APR 27 2000

ENGINEERING DATA TRANSMITTAL

Page 1 of 1
1. EDT 629022

2. To: (Receiving Organization) Distribution		3. From: (Originating Organization) Process Engineering		4. Related EDT No.: N/A	
5. Proj./Prog./Dept./Div.: Spent Nuclear Fuel Project		6. Design Authority/ Design Agent/Cog. Engr.: D. R. Duncan		7. Purchase Order No.: N/A	
8. Originator Remarks: For approval and release of feasibility study for usage of software system for scrap analysis.				9. Equip./Component No.: N/A	
				10. System/Bldg./Facility: Fuel Retrieval System	
11. Receiver Remarks: 11A. Design Baseline Document? ☐ Yes ☒ No USQ Screening Number: K-00-0530 JRD 4/26/00				12. Major Assm. Dwg. No.: N/A	
				13. Permit/Permit Application No.: N/A	
				14. Required Response Date:	

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Design- nator	Reason for Trans- mittal	Origina- tor Dispo- sition	Receiv- er Dispo- sition
1	SNF-6143	N/A	0	Machine Vision Tests for Spent Fuel Scrap Characteristics	N/A	1,2	1	/

16. KEY			
Approval Designator (F)	Reason for Transmittal (G)		Disposition (H) & (I)
E, S, Q, D or N/A (see WHC-CM-3-5, Sec. 12.7)	1. Approval 2. Release 3. Information	4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)									
(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.	(J) Name	(K) Signature (L) Date (M) MSIN
		Design Authority							
		Design Agent							
1	1	Cog. Eng. D.R. Duncan	<i>[Signature]</i>	4/25/00	R3-86				
1	1	Cog. Mgr. J.R. Frederickson	<i>[Signature]</i>	4/26/00	R3-86				
		QA							
		Safety							
		Env.							

18. Signature of EDT Originator <i>[Signature]</i> 4/25/00		19. Authorized Representative for Receiving Organization <i>[Signature]</i> 4/26/00		20. Design Authority/Cognizant Manager <i>[Signature]</i> 4/26/00		21. DOE APPROVAL (if required) Ctrl. No. N/A ☐ Approved ☐ Approved w/comments ☐ Disapproved w/comments	
---	--	--	--	--	--	---	--

SNF-6143
Revision 0

Machine Vision Tests for Spent Fuel Scrap Characteristics

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

Fluor Hanford
P.O. Box 1000
Richland, Washington

Machine Vision Tests for Spent Fuel Scrap Characteristics

K. Hingst
R. B. Schoenberger
Agris-Schoen Vision Systems, Inc.

W. E. Berger
M. G. Plys
Fauske & Associates, Inc.

Date Published
May 2000

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

Fluor Hanford
P.O. Box 1000
Richland, Washington

4/26/00
Release Approval Date

TRADEMARK DISCLAIMER

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy. Available in paper copy and microfiche.

Available electronically at <http://www.doe.gov/bridge>. Available for a processing fee to the U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865-576-8401
fax: 865-576-5728
email: reports@adonis.osti.gov(423) 576-8401

Printed in the United States of America

Total Pages: 29

SNF-6143, MW0

FAI/00-12, Revision 1

***MACHINE VISION TESTS FOR
SPENT FUEL SCRAP CHARACTERISTICS***

Prepared for:

**Darrel R. Duncan
Hanford Spent Nuclear Fuel Project
200 East Building MO 285
Richland WA 99352**

Prepared by:

