flow loop.

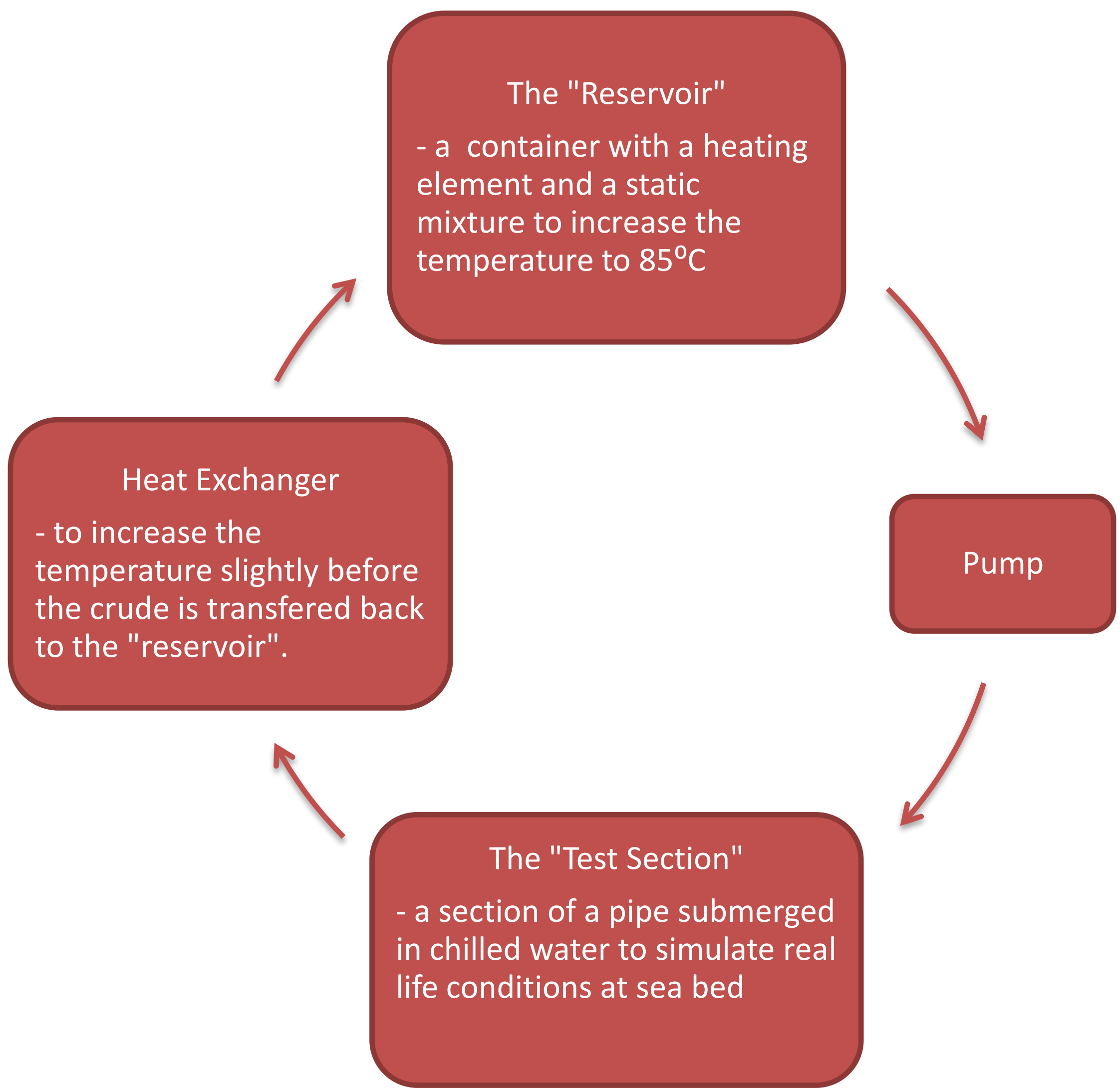
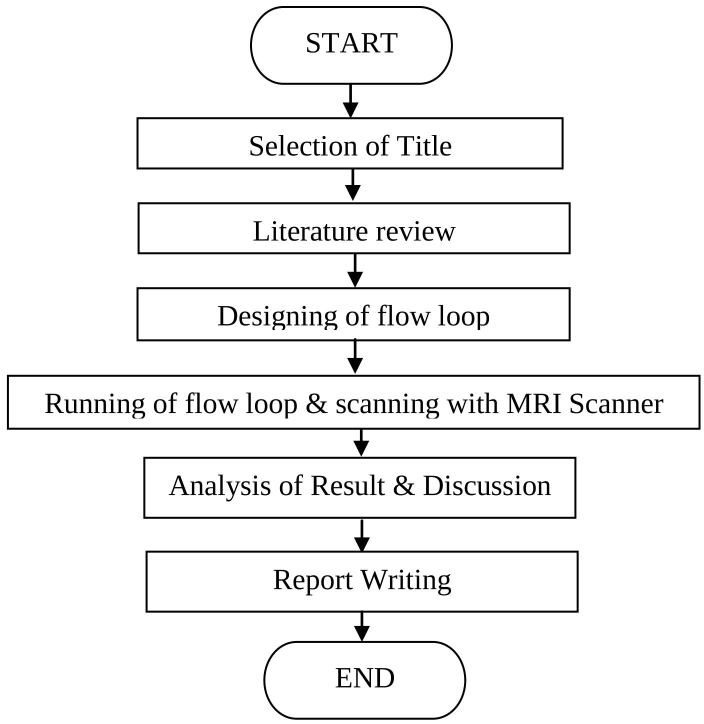


Chart 1: flow chart representation of flow loop

3.2 Project Work



3.3 Tools required

Equipments needed for this research:

i. MRI Scanner

ii. Designed flow loop (consists of):

a. Heated section
b. Chilled section
c. Pump
d. Piping

3.4 Project Planning

PROJECT PLANNING: GANTT CHART (FYP 1) Chart 2

Week Number Activities/ Milestones	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Selection of project title	■	■													
Initial research work	■	■													
Conceptual design of Flow Loop		■	■	■	■	■	■		■						
Submission of extended proposal						■									
Proposal defense									■	■					
Preliminary visit to USM										■					
Finalizing flow loop design											■	■	■		
Fabrication of flow loop													■	■	■
Submission of interim draft report														■	
Submission of interim report															■

Key Milestones:

i. Submission of extended proposal
ii. Proposal Defence
iii. Visit to USM
iv. Fabrication of flow loop
v. Submssion of interim report

PROJECT PLANNING: GANTT CHART (FYP 2) Chart 3

Week Number Activities/ Milestones	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Designing of flow loop															
Proposal from fabricator															
Fabrication of flow loop															
Test run of flow loop															
Flow loop testing at HUSM															
Submission of progress report															
Submission of Dissertation (soft bound)															
Submission of Technical Paper															
Oral Presentation															
Submission of Project Dissertation															

Key Milestones:

i. Test run of flow loop
ii. Flow loop testing at HUSM, Kelatan
iii. Submission of Project Dissertation

CHAPTER 4

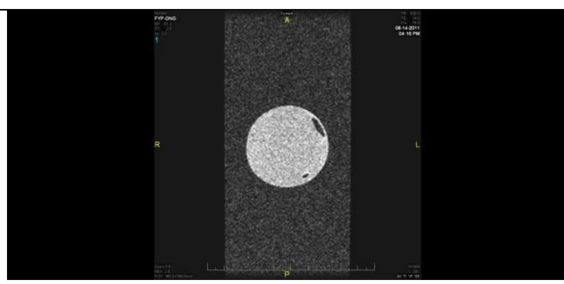
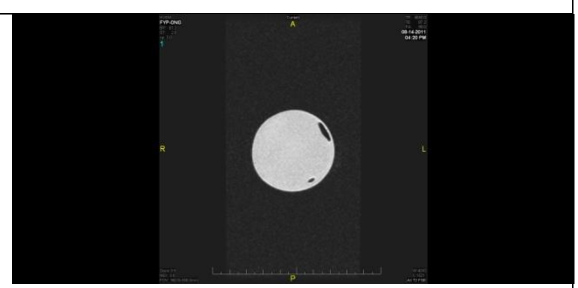
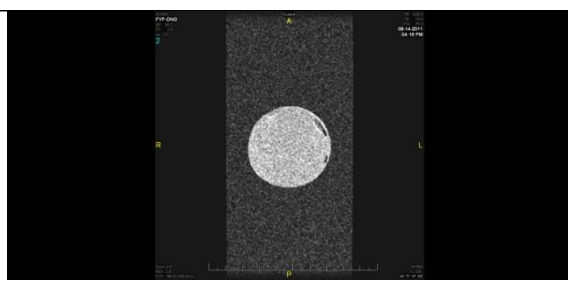
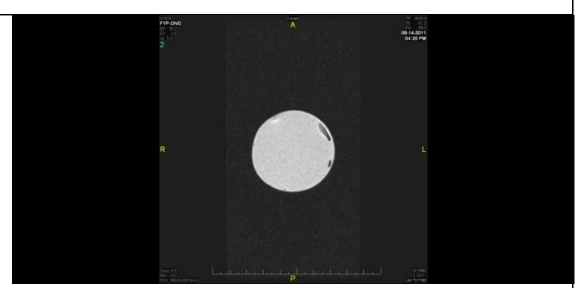
RESULTS AND DISCUSSION

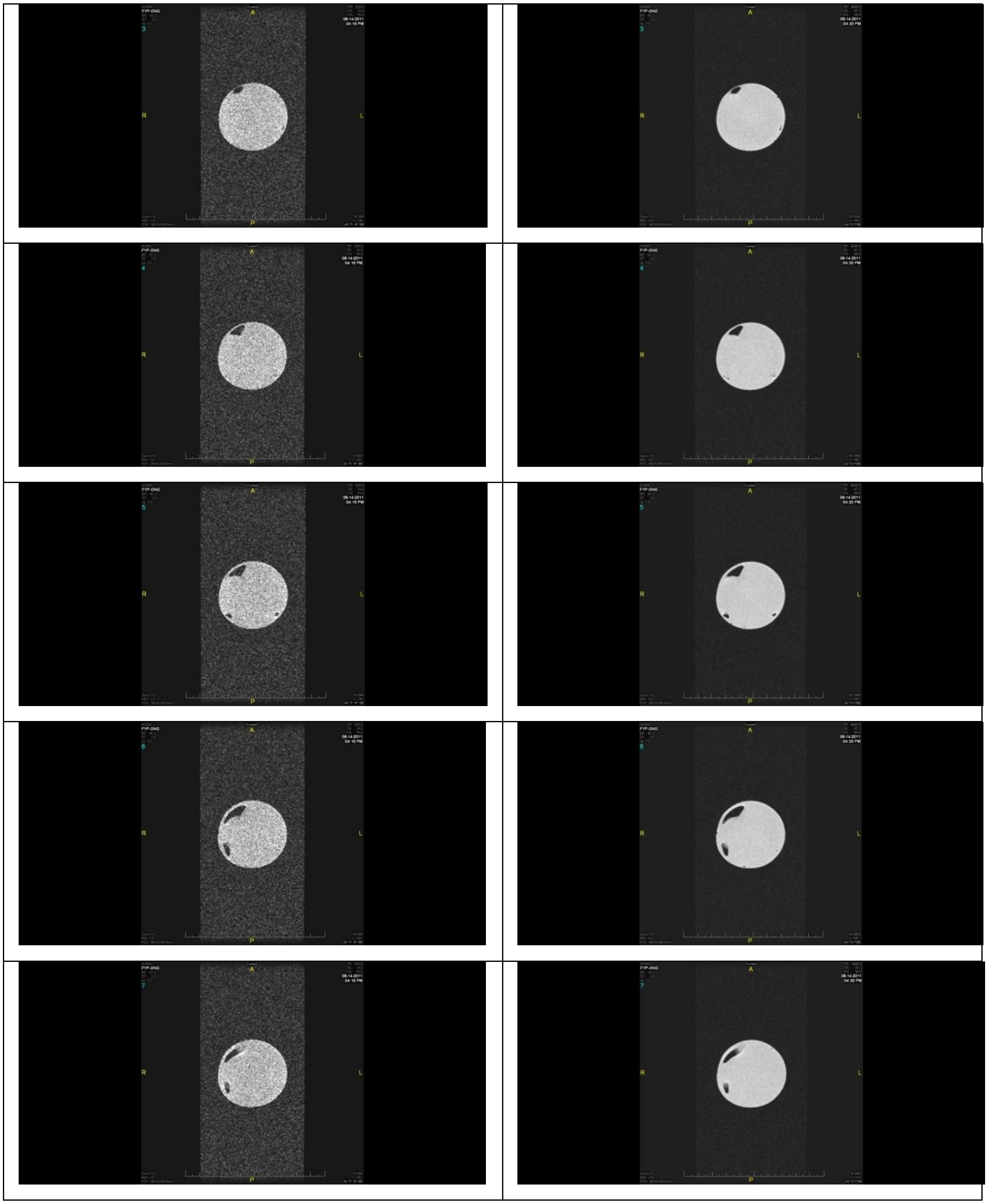
4.1 Test Run – Scanning Of Gel Tube

A preliminary task was done at HUSM, Kelantan. This test run was done to confirm that the MRI Scanner is able to tell the difference between gel and gas voids in a tube.

