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COMPARISON OF PULSED X-RAY SOURCE DIGITAL RADIOGRAPHY WITH ISOTOPIC RADIOGRAPHY ON PIPE

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1. ABSTRACT

Southwest Research Institute (SwRI®) conducted a study to determine whether pulsed x-ray sources used in conjunction with amorphous silicon real-time imaging plates could provide equivalent radiographs to those obtained using isotopic sources with conventional radiographic film for inspection of schedule 40 steel pipe. Radiographic procedures for the two techniques were developed; test welds for 4-, 6-, 10-, 14-, and 16-inch-diameter pipes were fabricated; and radiographs were obtained using Level II RT personnel and Level III review. This paper presents a description of the radiograph systems used, the results obtained, and a comparison of operational characteristics. In addition, a discussion of ASME code acceptance of the amorphous silicon real-time imaging plates is also provided.

2. INTRODUCTION

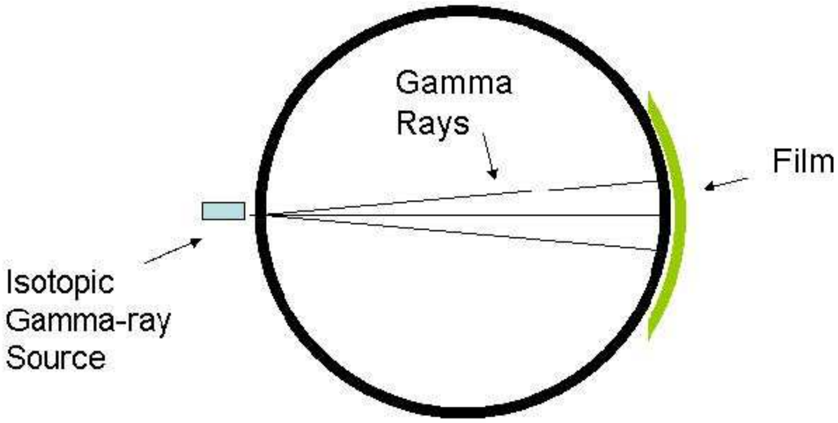
There is a push to minimize the use of isotopic sources throughout the world because often the sources are not adequately controlled and, subsequently, radioactive material can be inadvertently dispersed among the population. Providing alternative technologies for devices and products that do not require radioactive sources is one approach to minimize lost source incidences.

The approach suggested by SwRI was to identify an industrial sector that routinely uses isotopic radiation sources and to demonstrate that an alternative technology to isotopic sources can provide equivalent capability. One industrial sector that regularly uses isotopic sources to perform radiography of the pipeline welds is the pipeline industry. Ir^{192} (with a half life of 74.3 days and gamma ray energies of 310 keV, 470 keV, and 600 keV) is perhaps the most often used source for pipeline welds because the pipe wall thicknesses usually range between 0.25 and 0.4 inch. Sources are usually purchased with an activity of approximately 100 curies. The radiography conducted is usually double wall for detecting cracks, inclusions, and porosity in the welds as illustrated in Figure 1.

Figure 1.

An alternative approach would be to use pulsed x-ray sources, which provide radiation only when they are operating, if this technology was shown to provide equivalent capabilities. These sources are now capable of peak beam energies close to 300 kV with sufficient intensity output to be used for radiography of welds when used with a real-time imaging screen. The purpose of this work was to determine whether pulsed x-ray/real-time imaging would be equivalent to isotope/film radiography.

Isotopic source technology has a number of advantages over existing large x-ray sources. For example, the source technology employees a very compact geometrical envelop and does not require any electrical power. Conventional x-ray sources, on the other hand, require 220-V power and room for a cooling system (often water based). In addition, Ir^{192} provides very good radiographs, and this source has been used for many decades so that the knowledge base on its use is well accepted.



However, recent advancements have been made in pulsed x-ray sources that operate using 14.4-V battery power and have a geometrical envelop similar to the isotopic source shielded housing. For example, a common isotopic source is shown in Figure 2 and the XRS-3 is shown in Figure 3. The camera is approximately 15 inches by 6 inches by 4 inches wide and weighs approximately 40 pounds. This camera holds the isotopic source. It is connected to a drive cable that allows the isotopic source to be cranked out of the camera into a collimator placed on the pipe. The collimator is approximately 1 inch in diameter and 1½ inches long.

The conventional 300-kVp x-ray unit is nominally about 36 inches long, 14 inches in diameter, and weighs approximately 100 pounds. In addition, a cooler is needed, which is an additional box.