**William E. Berger and Martin G. Plys
Fauske & Associates, Inc.
16W070 West 83rd Street
Burr Ridge, IL 60521**

And

**Robert B. Schoenberger and Kai Hingst
Agris-Schoen Vision Systems, Inc.
4715-B Eisenhower Ave.
Alexandria, VA 22304**

March, 2000

TABLE OF CONTENTS

	<u>Page</u>
1.0 PURPOSE	1
2.0 BACKGROUND AND APPLICATION	1
3.0 MACHINE VISION SYSTEM	3
4.0 TEST SPECIMENS AND CONFIGURATION	4
5.0 TEST DESCRIPTION	7
5.1 General Description	7
5.2 Broad Field of View Tests	9
5.3 Narrow Field of View Tests	13
5.4 Orthogonal Grid Tests	15
5.5 Principal Dimension Determination	19
5.6 Clad vs. Unclad Determination	20
5.7 Discussion	21
6.0 CONCLUSIONS	22

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
2-1	Sorting Table Partial Plan View	2
4-1	Camera View Plan	6
5-1	Camera #7	9
5-2	Tests AO1, AO2, and AO3 Configuration	10
5-3	Example Specimen Layout	10
5-4	Example Specimen Identification	11
5-5	AO1 Deviation vs. Height	12
5-6	AO2 Deviation vs. Area	13
5-7	Narrow Field View Example	14
5-8	Narrow Field Deviations	15
5-9	Orthogonal Grid	16
5-10	Orthogonal Grid Side View	16
5-11	Orthogonal Grid Top View	17
5-12	Camera Angle	19

LIST OF TABLES

<u>Table</u>	<u>Page</u>
4-1 Test Sample	5
5-1 Test AO1 Results	11
5-2 Narrow Field View Results	14
5-3 Orthogonal Grid Results	18
5-4 Test AO1 Dimension Deviations	20
5-5 Clad Fraction Areas	21

1.0 PURPOSE

The purpose of this work is to perform a feasibility test of a Machine Vision system for potential use at the Hanford K basins during spent nuclear fuel (SNF) operations. This report documents the testing performed to establish functionality of the system including quantitative assessment of results. Fauske & Associates, Inc., which has been intimately involved in development of the SNF safety basis, has teamed with Agris-Schoen Vision Systems, experts in robotics, tele-robotics, and Machine Vision, for this work.

2.0 BACKGROUND AND APPLICATION

Metallic SNF is currently stored at the Hanford K-Basins in canisters. This fuel will be removed, cleaned, sorted and distributed into fuel and scrap baskets as a first step toward dry storage. In the K-basins when fuel is removed from canisters it will be placed on a sorting table for inspection and disposition (Figure 2-1). Pieces less than $\frac{1}{4}$ " in principal dimension will be vacuumed and treated as sludge. Pieces greater than 3" in principal dimension are placed in fuel baskets, and remaining pieces - between $\frac{1}{4}$ " and 3" - are placed in scrap baskets. Coarse scrap has a principal dimension greater than 1" and less than 3", while fine scrap has a dimension greater than $\frac{1}{4}$ " and less than 1".

Fine and coarse scrap pieces are the focus of the Machine Vision application, and we desire to determine the following scrap characteristics using Machine Vision:

1. Count the number of pieces,
2. Determine if a piece is coarse or fine (measure principle dimension),
3. Determine surface area, and
4. Determine the fraction of surface area which is reactive, i.e., unclad metallic uranium.

Figure 2-1: Sorting Table Partial Plan View.

The Machine Vision system is intended to perform these functions with minimal intrusion in currently planned operations.

At the present time, fuel sorting operations including Machine Vision are conceived as follows: At the north end the fuel will be dumped onto the sloping table where it will rest against the angle iron. The north end manipulator will remove the pieces exceeding 3" and place them on the sloping table for storage in the fuel basket. Currently the plan is for the operators to determine if a part is larger or smaller than 3" by comparing it to the jaw opening which is 3". Machine Vision can perform this determination, but demonstrating this was beyond the scope of the current task. If it is necessary to remove the inner element from the outer fuel element, this will first be performed using the center section of the table. It is at the center section that the Machine Vision system will investigate the remaining debris to determine if it will be categorized as coarse or fine fuel. The large pieces, greater than 3" are placed in the fuel basket by a south end manipulator. The duration for actual use of the south end manipulator exceeds that of the north end manipulator. Therefore, actions required to apply the Machine Vision process will not impede or delay the overall operation. Furthermore, once pictures are taken by the system, actual processing can be performed at a later time to determine the desired data. It is of interest to note that the computer image files can be maintained as a permanent record of the canister content.