The task involved scanning of a bottle of gel for the produced images. For this scanning, the bottle was scanned using a 2mm cut (2mm spacing between each image taken).

The bottle was first placed in the head coil by the operator. The scanning room is then closed shut as the operator instructs the machine from the control room with the computer inside. The time taken to scan the bottle roughly takes 10 minutes. After the scanning, the images are then reconstructed and shown in the control room computers as results. Below are the results for the scanning which was done at HUSM.

T_1 weighted image	T_2 weighted image
	
	


A
R
L
P

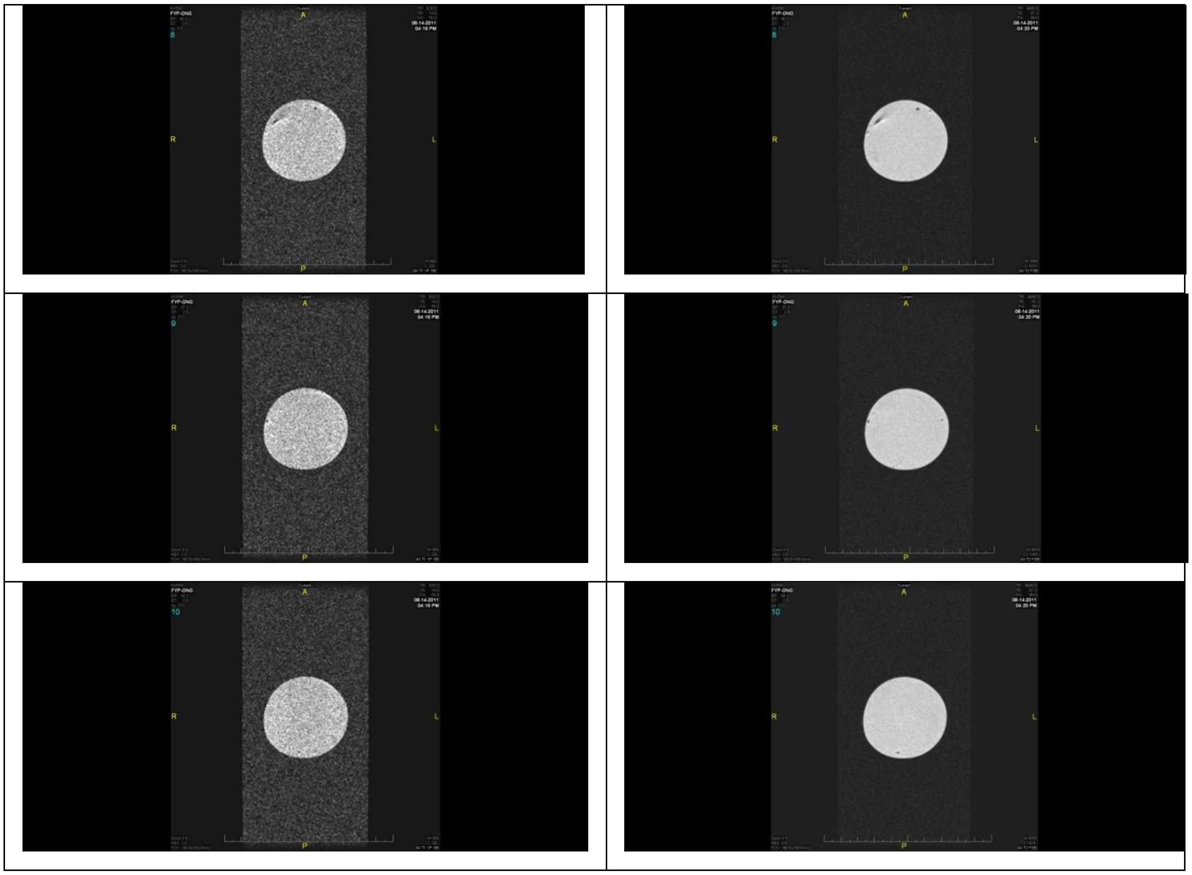


Table 1: Sample images of the MRI Scanning results. (These images have been scaled down. The complete set of pictures in the original size is attached in the appendix.)

The table above shows the two types of images that were obtained from the MRI Scanner. The right side of the table shows the T_2 weighted image, while left side of the table shows the T_1 weighted image. The other set of images that was not taken due to time constraints on the other day was the Photon Density Image.

4.2 Flow Loop Designing

4.2.1 Flow calculations

To size the pump needed for this flow loop, it is first needed to determine a few criteria of the fluid that needs to pump. Two main factors that must be considered in pump sizing which are, the characteristics of the fluid as well as the dimensions of the pipe.

For the pipe, originally it was proposed to have a diameter of 7.62cm with a test section length of 300cm. Since the flow loop needs to be mobile, it suggested that the diameter of the pipe as well as the section length is made smaller. Hence, the newly proposed diameter of the pipe is at 3cm. The test section is also reduced to 120cm using linear conversion as show below:

$$\frac{300\ cm}{7.5\ cm} = \frac{length\ of\ test\ section\ (cm)}{3\ cm}$$

$$length\ of\ test\ section\ (cm) = \frac{300}{7.5} \times 3$$

$$length\ of\ test\ section\ (cm) = 120cm\ @\ 1.2m$$

Now that the piping size has been decided, the characteristics of the fluid has to be decided and calculated which includes, the density, viscosity and flow rate.

For the specific gravity;

At standard conditions,

According to the Material Safety Data Sheet by El Pas Corporation,

The specific gravity (SG) of crude oil is at a rough estimation of: 0.8 – 0.98

Designing for the worst case scenario, the SG of the crude is estimated at 0.98

Hence, $density\ of\ flowing\ liquid\ (crude\ oil), \rho\ =\ 0.98\ \times 999 \frac{kg}{m^3}$

$$density\ of\ flowing\ liquid\ (crude\ oil), \rho = \ 979.02 \frac{kg}{m^3}$$

Also, viscosity (Centipoise) of Crude is in a range of 0.8 – 4500 cP. Again, taking the highest viscosity for the worst case scenario, we take the 4500cP which equals to 4.5 Pa.s

To calculate the flow needed in the flowloop to be the closest possible scenario as in the industry, the Reynolds's Number (RE) for both the flows are assumed to be similar. Hence, the RE is calculated for the pipe flow for the Sepat field.
Given,

Flow in pipes, Q = 1000 barrel/day

= (1000 barrel/day)(160 *l* / barrel)(1 ay/ 24 hours)(1hour/60 mins)

= 111. 11 *l*/min

= 0.00185 m^3/s

Speed of flow, U = Q/ Area of pipe,A

= 0.00185/0.017

= 0.1088 m/s

Hence, Re $= \frac{\rho\ U\ D}{\mu}$

$= \frac{979.02\ (0.1088)(0.1488)}{4.5}$

= 3.522

Assume that $Re_{max} \approx 5$

$Re_{modal} = \frac{979.02\ (U)(0.03)}{4.5} = 5$

U = 0.766 m/s

Q = AV

= $\pi(0.03/2)^2$ (0.766)

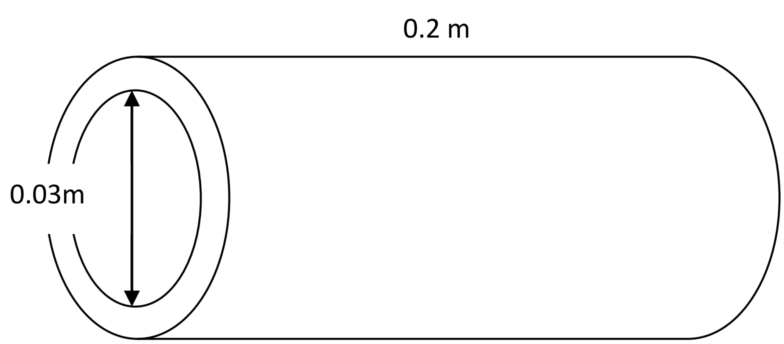
= 5.4145 $\times 10^{-4}$ m^3/s

= 32.51 *l*/m

Hence, we design the flow loop to be able to handle flow at 35 *l*/m and liquid with the viscosity of 4.5 Pa.s (to the maximum value of 10 Pa.s when the fluid is gelled up).

4.2.2 Piping Calculations

Piping calculations has to be done to determine what time of material should be used at the test section area. Mainly, the material should be of high heat conductivity. By doing so, the process of heat transfer can be faster, hence achieving the wanted results at a quicker time. The following are the calculations for the test section.



Length = 0.2m

d_i = 0.030m
d_o = 0.033m
r_i = 0.015m
r_o =0.0165m

ΔT = $(60\text{-}20)^oC$
= 40^oC = 40K

Materials considered for the test section are common materials that are easily found. In this case, PVC, glass and Perspex are in consideration.

To calculate the amount of heat flow, Q, the following equation is used.

$$Q = \frac{2\pi\, k\, l\, (\Delta T)}{\ln(r,outer)/(r,inside)}$$

$$Q = \frac{2\pi\, k\, (0.2)\, (40)}{\ln(0.0165/0.015)}$$

The values of k are different with each material used. The k values are obtained from Thermal Conductivity of Common Materials (via www.engineeringtoolbox.com)

For PVC k = 0.19 W/mK

$$Q = \frac{2\pi\, k\, (0.2)\, (40)}{\ln(0.0165/0.015)}$$

$$Q = \frac{2\pi\, (0.19)\, (0.2)\, (40)}{\ln(0.0165/0.015)}$$

Q = 100.204 W

For Glass k = 1.05 W/mK

$$Q = \frac{2\pi\, k\, (0.2)\, (40)}{\ln(0.0165/0.015)}$$

$$Q = \frac{2\pi\, 1.05\, (0.2)\, (40)}{\ln(0.0165/0.015)}$$

Q = 553.794 W

For Perspex k = 0.189

$$Q = \frac{2\pi\, k\, (0.2)\, (40)}{\ln(0.0165/0.015)}$$

$$Q = \frac{2\pi\, (0.189)\, (0.2)\, (40)}{\ln(0.0165/0.015)}$$

Q = 99.676 W

From the calculation above, it is evident that glass would be the preferred material. However considering the fragileness of glass, it is much wiser to opt for Perspex as the material for the test section. Perspex has reasonable heat transfer rate, is less fragile and transparent. Being transparent, a rough idea can be achieved on the state of the pipe since we are able to see the insides of the pipe. However, a Perspex test tube is subject to the manufacturer's availability.

4.2.3 Heat Exchanger Sizing

Calculation of heating requirements to heat crude oil with a flow rate, q_c= 35lpm, with a ΔT= 40°C (60°C - 20°C)

From previous calculations and data,

P_c= 979.02 kg/m^3

Cp_c= 0.4313 BTU/lbm °F = 1804.274 J/kg °C

*Assume – water bath volume and water bath flow rate

Water dimensions = 0.3m x 0.3m x 1.2m

= 0.108m^3

Water in tank regulates every 1 minute, q_w= 0.108m^3/min

$\dot{m}_{crude}$ = $P_c\, q_c$

= (979.02 kg/m^3)(35 l/min)(1m^3/1000 l)(1min/60sec)

= 0.5711kg/s

Q_1 = (1804.274 J/kg °C)(0.5711 kg/s)(40°C)

= 41216.835 J/s

= 41.216 kW

Now to calculate the temperature rise of the water bath,

ΔT = T_{after} - T_{before}

$\dot{m}_{water}$ = $P_{water}\, q_{water}$

= (1000kg/m^3)(0.108m^3/min)(1min/60sec)

= 1.8 kg/s

$$Q_2 = \dot{m}_{water} Cp_{water} \Delta T$$

Since, $Q_1 = Q_2$

$$41.216 \text{ kW} = (1.8\text{kg/s})(4.2 \text{ kJ/kg }^{o}\text{C})(T_{after} - T_{before})$$

$$41.216 \text{ kW} = (1.8\text{kg/s})(4.2 \text{ kJ/kg }^{o}\text{C})(T_{after} - 20^{o}\text{C})$$

$$T_{after} = 25.452^{o}\text{C}$$

In conclusion, the heater of the crude oil that heats the crude from 20ᴼC to 60ᴼC needs to be a heater with roughly 42kW output. The temperature rise of the water bath will be roughly 25ᴼC after a minute. So, a chiller need to be installed to keep the water constantly chilled.

4.2.4 Design of Flow Loop

The figure below shows the original rough design of the flow loop.