The XRS-3 is 14 inches by 4.5 inches by 7.5 inches and weighs 12 lbs. The specifications for the XRS-3 are also provided in Figure 3. Since it is a pulsed source, it does not require a coolant system. However, a pulsed x-ray source must be used with a real-time imaging plate. The question that this work was to address was "will a pipe inspection company be willing to utilize this technology for actual inspection work?"

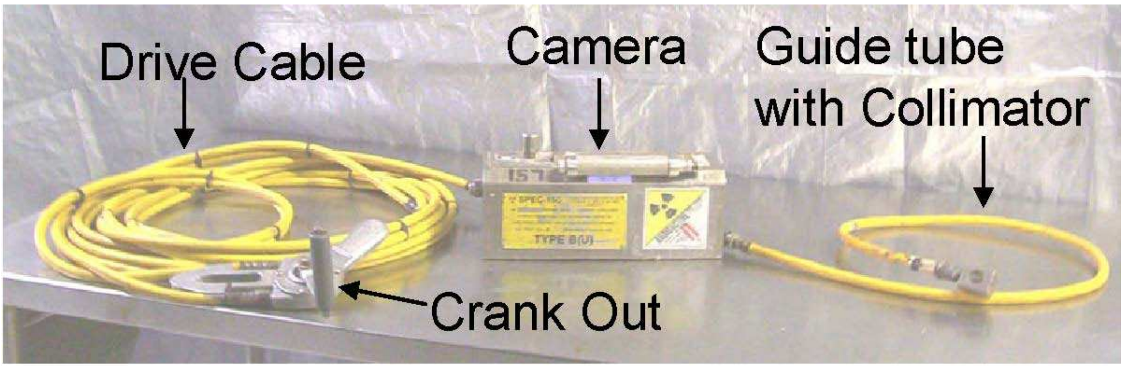


Figure 2.

The XRS-3 is a light duty X-ray machine that requires little maintenance. The modular design makes component replacement easy and cost effective. The DeWalt® 14.4V battery and battery charger are commercially available in retail stores worldwide.

Lead shielding in the XRS-3 protects the user by minimizing radiation leakage outside of the X-ray beam while a time delay button and remote cable allow the operator to move a safe distance from the unit when it is in operation. Visual and audible indicators in the unit alert the operator when the XRS-3 is activated. Also, the XRS-3 contains no radioactive material. The unit produces radiation only when it is pulsing.

Specifications

Size (Including battery pack)	14" (35.6 cm) x 4.5" (11.5 cm) x 7.5" (19.0 cm)
Weight (Including battery pack)	12lbs (5.4kg)
Output dose	4.0 mR/pulse max, 2.6 mR/pulse min, measured 12 inches from source
Pulse rate	15 pulse per second nominal
X-ray source size	1/8 in. (3 mm)
Maximum photon energy	270 KVP
X-ray pulse width	50 nanoseconds
Current draw	20 amps @ 13.4 volts
Power supply	DeWalt® 14.4 volt, removable, rechargeable, nickel-cadmium battery
Battery recharge time	1 hour with standard DeWalt® charger, 15 minute charger available
Number of pulses per battery charge	4000
Temperature range	-10 to 120 degrees F (-23 to 50 degrees C)
Maximum duty cycle	200 pulses every 4 minutes (3000 pulses per hr)
Warm-up	None required
X-ray leakage	3 mR per 100 pulses measured 2 inches behind the unit
Warranty	1 year limited warranty

Figure 3.

3. DISCUSSION OF TESTING

Procedures for both the isotopic and x-ray inspection techniques were developed and formalized. Five (5) pipe samples were used in the project (listed in Table 1). The pipes were welded so that naturally occurring flaws were produced in each weld, including porosity, slag, lack of penetration and lack of fusion. Ground truth radiographic data were collected using a panoramic x-ray technique where the source is placed inside the pipe and single wall radiographs were obtained.