3.0 MACHINE VISION SYSTEM

A Machine Vision system consists of camera(s) whose output is sent to a PC where a frame grabber card receives the camera analog signal, converts this to a digital signal, and stores the image. This captured view can then be analyzed by software to quantify scrap characteristics. The intent of the application for Hanford is to achieve the four objectives outlined in Section 2.0. Given a specially prepared known background relating to color, the software can compare the characteristics of each pixel* in the image to the characteristics of the

* "Pixel" is short for "Picture Element" and is equivalent to the dots on a laser or ink jet printer. A standard image from a video camera such as the ones used at Hanford is 640 horizontal pixels by 480 vertical pixels.

background and identify objects whose color content is not that of the established background. The result is a captured image of the sample. This is similar to the technology used on the nightly news to put a weather map behind the meteorologist. This special background was designed to permit both bright and dark objects to be analyzed. By looking at the image and the pixels occupied by the object, the software can determine the area, the perimeter, and the principal dimension of the object

Principal components of the Machine Vision system are the cameras, the frame grabber card, PC and related software as follows:

Cameras:	Those presently deployed for SNF operations
Frame Grabber:	Imagenation PXC200 or Integral Technologies Flashbus
Software:	X Caliper 4
PC:	Windows NT, 64 MB Ram, Pentium II processor

4.0 TEST SPECIMENS AND CONFIGURATION

In advance of the test, specimens and backgrounds were prepared. Test specimen scrap pieces were fabricated by FAI in accordance with Table 4-1. Once completed, the measurements for each piece were recorded using a digital calibrated caliper.

Two background configurations were prepared. The first was a 15" x 27" anodized blue aluminum sheet with a 3" x 3" rectangular grid superimposed as sketched in Figure 4-1 (photos of the background appear later).

Table 4-1: Test Sample.		
Sample	Picture	Description
1		1/4" cube all black surfaces.
2		1/2" cube with sides of varying color.
3		0.9" cube with sides of varying color.
4 & 5		Cube with principle dimensions of 1.0" and 1.1" varying color on sides.
6		Cube with notch on top, principle dimension of 1/2", sides of varying color.
7		Cube with notch on top principle dimension of 1/4". All black surfaces.
8		Arc piece with principle dimension of 1".
9		Wedge piece (big).
10		Wedge piece (small).
11		Arc piece ~ 300° arc.
12		Circular piece with wedge missing.

Figure 4-1: Camera View Plan.

The six views actually overlap at neighbor boundaries by slightly more than 3" on each side. The reason for this is that any object 3" or shorter will always be completely contained in at least one camera view and never be cut off in all views. The software will account for this overlap and make sure to not double count any item.

A second background, also of blue anodized aluminum, was constructed as three sides of a 3" x 3" x 3" cube with a 1/4" grid.

Construction of these backgrounds was performed in a controlled manner. The first grid plates were fabricated using a numerically controlled milling machine. During the manufacturing, it was necessary to hold the aluminum down to the bed of the milling machine with a metal strap running the length of the aluminum. This was necessary due to bowing of the material and the minimal depth of the engraving of the text and gridlines.

The grid contained grid lines which were spaced 3" apart. Each 3" x 3" section also contained two copies of the section's coordinates: letter and two digits. Following the formation of the grid, the aluminum plate was anodized blue. Green was also examined, but it reflected

nearly equal amounts of blue and green, whereas the blue reflected twice as much blue as green, making the ratio not equal to 1, and hence, more recognizable.

The cubicle was manufactured in a similar manner, but with a smaller grid spacing and letters only along the edges.