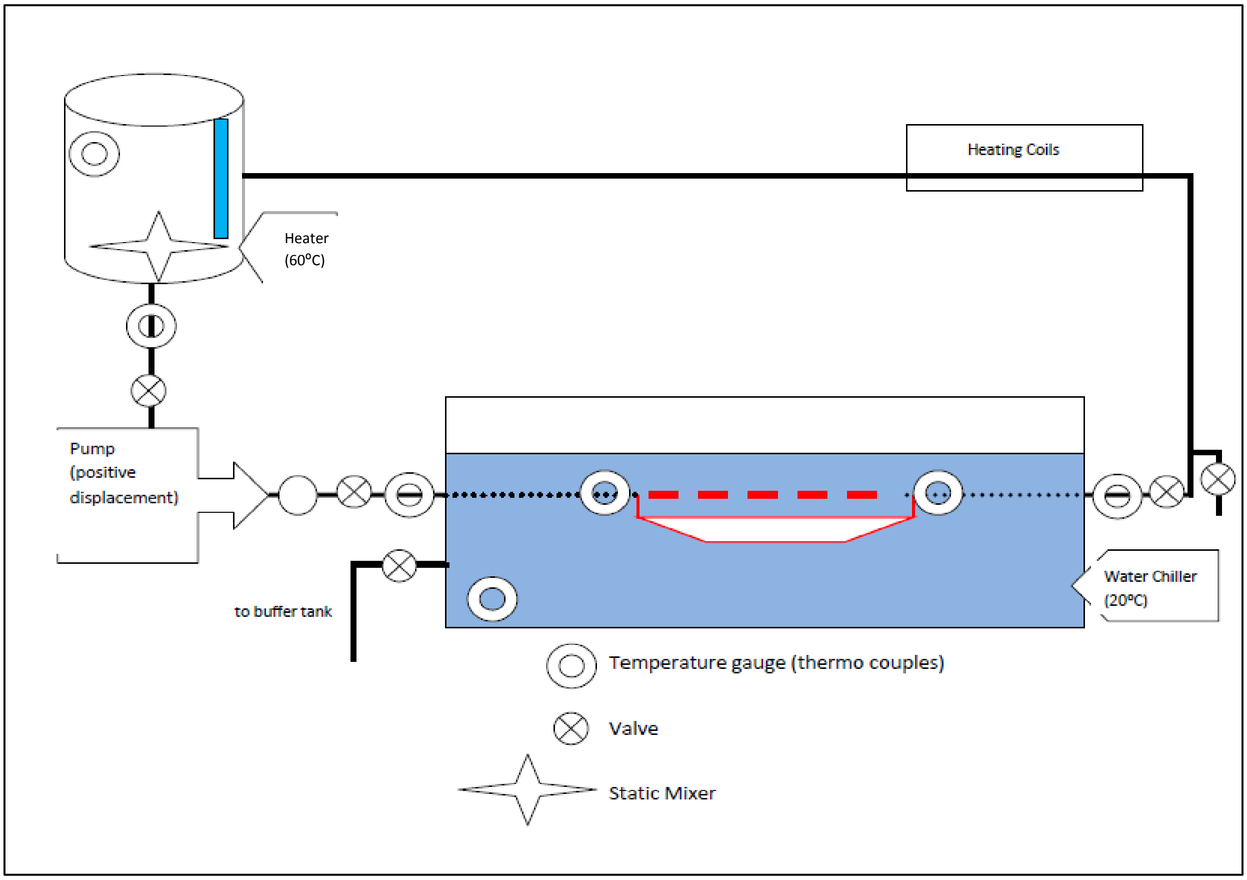


Figure 5 : Initial drawing of flow loop

After alterations to the flow loop, the flow loop was altered and the following figure shows the current design of the flow loop which is at the manufactures and waiting for it to be done.

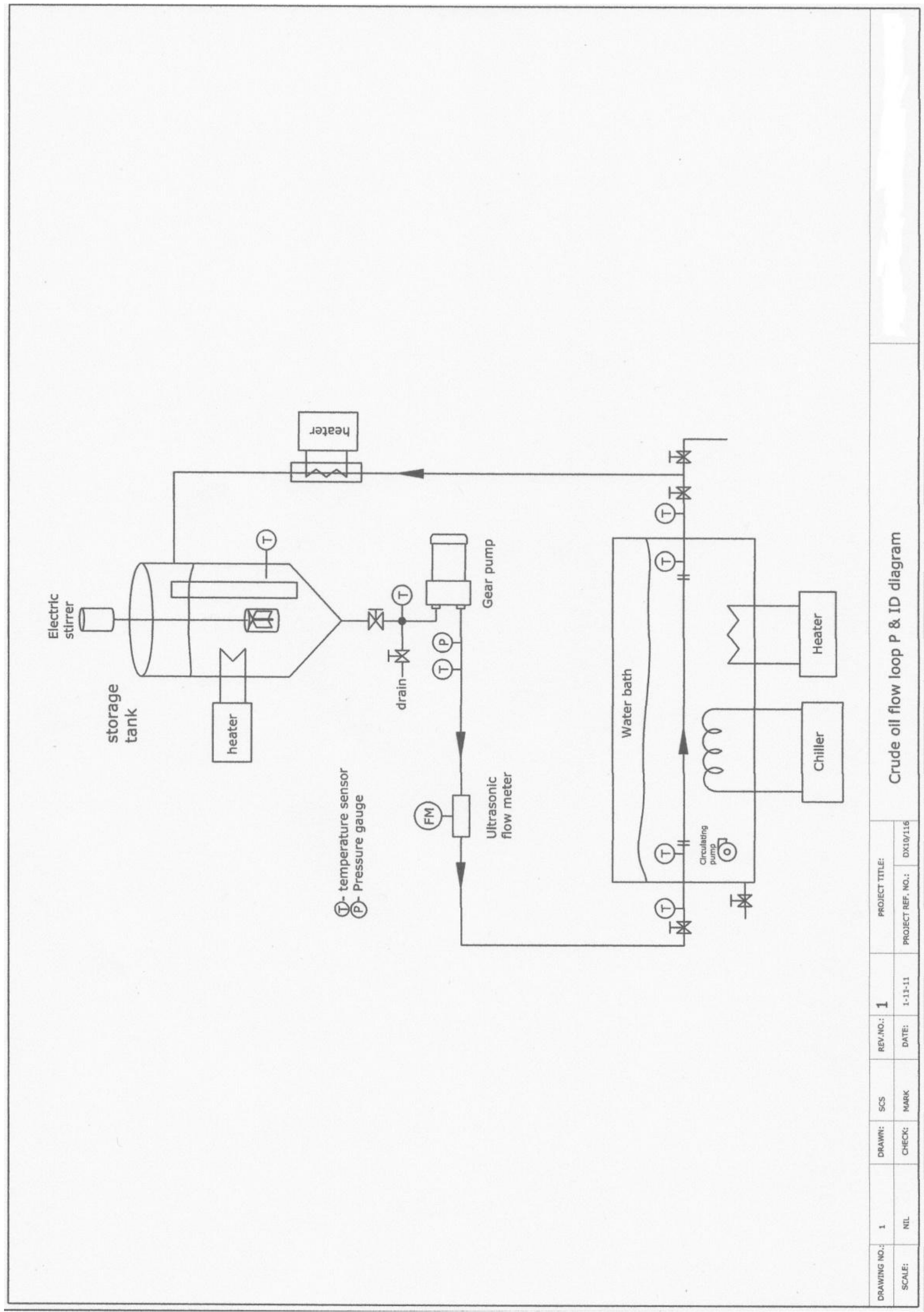


Figure 6: Current design of flow loop

CHAPTER 5

CONCLUSIONS

The objective of this final year study is to design a flow loop to study the compressibility of waxy crude oil under thermal shrinkage and gas void formations has been achieved. Fields nowadays are producing crude oil with high wax context. This crude usually consists of higher value of carbon chain hydrocarbons. It is evident that the transport of this highly waxy crude oil causes many problems especially when the wax gels up from static cooling. The restart pressure applied to move the gel depends on the evaluation of the lowest pressure needed to be applied at the pipe inlet to restart the flow. The calculation of the restart pressure can be improved from the study of the gas voids and thermal shrinkage of waxy crude oil which will be tested on this designed flow loop.

The scope covered on this project is designing the flow loop to test the compressibility of the crude oil. The flow loop has been designed to duplicate the conditions at sea bed, mainly the sea temperature, and the test section can be taken out to be scanned under a MRI Scanner to study the gas voids and further research on the compressibility of the crude oil. Besides that, this design also considers the transfer of crude through piping where the Reynolds number of the industrial crude flow is matched with the Reynolds number of the flow in the said flow loop.

The designed flow loop will be able to study the effects of both dynamic cooling and static cooling towards the crude in the pipe when submerged to cooler water. By doing so, the study of the compressibility of crude oil is not only limited to only static cooling. That way, a better study can be done.

However, the flow loop is still under manufacturing and is unable to be tested due to unforeseen circumstances.

RECOMMENDATIONS

Recommendations for this study are to continue the experiment once the flow loop has arrived. The flow rate can be changed to experimentally simulate the flow rate of different crude pipes, and different crude oil can be used in the flow loop to study the compressibility of it further.

By studying the images produced by the MRI Scanner, it is recommended to further research the compressibility of the crude oil to further improve the formula used to study the compressibility of gelled up crude. Besides that, it is advisable to immediately scan the flow loop, once it has gelled up, to be able to scan the exact state of the gel. By doing so, the other factors such as heat after the test section is taken out of the water bath, can be eliminated.

Once the study of compressibility of crude oil is done, the study can be improved further by introducing a compressibility factor into the equation which is used to calculate the restart pressure. This factor will take into account the gas voids and the thermal shrinkage formed by the gelled up crude oil.

In addition, this flow loop can be used to test crude oil from other field by varying the conditions to match those on the field (temperature and flow rate). If the temperature and/or flow rate can’t be achieved by the current set up of equipments, the equipments (for example pumps) can be replaced to accommodate for the change of conditions.

This flow loop is no doubt useful for future studies and its parts can be exchanged to suit the study even better.

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APPENDIX 1

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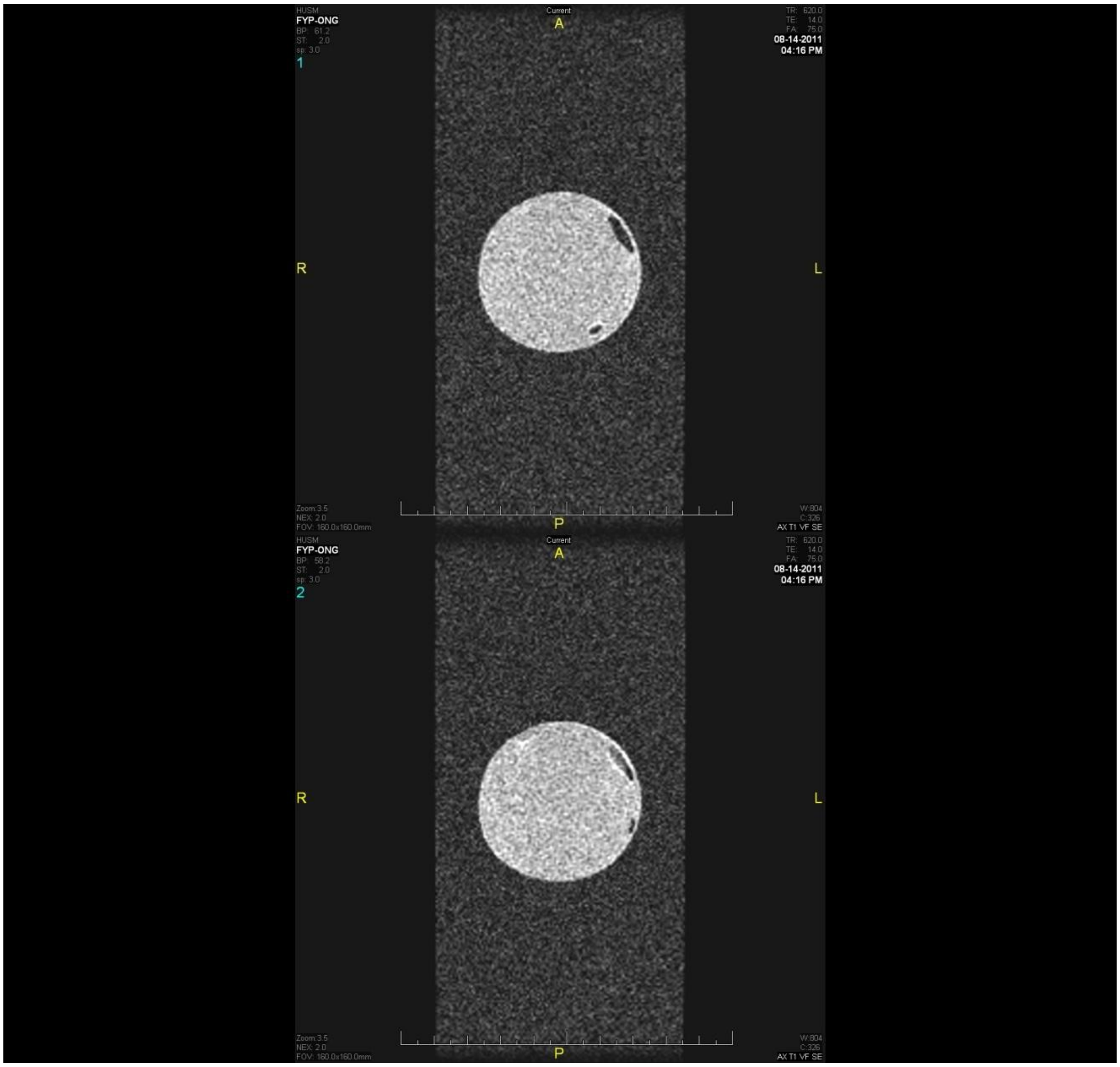