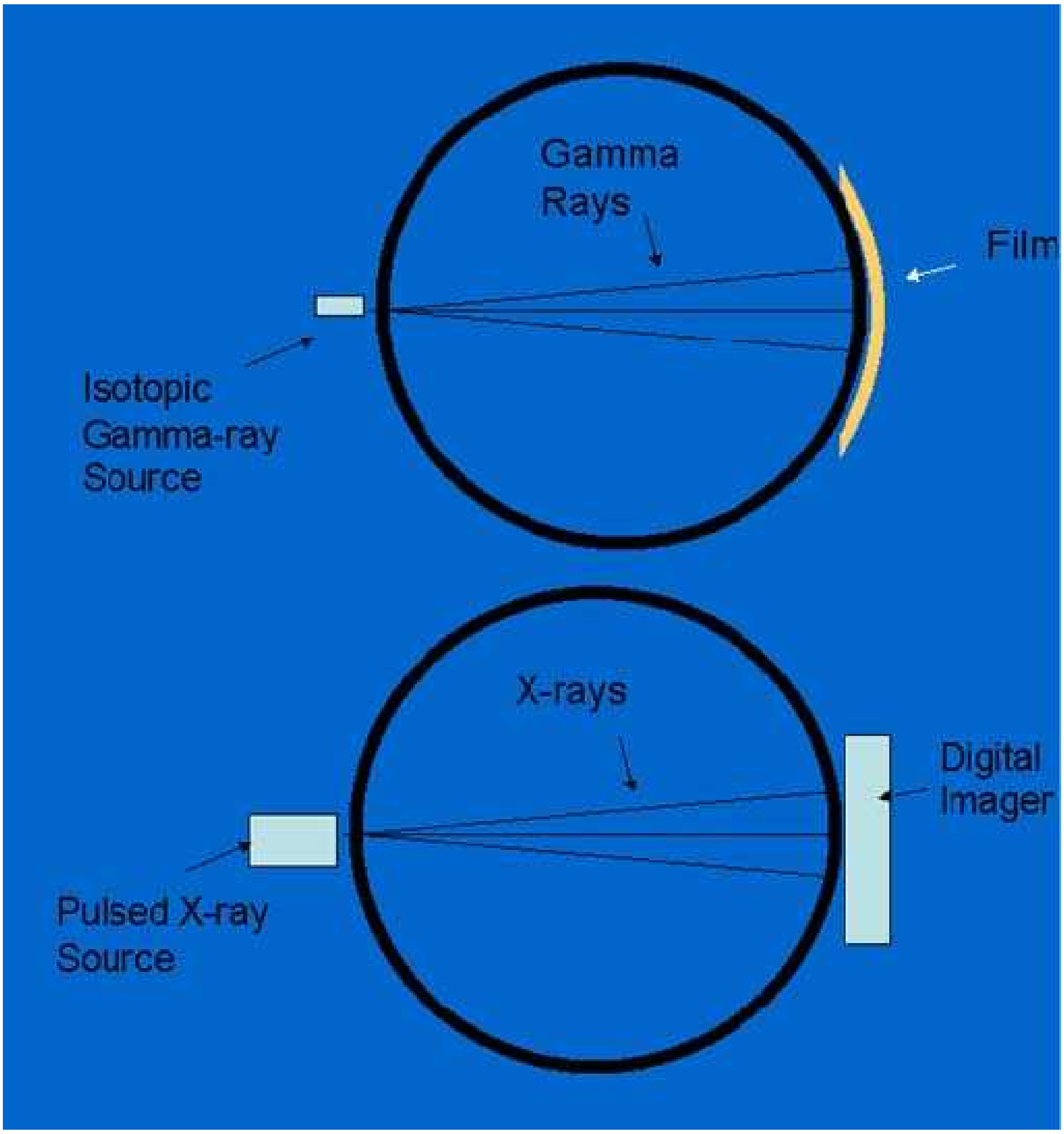
Table 1. Pipes Used for Pilot Demonstration

NOMINAL PIPE DIAMETER (inch)	PIPE WALL THICKNESS (inch)	PIPE LENGTH (inch)	LOCATION OF WELD AND TYPES OF DEFECTS
4	0.225	24	Weld located mid-length, lack of penetration, porosity
6	0.200	24	Weld located mid-length, lack of penetration, porosity

10	0.250	24	Weld located mid-length, lack of penetration, porosity, lack of fusion
14	0.350	24	Weld located mid-length, lack of penetration, porosity, lack of fusion
16	0.200	24	Weld located mid-length, lack of penetration, porosity, lack of fusion

Isotopic, double wall radiographs were conducted by an industrial radiography vendor for each pipe using an Ir^{192} source and D-4 type film, and the pulsed x-ray, real-time radiographs were done by SwRI using the XRS-3 x-ray source and the Vidisco real-time imaging system. Level III RT personnel read and compared both the radiographs and real-time images obtained.