5.0 TEST DESCRIPTION

5.1 General Description

These tests with the Machine Vision system were performed over the period from January 13, 2000 through January 18, 2000 at the Hanford Building 305 Laboratory. A significant amount of test data was accumulated over this period to help in determining the effectiveness of the approach.

Building 305 contains a pit and a sorting table that is replica of the arrangement used in the K-Basin, where the actual sorting of the fuel will take place. The test was performed using the pit and the cameras.

Key to the operation of the Machine Vision system is the definition of the background and the focus of the camera. The background that was used was a 15-in. by 27-in. anodized blue aluminum sheet with 3-in by 3-in. grid markings. The camera was then adjusted to place in its field of view approximately the first third of the grid. The nine specimens were then located on the grids and recorded. An image was then captured and stored through the frame grabber card. The specimens were then rotated and again an image captured, and finally they were rotated a third time and the image captured. These were identified as tests AO1, AO2, and AO3.

The focus of the camera was then readjusted to narrow the field of view to just four grid spaces. The nine specimens were rotated through these four grids at various sides and images captured. These were identified as tests CO1, CO2, CO3, DO1, DO2, DO3, EO1, and EO2.

A second background in the form of a cube was also developed which included a grid on the three orthogonal sides with a 0.25 inch markings. This configuration would allow multiple cameras to take images of three sides, thus reducing the need to rotate the object. Images were taken from the top and from the side for all the specimens and for all of their sides. Increased magnification linearly improves accuracy. By using a smaller field of view, approximately 4" x 3", compared to a field of view of approximately 12" x 9", the single axis accuracy is increased by a factor of approximately 3.

The grid markings perform two functions. First, they allow the computer to auto-calibrate scale factors for making measurements and to determine parallax and lens distortion. Second, the markings allow an operator to quickly determine the approximate size of an object by eye.

In addition to these tests, a number of separate effects tests were performed where the lighting, distances, backgrounds, and other configurations were varied in order to determine an optimization of configuration factors. These tests will be important in finalizing the best method for taking the images with the optimum results.

Data for all of the tests was taken using camera number 7, shown in Figure 5-1. It is key to note that the camera has a stop which prevents it from tilting completely down. Thus, the camera is not perpendicular to the background.

Figure 5-1: Camera #7.

5.2 Broad Field of View Tests

For tests AO1 through AO3, the test configuration is as shown in Figure 5-2. At the bottom of the picture is the 15" by 27" background with test samples in place for the capture of an image. The close-up view of the test specimens and the background are shown in Figure 5-3. Captured images outlining the shapes for determination of dimensions are depicted in Figure 5-4. An outline image, like that of Figure 5-4, is used to calculate the dimensions and areas. Highlighted sections are based on the software evaluating the images and selecting that which is not the background or shadows. Results from Test AO1 are presented in Table 5-1, where negative deviation indicates overestimation of true area (true area less than estimated area).

Figure 5-2: Tests AO1, AO2, and AO3 Configuration.

Figure 5-3: Example Specimen Layout.

Figure 5-4: Example Specimen Identification.

Table 5-1: Test A01 Results.

TEST A01 Dimensions						
Grid	Sample	Side	Calculated		Area Mach. Vis. (in ³)	% Deviation
			Perim. (in)	Area (in ²)		
A01	1	Back	1.039	0.067	0.0729	- 8%
A02	2	Right	2.044	0.261	0.352	- 34.80%
A03	3	Top	3.481	0.757	0.999	- 31.91%
A04	4	Front	3.784	0.895	1.309	- 46.27%
B01	6	Top	1.999	0.238	0.257	- 7.85%
B02	10	Top	1.13	0.080	0.069	13.54%
B03	9	Right	2.826	0.499	0.428	14.25%
B04	11	Front	4.168	1.086	1.152	- 6.10%
C01	12	Top	4.43	1.227	1.047	14.64%

The table shows that the deviations are within the expected + or – 50%. It should be noted that the test specimens varied in height when measured from the background and the calibration was based on the surface of the background material. Thus, a variation in height may introduce an error. Based on the AO1 test data, a graph of the deviation versus the height from the background of the test specimens was developed, Figure 5-5.