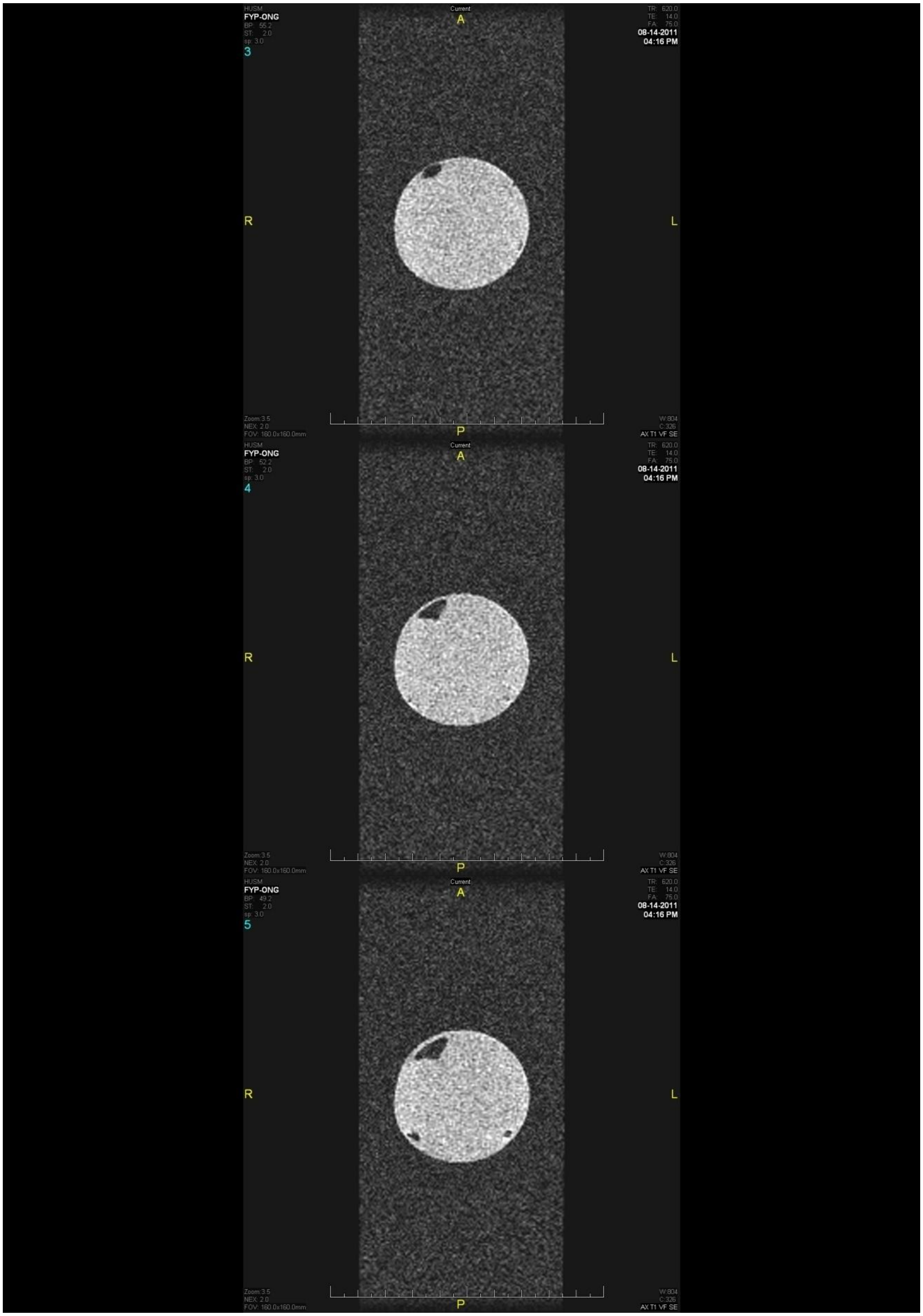
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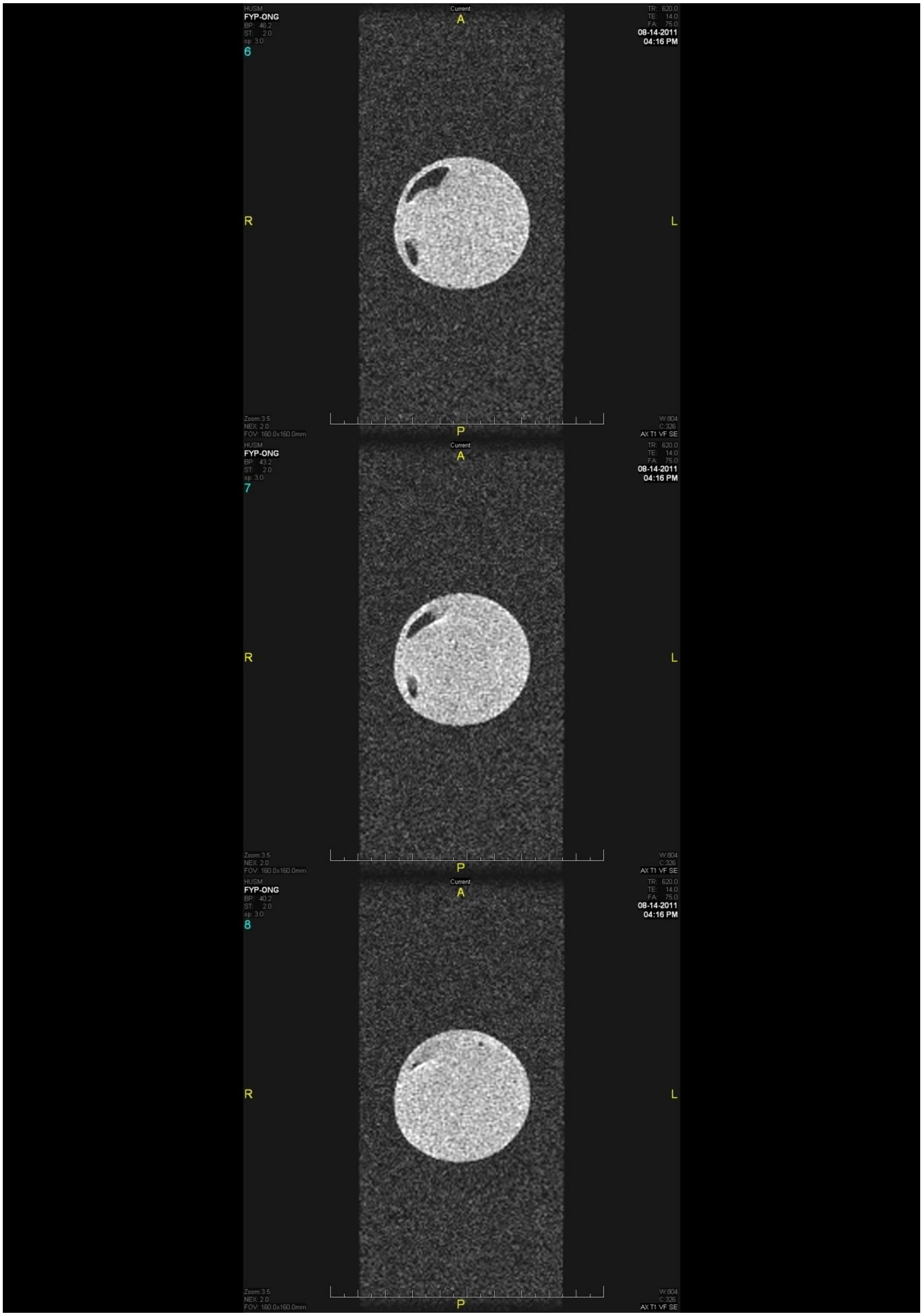
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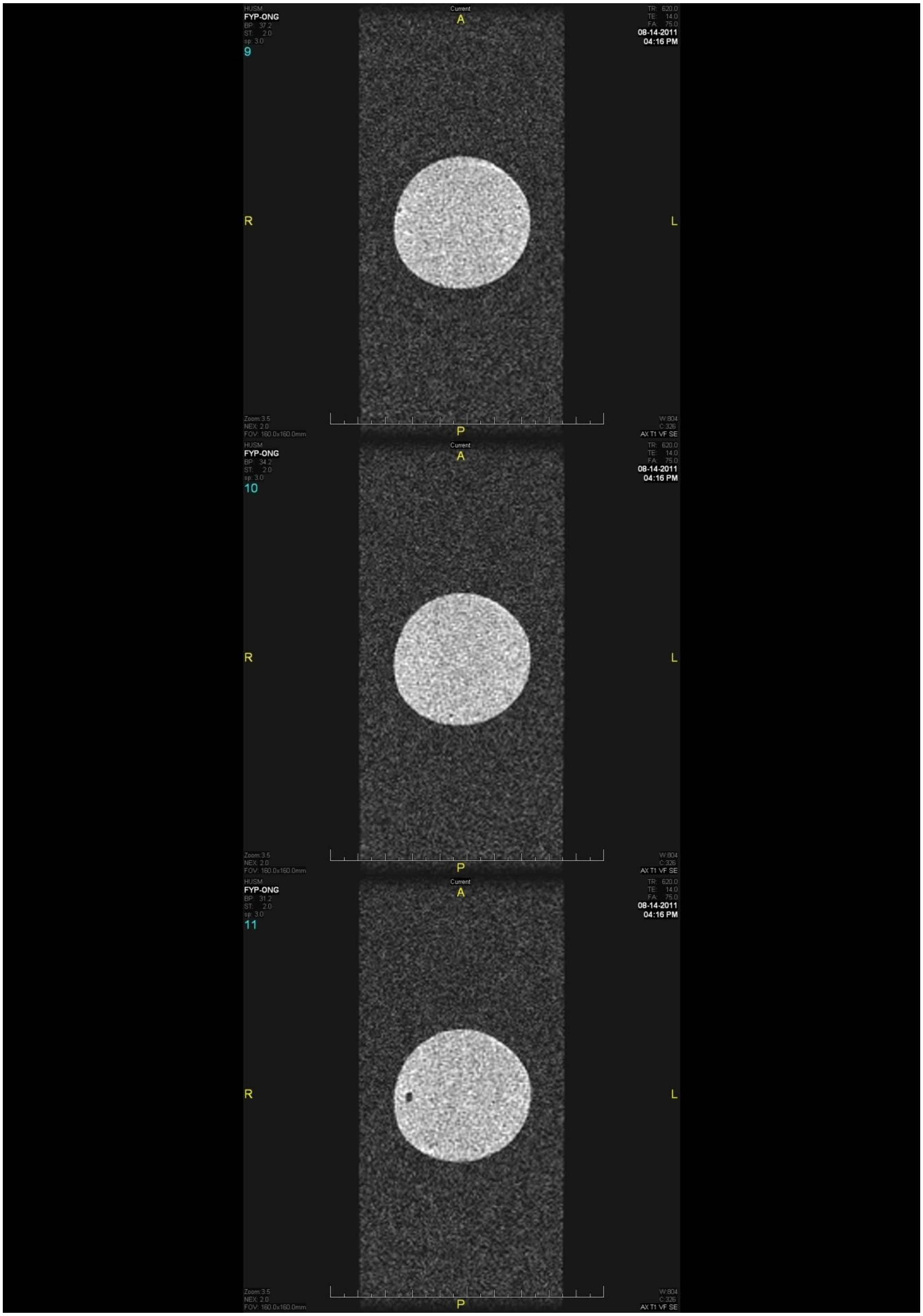
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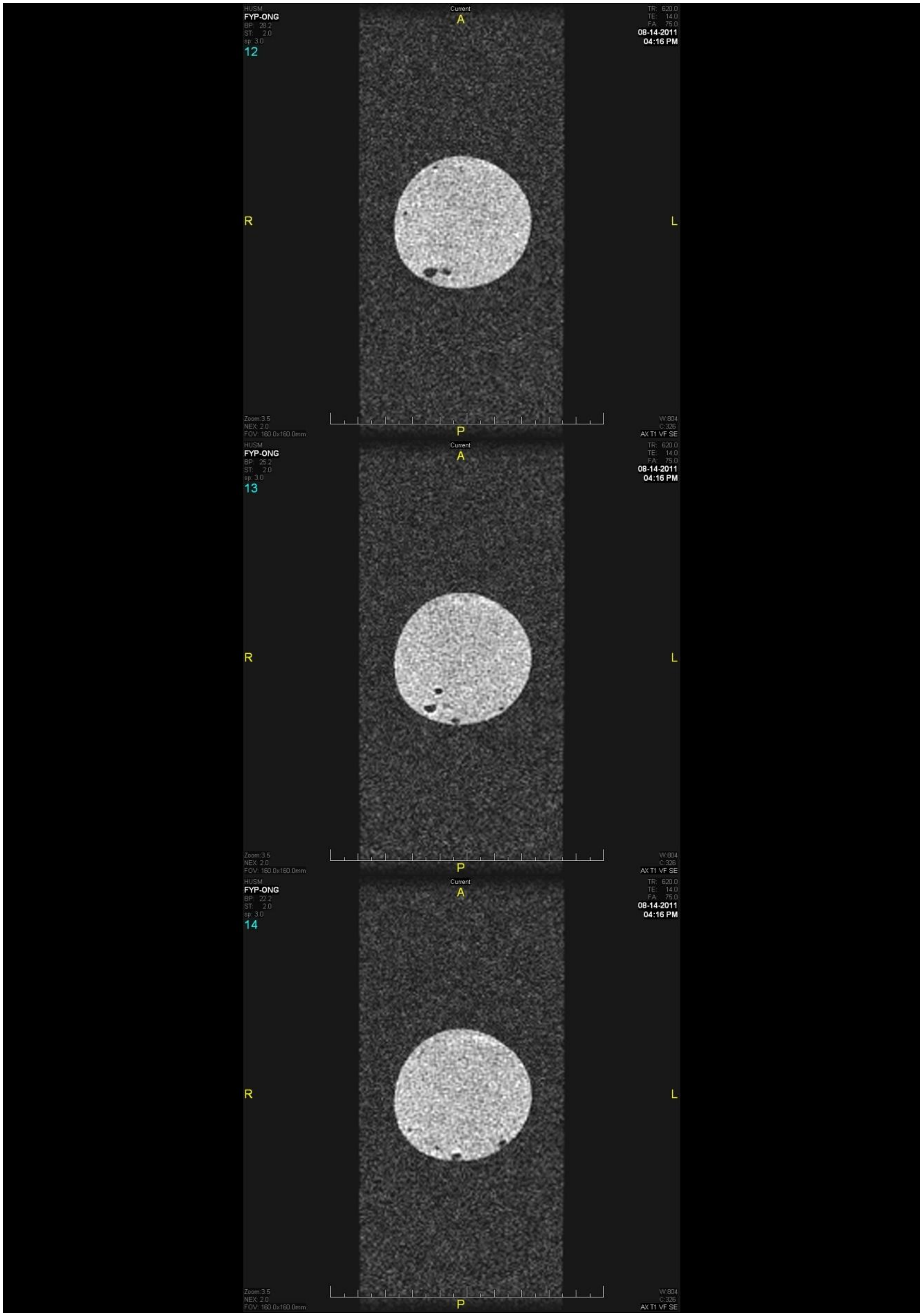
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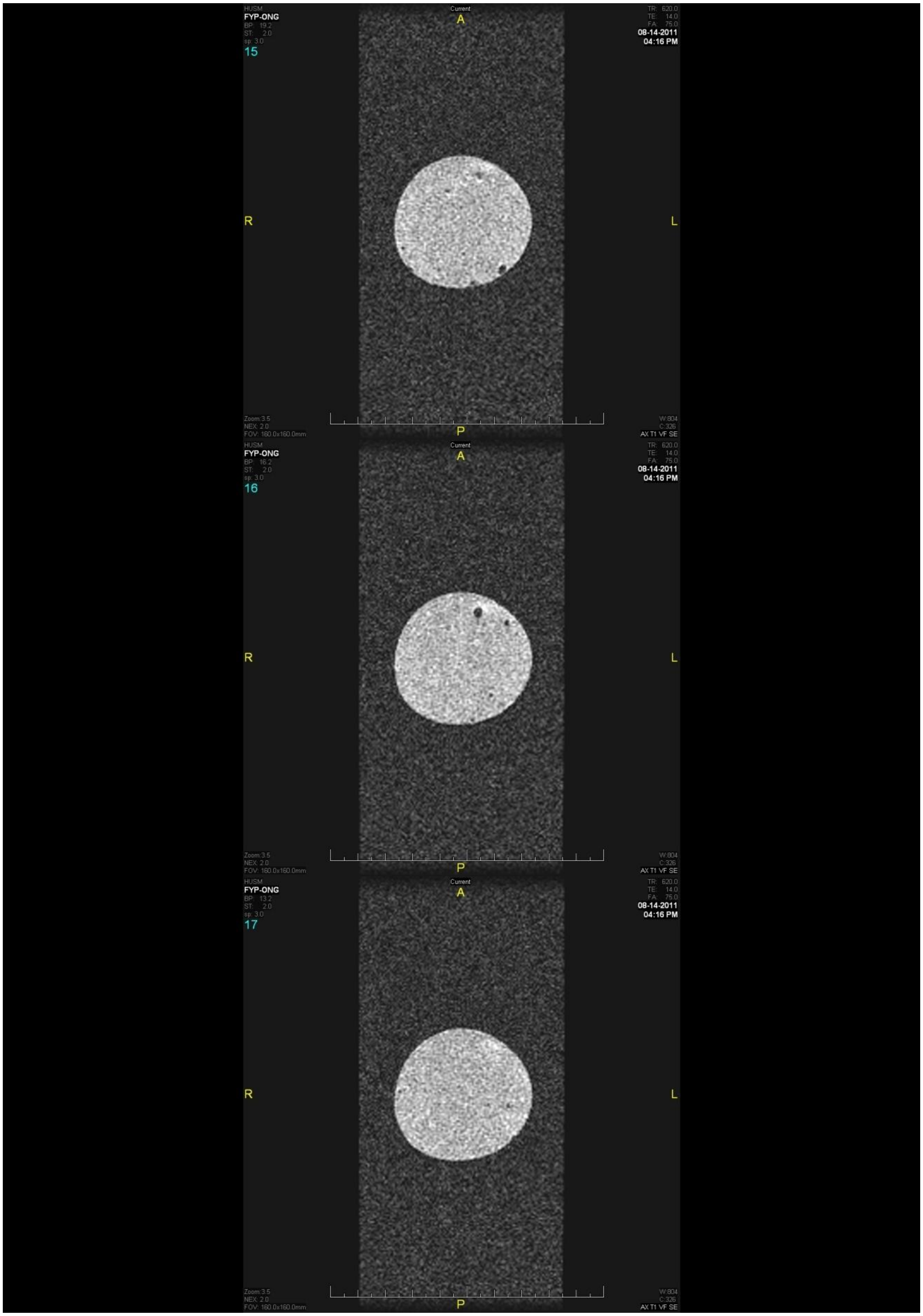