The demonstration application was double wall radiography (where the source is placed on one side of the pipe and the film or imager is on the other side of the pipe) for a variety of pipe welds (ranging in diameters from 4 to 16 inches). This is illustrated in Figure 4. Examples of the pipes and defect locations are illustrated in Figure 5. Photographs showing how the single wall and double wall radiographs were obtained with the isotopic source and the pulsed x-ray source are shown in Figures 6 and 7.



Gamma
Rays
Film
Isotopic
Gamma-ray
Source
X-rays
Digital
Imager
Pulsed X-ray
Source

Figure 4.

Figure 5.

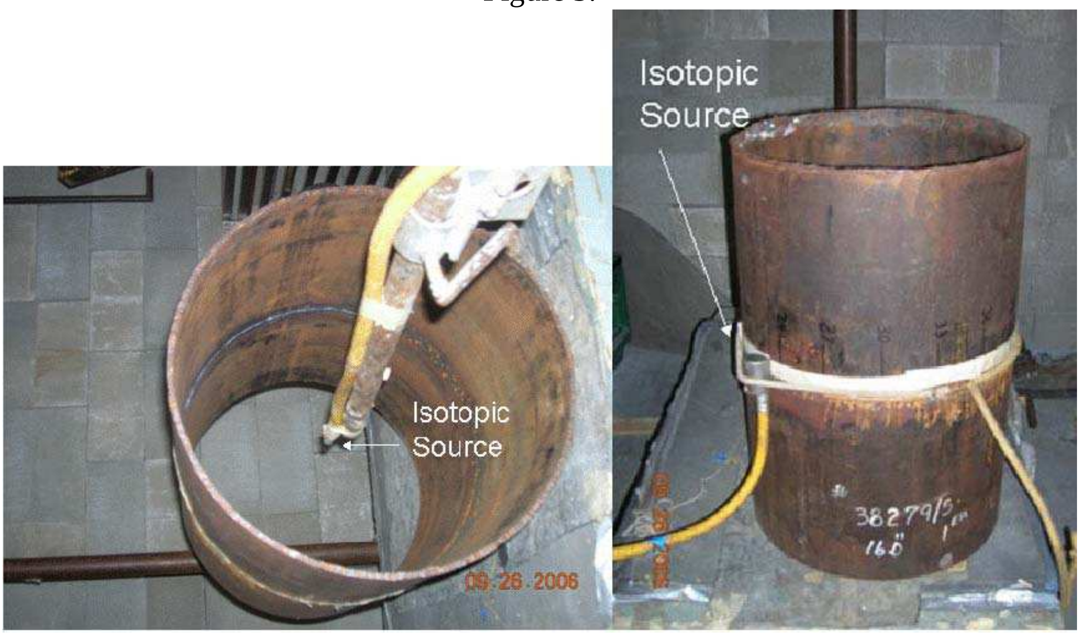


Figure 6.

Figure 7.

4. RESULTS

Single wall, isotopic radiographs were taken as a standard to verify defect detection. An example of a single wall radiograph is shown in Figure 8 (note that the film radiographs are reproduced by photographing the film on the light table, thus, the image quality presented in this paper is not as good as the radiography reader would observe on the light table). The double wall, isotopic radiographs were obtained using standard, normal field inspection techniques. An example of the double wall isotopic radiograph is shown in Figure 9. Then, double wall radiographs were taken using the pulsed 270-kVp XRS-3 source with a Vidisco real-time imaging system. An example image obtained using this approach is shown in Figure 10.