Figure 5-5: AO1 Deviation vs. Height.

In Figure 5-5 we see that for the configuration given in test AO1, the deviation is within a band of +10% to –10% for small elevations and grows in magnitude the higher the specimen is elevated from the background. This graph also shows that the deviation grows in the negative direction as the height increases indicating that the system is over predicting the area. The trend for deviation versus surface area being viewed in Test AO1 is shown in Figure 5-6.

Figure 5-6: AO2 Deviation vs. Area.

Figure 5-6 shows that deviations are independent of the area as expected and thus the size of the specimen being measured is not considered a factor relative to accuracy.

5.3 Narrow Field of View Tests

As stated above, the tests were also conducted focusing in on the grid to only four squares as opposed to 12 squares as used in Tests AO1, AO2, and AO3. A view of this arrangement is shown in Figure 5-7.

Results from these narrow field tests are as shown in Table 5-2, where again negative deviation indicates overestimation. Again these results were examined for variation based on the height of the object from the background, Figure 5-8.

Figure 5-7: Narrow Field View Example.

Table 5-2: Narrow Field View Results.
(Note all dimensions are in inches and inches squared.)

TEST	GRID	SAMPLE	SIDE	Calculated		AREA	% Deviation
				Perim	Area	MACH.VIS.	
C01	C02	2	Right	2.044	0.361	0.301	-15.27%
	C03	3	Top	3.481	0.757	0.918	-21.21%
	D02	10	Bottom	0.7508	0.035	0.072	-104.53%
	D03	9	Right	2.825	0.499	0.388	22.27%
C02	C02	1	Back	1.039	0.067	0.077	-14.12%
	C03	4	Front	3.784	0.895	1.147	-28.17%
	D02	6	Top	1.999	0.250	0.251	-4.50%
	D03	11	Front	4.198	1.086	1.077	0.81%
C03	C02	12	Top	4.43	1.227	0.962	19.94%
D01	C02	2	Top	2.005	0.252	0.303	-19.04%
	C03	3	Right	3.495	0.763	0.969	-26.03%
	D02	10	Right	1.338	0.112	0.115	-2.78%
	D03	9	Left	2.756	0.475	0.357	24.80%
D02	C02	1	Bottom	0.987	0.061	0.077	-26.47%
	C03	4	Left	3.965	0.983	1.189	-21.01%
	D02	6	Front	1.89	0.223	0.266	-19.15%
	D03	11	Back	3.4	0.723	1.049	-45.19%
D03	C02	12	Bottom	4.43	1.227	1.152	6.08%
E01	C02	2	Left	2.047	0.282	0.31	-18.97%
	C03	3	Bottom	3.4	0.723	0.925	-28.03%
	D02	10	Back	1.091	0.074	0.066	11.28%
	D03	9	Top	2.442	0.373	0.268	28.83%

Figure 5-8: Narrow Field Deviations.

It is interesting to note that the band in the deviation is about +20% to -20% and consistent for all of the samples.

5.4 Orthogonal Grid Tests

The next set of tests employed the use of the orthogonal grid, Figure 5-9.

The purpose of these tests was to determine if the use of a finer grid and more narrow focus would result in higher accuracy. Furthermore, the cube-type grid structure would permit multiple cameras to view three sides simultaneously without requiring rotation through the use of the manipulator arm. This method was being considered for the coarse scrap material where a measurement of more than one side would be required in order to improve on surface area size. The test pictures captured from the side (Figure 5-10) would represent the image of a surface using multiple cameras.

Figure 5-9: Orthogonal Grid.

Figure 5-10: Orthogonal Grid Side View.