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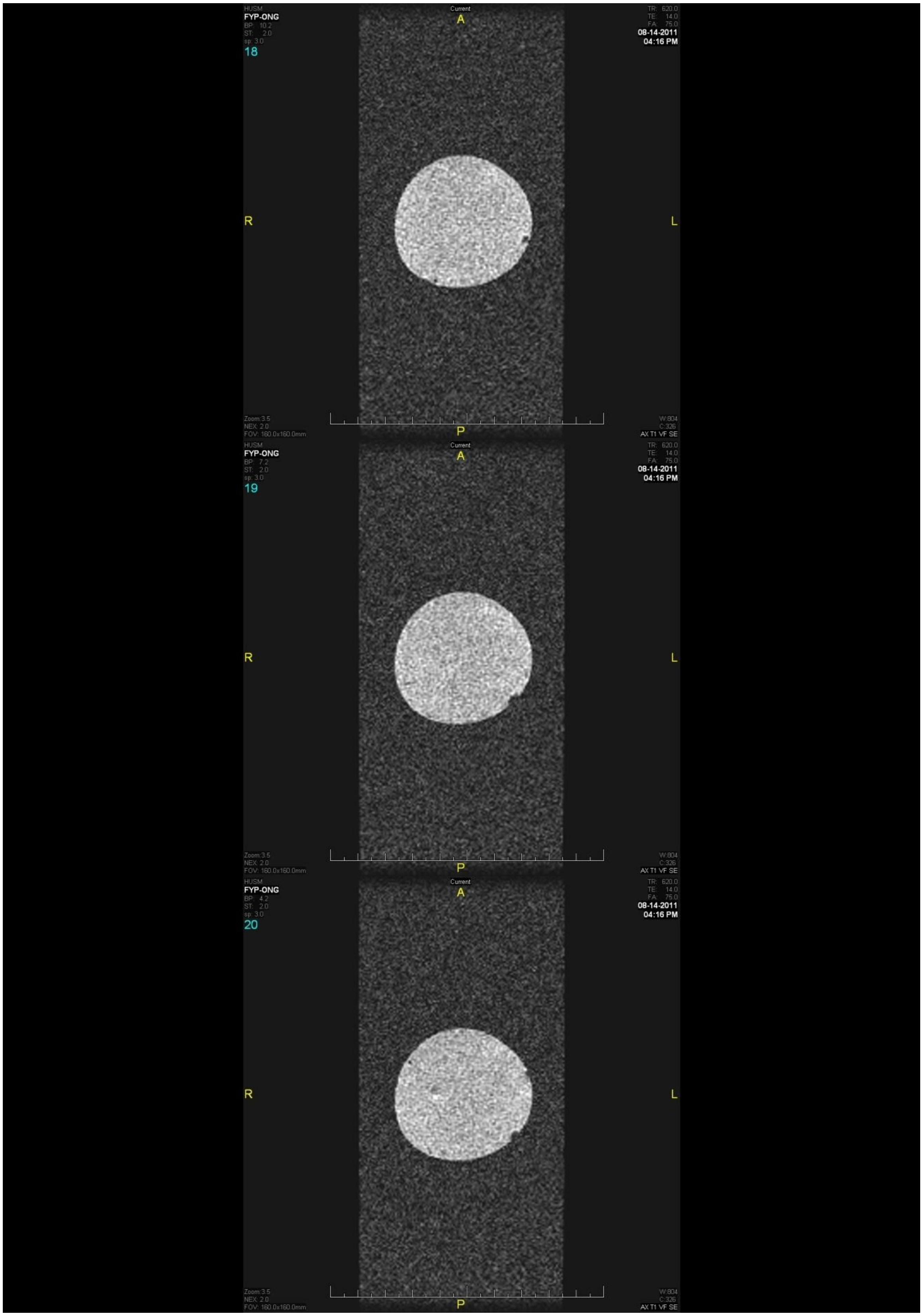
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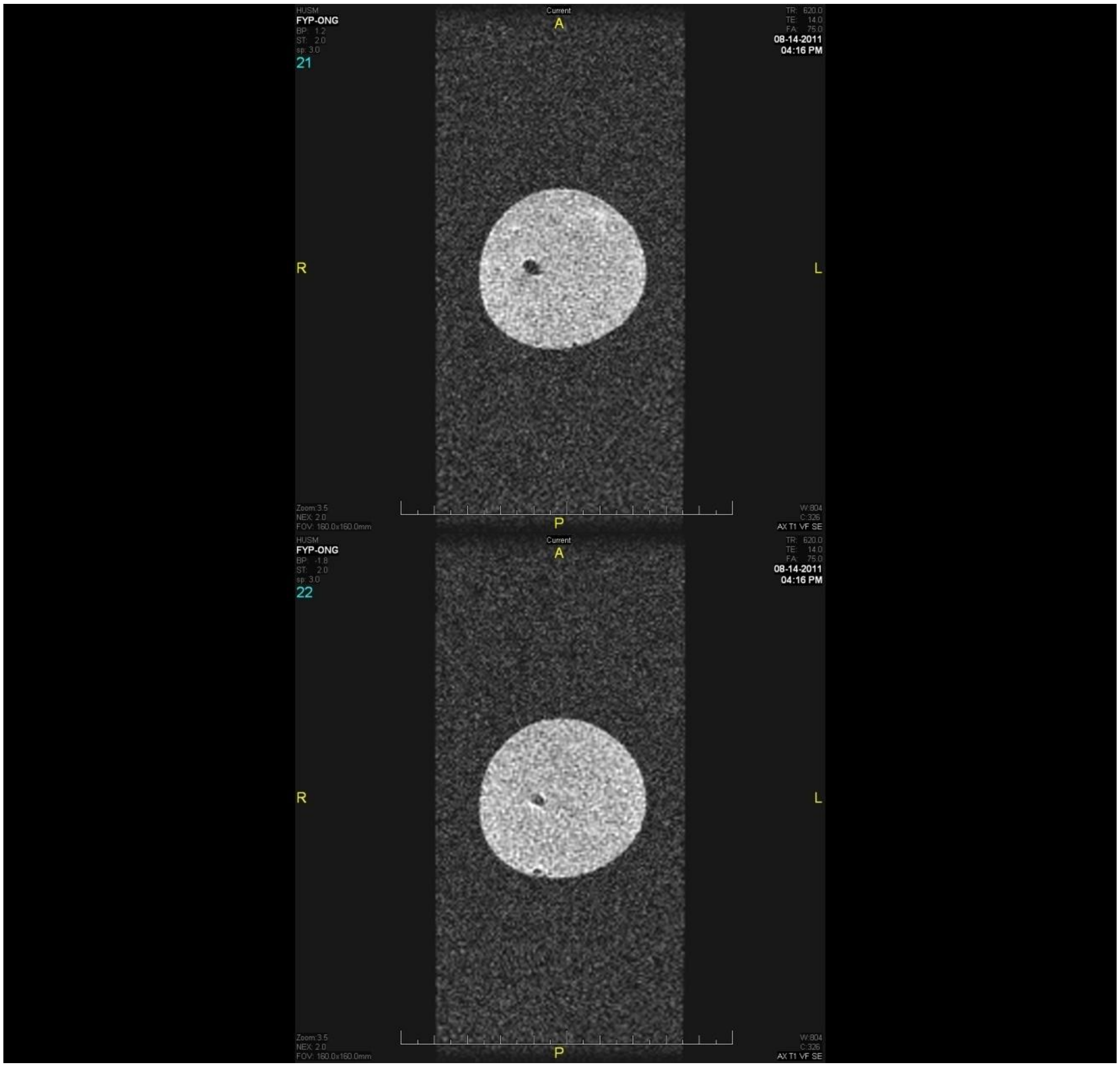
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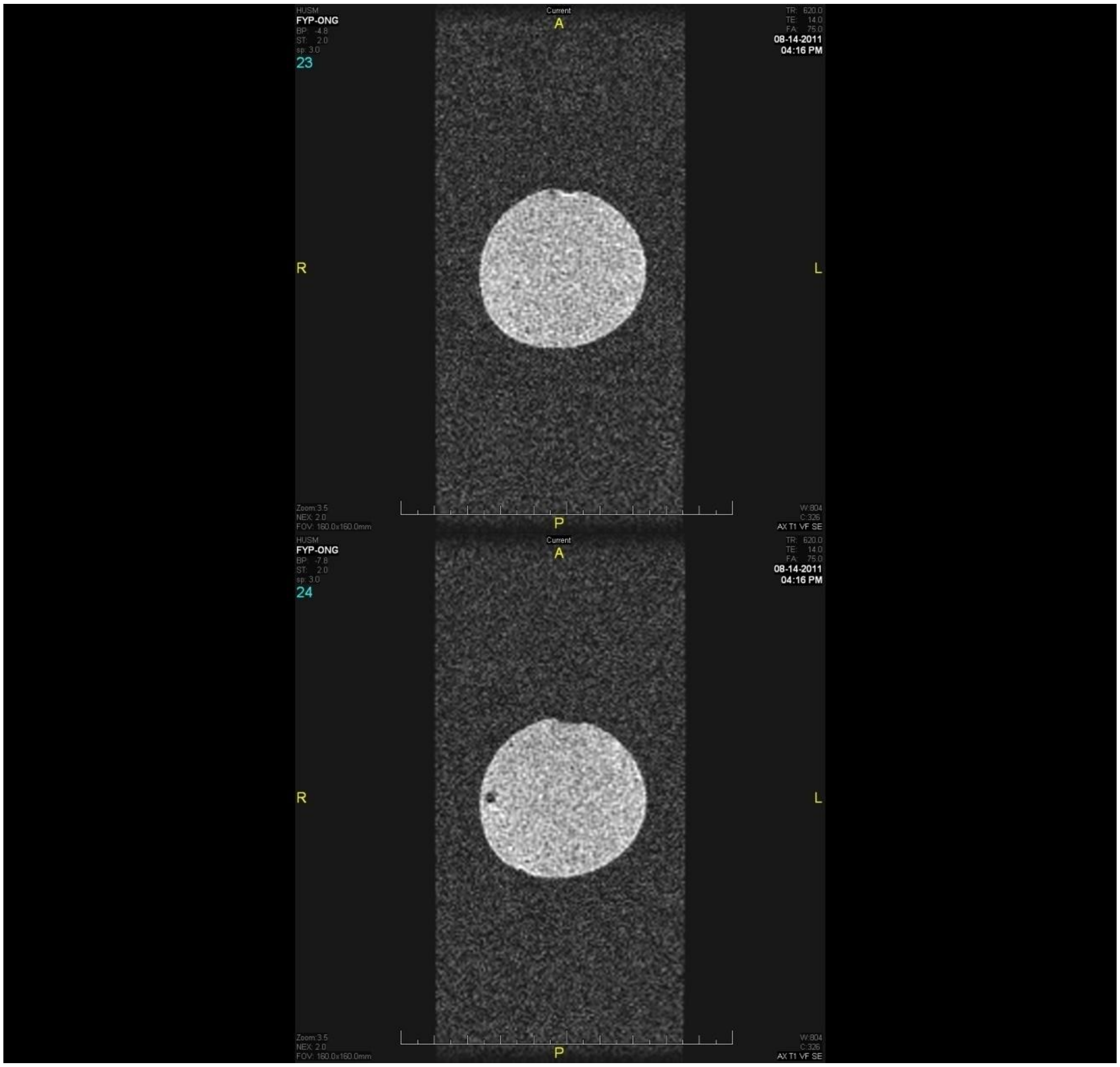
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APPENDIX 2