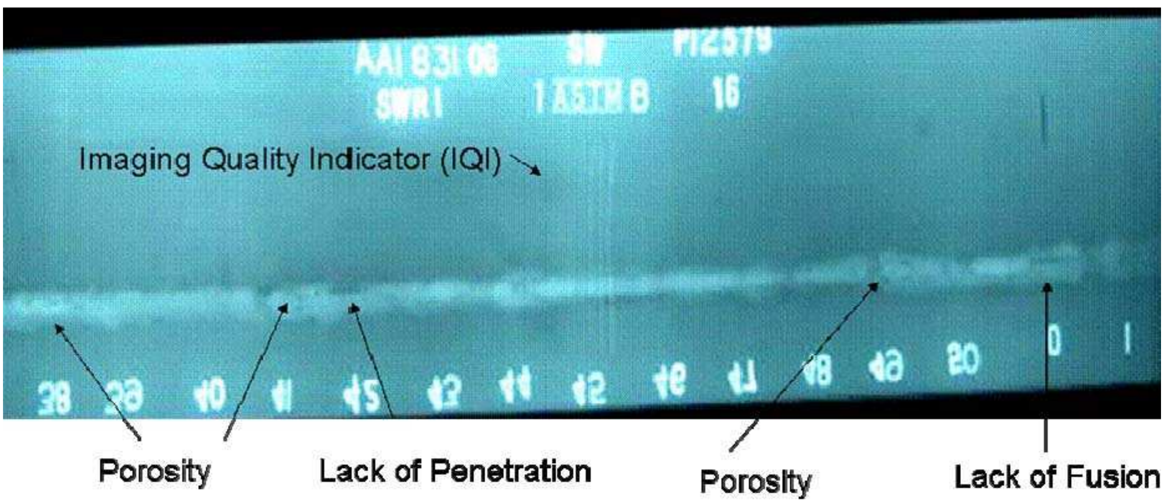


Figure 8.

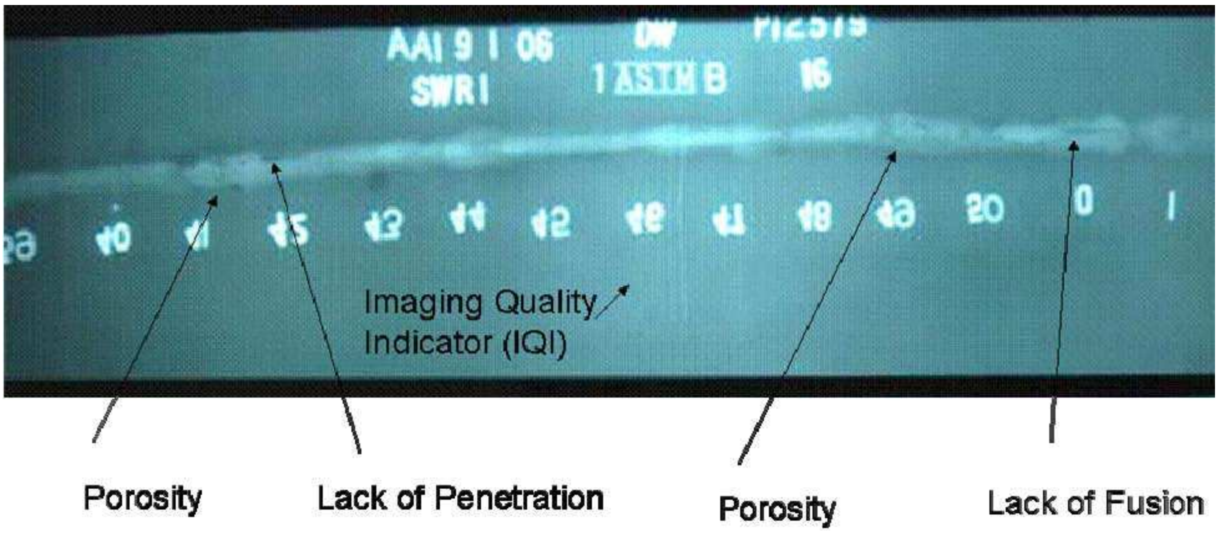


Figure 9.