Once the image is captured and the software distinguishes an image from the background, the result is that shown in Figure 5-11. It is through this captured image that the number of pixels is determined and principal features are derived.

Figure 5-11: Orthogonal Grid Top View.

Results from the measurements for the cube are shown in Table 5-3.

As with the previous tests, a range in deviation is seen based in part due to the object height from the background material. The mean value in deviation for the views captured with the cube was -16% and about the same mean was calculated based on the wider field of view (Tests AO1 through AO3). The deviation determined may be dominated by the camera angle for both test sets. If we view an object from an angle as shown in Figure 5-12, the image seen by camera #1 will be Area A, while that for camera #2 is the Area A times the cosine of the angle. Thus, an angle of 10° would produce an approximate reduction in area of 1.5%. The

Table 5-3: Orthogonal Grid Results.**(Area measurements are in inches and inches squared.)**

Frame	Sample	Side	Calculated		Machine Vision			% Deviation
			Perim	Area	Pixels	Calibration	Area	
C07_P02_S1	2	Bottom	2.039	0.260	4762	16028	0.297	-14%
C07_P02_S2		Front	1.969	0.242	3985	16028	0.249	-3%
C07_P02_S3		Right	2.044	0.261	5099	16028	0.318	-22%
C07_P02_S4		Back	2.039	0.260	4904	16028	0.306	-18%
C07_P02_S5		Left	2.047	0.262	4472	16028	0.279	-7%
C07_P02_S6		Top	2.008	0.252	4192	16028	0.262	-4%
C07_P01_S1	1	Front	1.041	0.068	1329	16045	0.083	-22%
C07_P01_S2		Right	0.955	0.057	1094	16045	0.068	-20%
C07_P01_S3		Back	1.039	0.067	1337	16045	0.083	-24%
C07_P01_S4		Left	0.928	0.054	1212	16045	0.076	-40%
C07_P01_S5		Top	0.939	0.055	1166	16045	0.073	-32%
C07_P01_S6		Bottom	0.987	0.061	1186	16045	0.074	-21%
C07_P03_S1	3	Front	3.481	0.757	15995	16020	0.998	-32%
C07_P03_S2		Right	3.495	0.763	15184	16020	0.948	-24%
C07_P03_S3		Back	3.536	0.781	15491	16020	0.967	-24%
C07_P03_S4		Left	3.469	0.752	15049	16020	0.939	-25%
C07_P03_S5		Top	3.481	0.757	13611	16020	0.850	-12%
C07_P03_S6		Bottom	3.4	0.723	13737	16020	0.857	-19%
C07_P04_S1	4	Front	3.784	0.895	17649	16043	1.100	-23%
C07_P04_S2		Right	3.944	0.972	17737	16043	1.106	-14%
C07_P04_S3		Back	3.812	0.908	18195	16043	1.134	-25%
C07_P04_S4		Left	3.965	0.983	18927	16043	1.180	-20%
C07_P04_S5		Top	3.927	0.964	19307	16043	1.203	-25%
C07_P04_S6		Bottom	3.949	0.975	19407	16043	1.210	-24%
C07_P06_S1	6	Front		0.1509	4095	16049	0.255	-69%
C07_P06_S2		Right		0.2244	5114	16049	0.319	-42%
C07_P06_S3		Back		0.1553	4033	16049	0.251	-62%
C07_P06_S4		Left		0.2	4860	16049	0.303	-51%
C07_P06_S5		Top		0.2383	4188	16049	0.261	-10%
C07_P06_S6		Bottom		0.1989	4146	16049	0.258	-30%
C07_P09_S1	9	Front	1.126	0.079	2027	16028	0.126	-60%
C07_P09_S2		Right	2.826	0.499	6219	16028	0.388	22%
C07_P09_S3		Back	1.106	0.076	1699	16028	0.106	-39%
C07_P09_S4		Left	2.756	0.475	6239	16028	0.389	18%
C07_P09_S5		Top	2.442	0.373	4055	16028	0.253	32%
C07_P010_S1	10	Front	1.146	0.082	1353	16028	0.084	-3%
C07_P010_S2		Left	1.308	0.107	1739	16028	0.108	-1%
C07_P010_S3		Back	1.091	0.074	1159	16028	0.072	3%
C07_P010_S4		Right	1.338	0.112	1774	16028	0.111	1%
C07_P010_S5		Top	1.13	0.080	1179	16028	0.074	8%
C07_P011_S1	11	Front	4.168	1.086	17160	16028	1.071	1%
C07_P011_S2		Right	2.628	0.432	5091	16028	0.318	26%
C07_P011_S3		Back	3.4	0.723	17102	16028	1.067	-48%
C07_P011_S4		Left	3.394	0.720	6326	16028	0.395	45%
C07_P012_S1	12	Top	4.43	1.227	15769	16028	0.984	20%
C07_P012_S2		Bottom	4.43	1.227	17671	16028	1.103	10%