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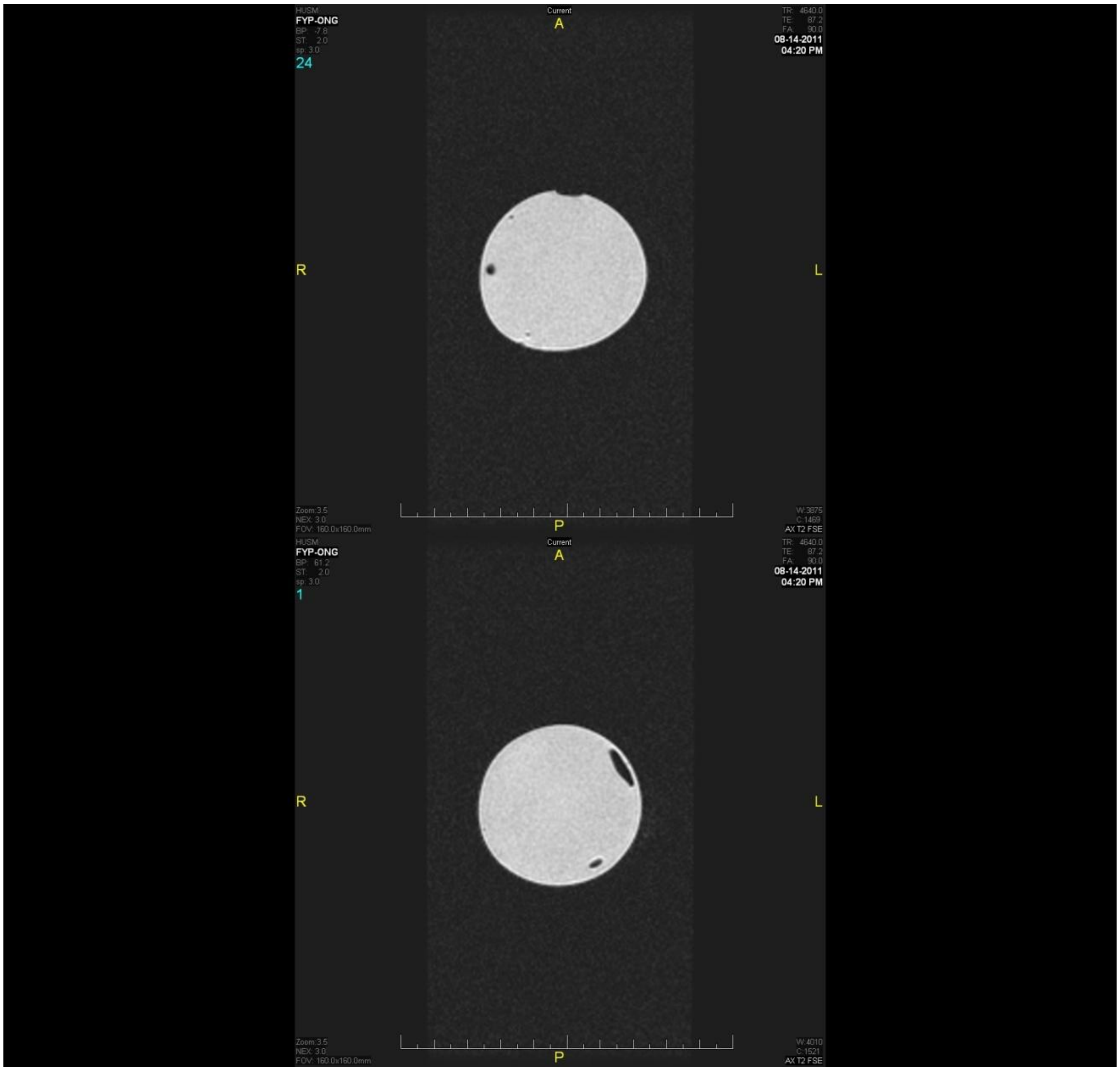