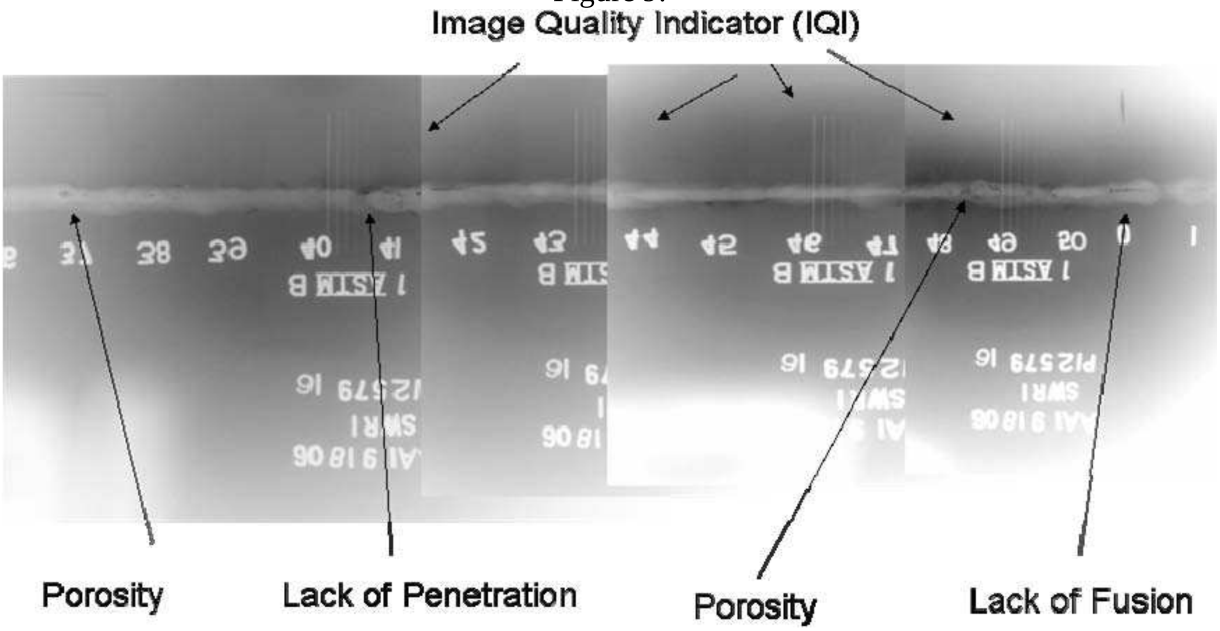


Figure 10.

The inspection procedures used to produce the double wall, isotopic radiographs required approximately 10 seconds exposure for each radiograph and 30 minutes for film development. For the pulsed x-ray source, real-time imaging system, each image required approximately 2 seconds of exposure and the image was observed within about 10 seconds. When comparing the film radiographs with the real-time images, it was obvious that the pulsed x-ray source, real-time images are very similar in sharpness and clarity to the isotopic radiography. The IQI wires (0.032 inch, 0.026 inch, 0.020 inch, 0.016 inch, 0.013 inch, and 0.010 inch) were all detected using both techniques.

5. CONCLUSIONS

The goal of this work was to demonstrate a radiography technology for inspection of pipe welds that does not require the use of isotopic sources. The technical approach followed included developing procedures for inspection of schedule 40 pipe in the range of 3 to 16 inches in diameter; producing radiographs with both an Ir^{192} source and a pulse, battery operated, portable x-ray source with a peak x-ray energy of 270 kV; and comparing the results obtained as well as the operational issues associated with using the x-ray source compared to the isotopic source. The results indicated that the quality of the radiographic information obtained from both approaches is equivalent. A comparison of the various technologies in terms of fielding issues is shown in Table 2. Issues addressed included differences in the procedures in terms of time, set up, personnel required, source cost and labor/cost associated with following regulations, ease of use, and a discussion of the likelihood of successfully transferring this technology to industry.

Table 2. Comparison of Isotopic Radiography and Pulsed X-ray Radiography

CHARACTERISTICS	ISOTOPIC SOURCE/FILM	PULSED X-RAY SOURCE/REAL-TIME IMAGER
Cost of the source	$5,000	$5,000
Cost of portable film developing unit	$20,000	Not required
Cost of imaging device	$1-$22/piece of film	$60,000 for real-time imaging screen
Cost of film processing chemicals for each job (consider a job being 50 radiographic films)	3 hours of labor and $200 in chemicals	Not required
Time required to get images from a 16-inch pipe	10 minutes for x-raying and 30 minutes for film development	10 minutes for x-raying and 6-10 minutes for reviewing real-time data
Cost of chemicals	$200 or more/week	None
Requirements for electrical power	None	Pulsed x-ray source is operated using 14.4V battery, imaging device requires battery, computer has its own battery….all of these batteries require AC power to recharge
Image quality	Can detect all wires of an ASME B wire IQI	Can detect all wires of an ASME B wire IQI
Number of shots to cover 10 linear inches of weld	1 shot	Approximately 3- 4 shots
Acceptance of technology	Isotopic radiography has been a standard for more than 50 years	Pulsed X-ray source with real-time imager has been in the field on the order of a few years

Source size that must be placed close to the pipe	0.25 inch diameter by 0.75 inch long	14 inch by 4.5 inch by 7.5 inch
Source weight	Less than 1 pound	12 pounds
Power requirement	None	Battery powered
Source energy	Gamma ray lines at 0.31, 0.47, and 0.6 MeV for Ir^{192}	Up to 270 kV
Personnel required for use	Two radiographers are required when using isotopic sources	In many states in the U.S., only one radiographer is required when using an x-ray source

6. LIST OF FIGURES