Figure 5-12: Camera Angle.

camera angle also produces an error due to its expanded field of view. While at an angle, the field of vision is expanded such that image also includes some portion of the object's sides. The camera angle effect also applies to the case when the camera is perpendicular to the background and the object is located off center. This effect was certainly true when Tests AO1 through AO3 were performed. Here the images of several objects were captured for analyses with some located off center.

5.5 Principal Dimension Determination

It is important to note the ability of the system to determine the dimension of the specimens. For Test AO1, Table 5-4 contains a comparison measuring the maximum or principal axial dimension of the specimen.

Table 5-4: Test AO1 Dimension Deviations.
(Note all dimensions are in inches and inches squared.)

TEST AO1					
GRID	SAMPLE	SIDE	Calculated Dimension	Mach Vis Dimension	% Deviation
A01	1	Back	0.266	0.266	0.0%
A02	2	Right	0.511	0.532	-4.1%
A03	3	Top	0.9005	0.935	-3.8%
A04	4	Front	0.9545	1.066	-11.7%
B01	6	Top	0.879	0.518	41.1%
B02	10	Top	0.311	0.356	-14.5%
B03	9	Right	0.98	1.082	-10.4%
B04	11	Front	1.1	1.05	4.5%
C01	12	Top	1.25	1.256	-0.5%

It is clear from this table that the deviation in the maximum or principal dimension is rather small. Thus the Machine Vision system works well for determining the principal dimension which is the value needed to determine whether an object is fine scrap, coarse scrap, or fuel.

5.6 Clad vs. Unclad Determination

A remaining criteria for analyses was identifying the fraction of reacted versus unreacted surface area. Using a technique similar to that for determining the object against a blue background, the dark or reacted area is identified from the unreacted area. The specific process first determined whether an object was present against the blue background. As stated earlier, this determination is merely identifying within the software the color blue and then seeking objects which do not meet this definition. Once the objects are identified, the software is then trained to look only at the object and define bright from dark. This distinction is made again by defining what is bright and dark. Results of this analysis from Test AO1 are displayed below in Table 5-5.

Table 5-5: Clad Fraction Areas.

Sample	% Reacted Clad Calculated	% Reacted Clad Machine Vision
1	100%	100.1%
2	50%	71%
3	100%	98.9%
4	50%	64%
6	100%	95.4%
10	100%	95%
9	50%	50%
11	50%	44%
12	0%	0%

5.7 Discussion

These results demonstrate that the Machine Vision system is capable of providing good estimates of the clad versus unclad areas. Variations in results can be attributed to the cleanliness of the surface area. A sharp contrast in color content between reacted and unreacted will produce good results. However, discoloration due to other factors may contribute to deviations as expected. The system however does provide reasonable results in this area.