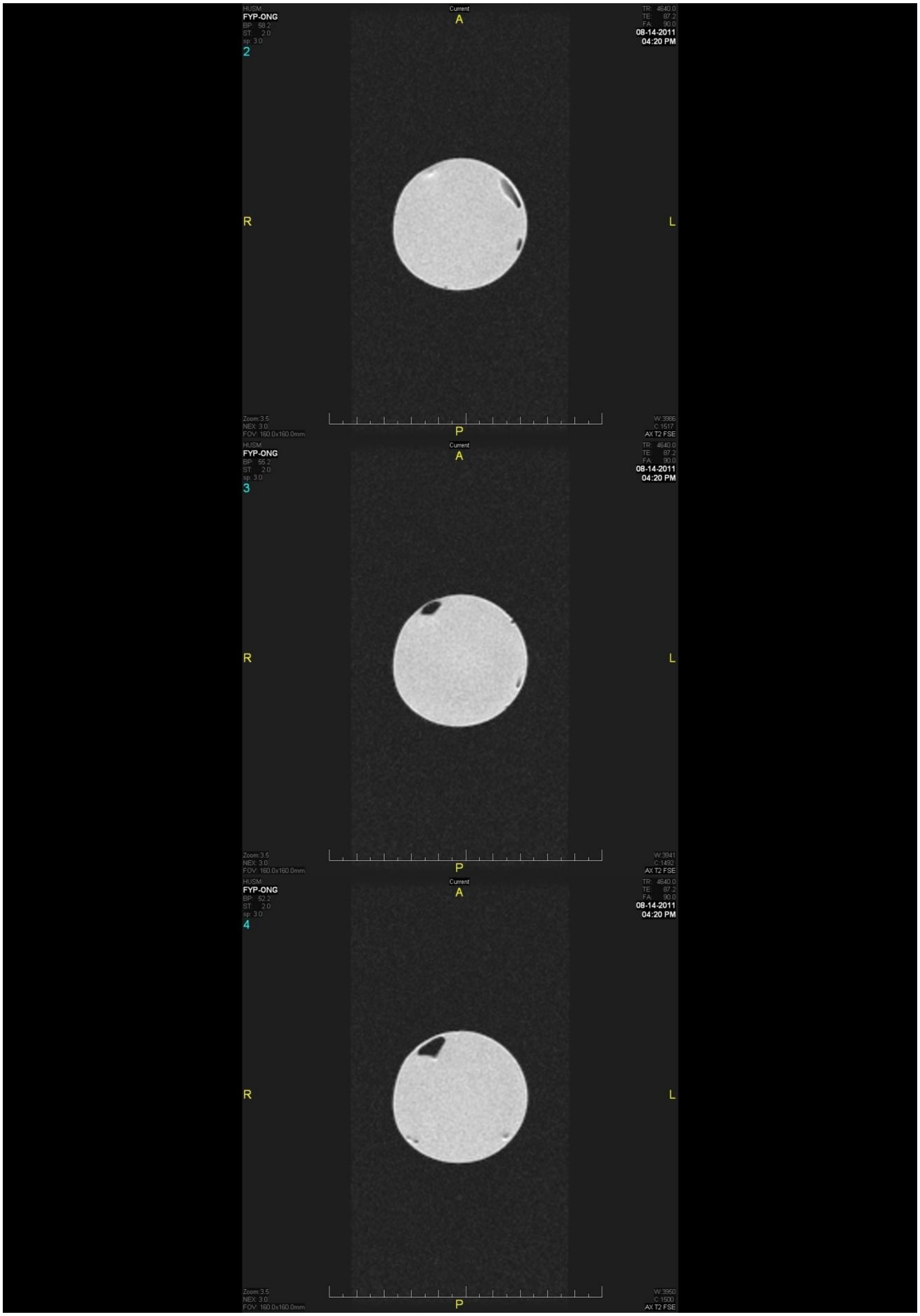
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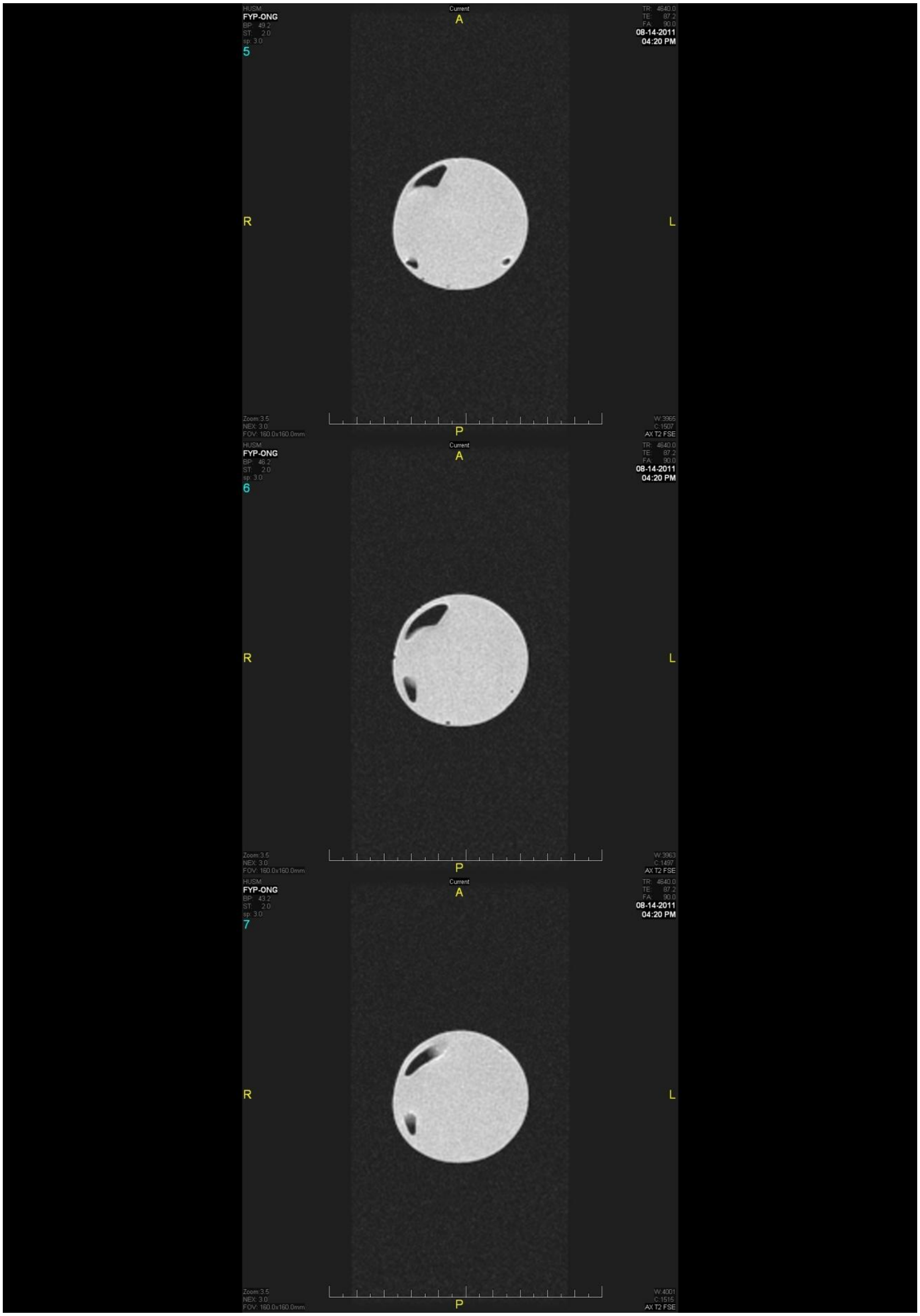
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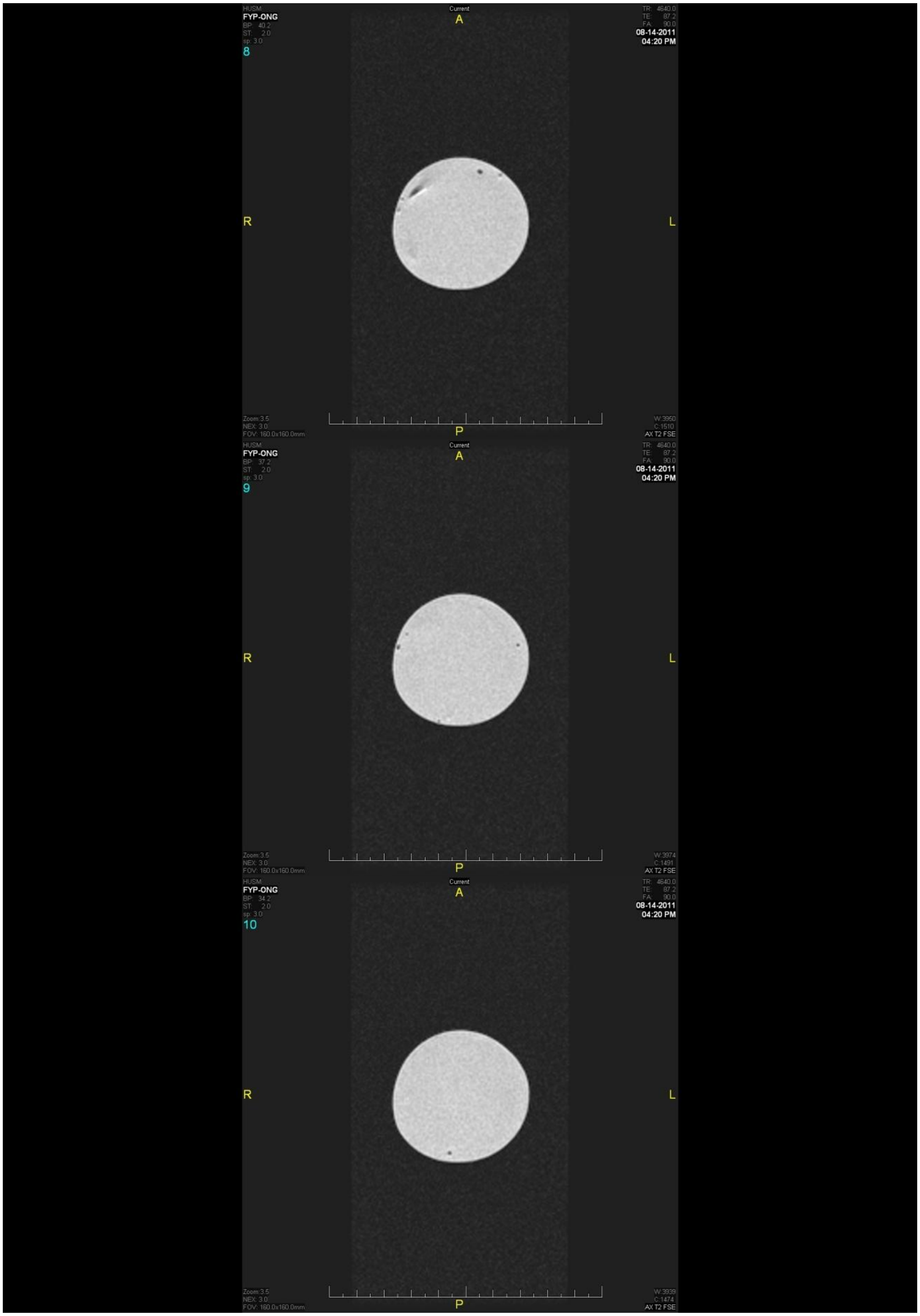
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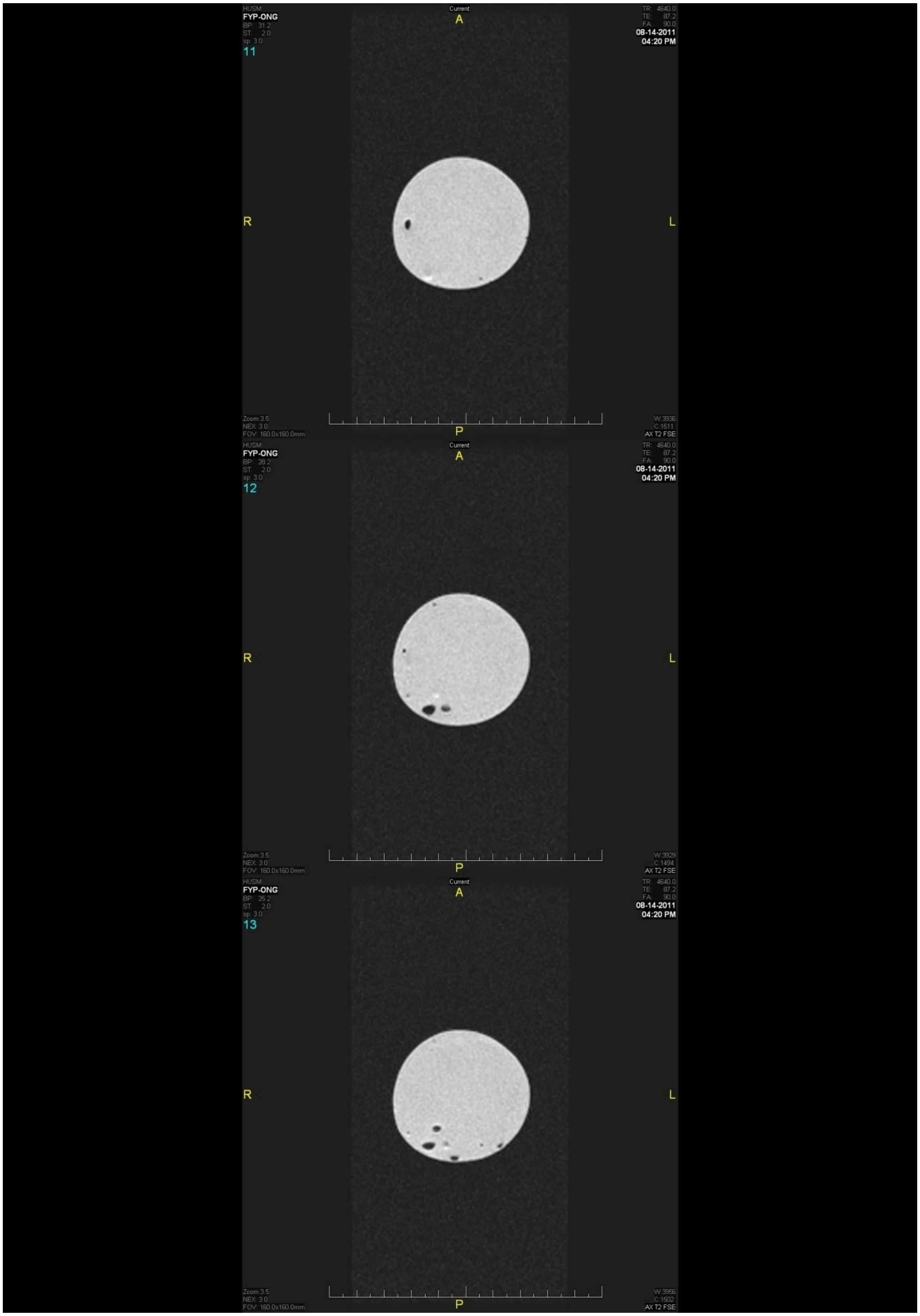
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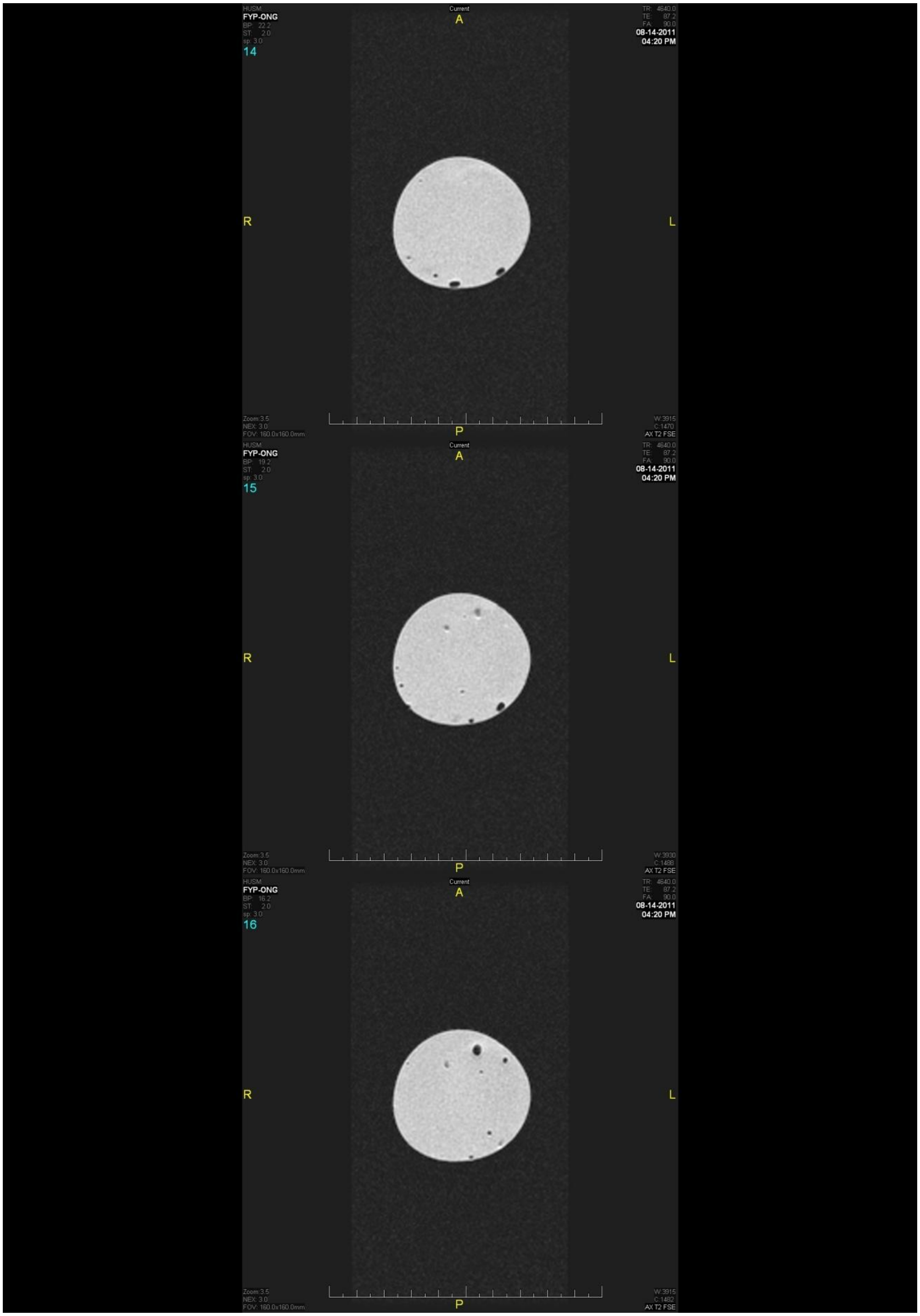
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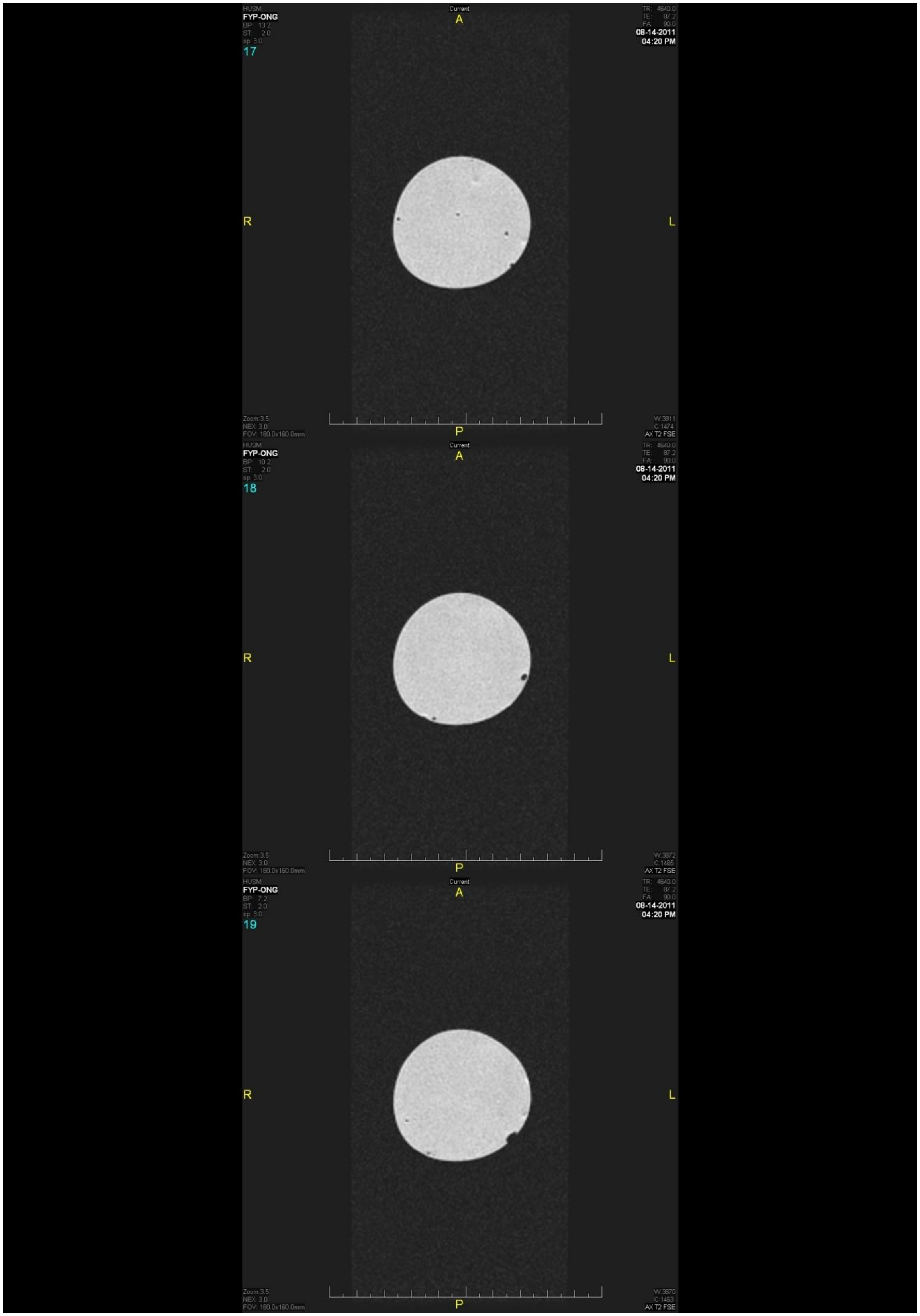
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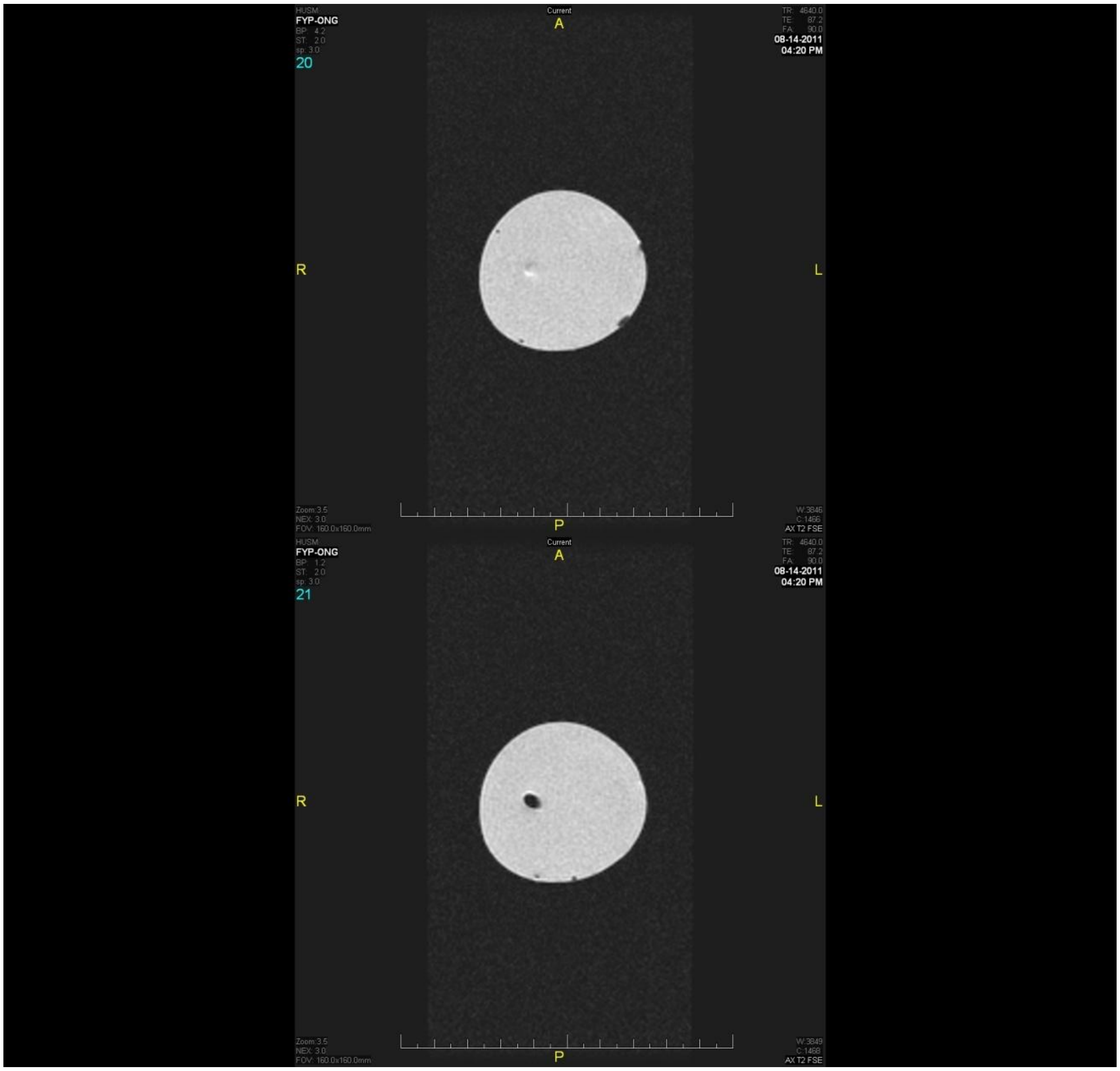

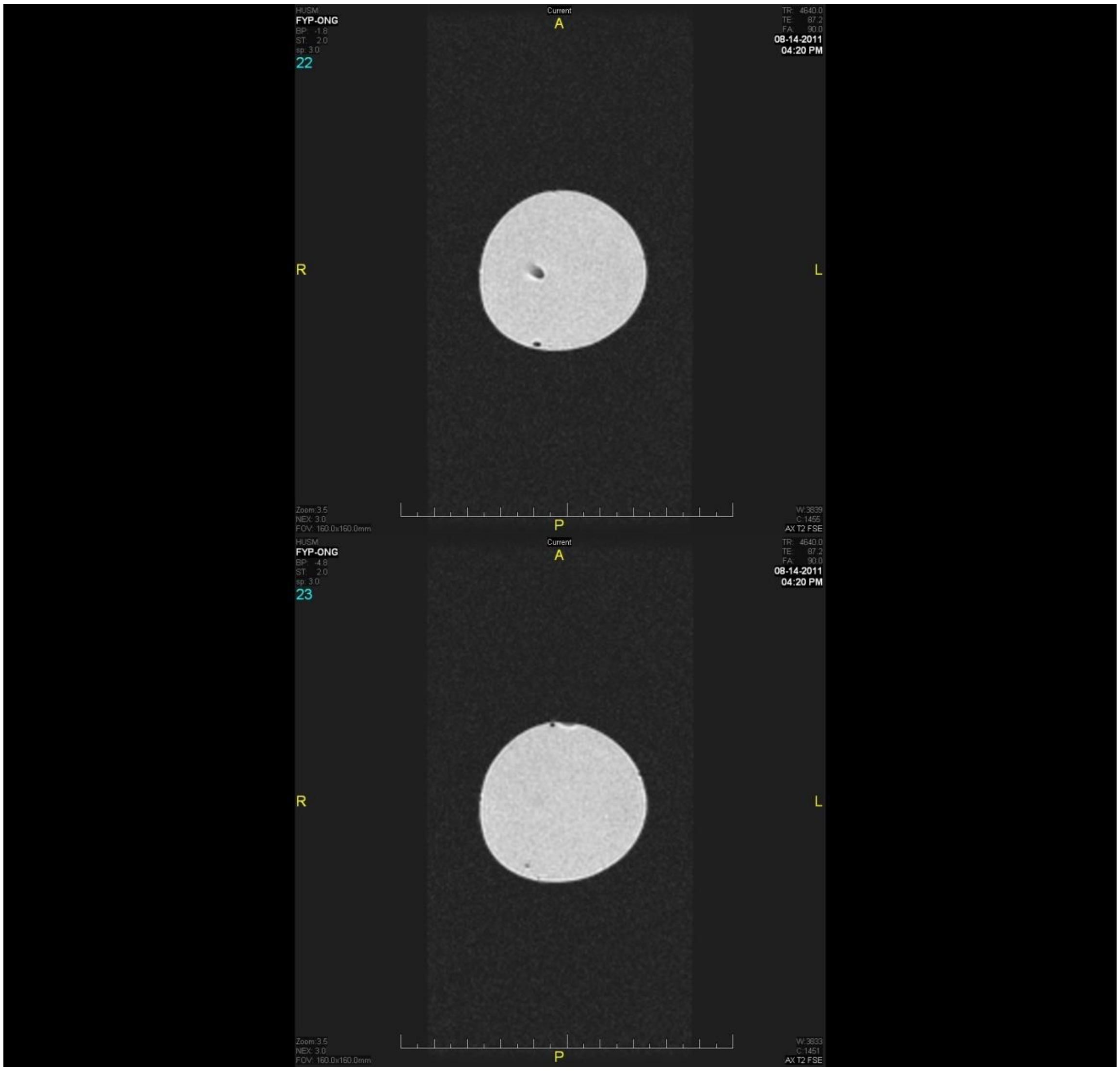
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