The shape of the objects was also thought to be a factor when preparing the test samples. The first five samples were all cubic and varied in height. The purpose was to determine how well principle dimensions would be determined. Sample 6 included a notch in the top surface. This notch was intended to represent, in an exaggerated manner, any imperfections as crevices on the surface of the fuel object. The camera could only see a projected surface which would be viewed as if the notch were not present. Results showed location of about 5% (viewed in cube) to about 8% (AO2 Test) which is well below the mean value of 16%. This substantial imperfection should not be a contributing factor. Sample #9, when viewed from the front, appears as a triangle. The left and right sides with top views would have a decreasing slope as the surface area. These sides had deviations in the range of 20% well above the mean. Curved

surfaces were also included to determine how the shape would impact the projected view to the camera. The deviations recorded were independent of the surface structure since the same range was found whether the object was a flat surface or varied shape.

6.0 CONCLUSIONS

In Section 2.0, four objectives were stated as the primary focus for this project. Each of these are addressed first:

1. Count the number of pieces: It was clear from the captured images that the quantity of pieces was readily discernible.
2. Determine if piece is coarse or fine: Table 5-4 reported the comparison of principal dimension. All pieces were measured to within about 10%, except the top view of pieces 6 and 10. Referring to Table 4-1, it is clear that sample 6 with its topside notch may introduce some error. The top view of sample 10 would also include the sides, and again, introduce error. These pieces were selected for this reason, also even with the error; these pieces would still have been correctly categorized.
3. Determine surface area: It was required to determine the sample surface area to within 50% accuracy. As stated throughout this report, a member of test configuration was tried and a mean deviation of about 16% was experienced.
4. Determine reacted vs. unreacted surface area: These results were contained in Table 5-5 and again a reasonable comparison was achieved.

In general, the four objectives of the study were met with results which indicate that the use of Machine Vision would appear as a good alternative to supporting the spent fuel storage process. Based on our experience there are two key technical aspects of basin application that require testing of fuel in the K basins:

1. Surface character. Real cladding and fuel surface characteristics will be different than those used for testing. In particular there is variation in surface coatings from light to dark. Water attenuation of light will be

different from air, and to assess this impact, actual conditions will be required. Basin lighting itself differs from that of the 305 laboratory.

2. Need for simultaneous views. Using additional cameras will allow a measurement of scrap height and hence total surface area. The height measurement is also important for calibration to background surface. Analytical techniques combined with Machine Vision for multiple camera views can be tested for accuracy.

Finally, concerning practical implementation and coordination with operations, actual performance of equipment and apparatus with the Machine Vision system is needed to establish a workable procedure.

DISTRIBUTION SHEET

To	From	Page 1 of 1
Distribution	Process Engineering	Date 4/25/00
Project Title/Work Order		EDT No. 629022
Machine Vision Tests for Spent Fuel Scrap Characteristics		ECN No. N/A

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
------	------	-----------------------------	--------------	------------------------------	-----------------

Spent Nuclear Fuel Project

M. D. Crippen	R3-86	X		
R. D. Crowe	R3-26	X		
D. R. Duncan	R3-86	X		
J. R. Frederickson	R3-86	X		
M. J. Langevin	X4-01	X		
A. L. Pajunen	R3-86	X		
A. L. Pitner	R3-86	X		
G. L. Stegen	X4-01	X		
SNF Project Files	R3-11	X		
SNF Project Procedures (SD only)	X3-86			X
SNF Project Training (SD only)	S2-45			X

Offsite

M. G. Plys Fauske & Associates, Inc. 16W070 W. 83 rd St. Burr Ridge, IL 60521	W. E. Berger Fauske & Associates, Inc. 16W070 W. 83 rd St. Burr Ridge, IL 60521
R. B. Schoenberger Agris-Schoen Vision Systems, Inc. 4715-B Eisenhower Avenue Alexandria, VA 22304	Kai Hingst Agris-Schoen Vision Systems, Inc. 4715-B Eisenhower Avenue Alexandria, VA 22304