A Set of Experiments on Steel Balls Under Extension :

A Slide Show

By

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The experiments were carried out at the Bureau of Economic Geology, The University of Texas at Austin.

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INTRODUCTION

Boerner, (1989) carried out the original set of experiments on steel balls under extension for his Master's Thesis at the University of Texas at Austin. These experiments initially consisted of an examination of the dilation and then faulting of steel balls of uniform size in an apparatus one row thick where he could vary the number of layers. This apparatus approximated the behavior of steel balls in two dimensions. By modifying the apparatus to increase the number of rows he completed a similar set of experiments in the three dimensions. For these experiments, which were meant to be analogues of the behaviour of sand in sand boxes, he varied the size of the balls. Boerner (1989) describes each experiment in detail. Boerner and Sclater (in preparation) are about to submit a summary of these experiments including an explanation of the main findings to the Journal of Geophysical Research.

The experiments have generated interest among applied mechanicists interested in understanding the physical principles governing the behavior of aggregates and among geologists studying the application of experiments on cohesionless materials, such as sand, to extension by normal faulting of soft sediments and continental crust.

We present, with this set of slides, an overview of the experiments carried out by Boerner (1989) and some slides illustrating different packing geometries. The slides give a more detailed picture of the deformation than is presented in Boerner and Sclater (in preparation) and, hence, extend the documentation for this paper. We present the slides of the experiments in roughly the same order as Boerner (1989). The relevent slides start with diagrams and a picture of the two dimensional apparatus which are followed by a series of snapshots at specific times of the relevant two dimensional experiments. They finish with a diagram of the three dimensional apparatus followed by snapshots of the three dimensional experiments. Each experiment commences with a title slide which includes the run number for ease of comparison with the figures in Boerner (1989) and Boerner and Sclater (in preparation). Each snapshot within an individual run is defined by a β value, where β equals the ratio of the length of the model at the time of the snapshot to the original length of the model. We believe that the differences etween Run #36 and Run #38 which were identical in setup can be attributed ot the effects of using balls where the paint had not completely dried in Run #36. The slides terminate with some photographs of ping pong balls used by Boerner and Sclater (in preparation) to examine possible geometries for close packed steel balls.

REFERENCES

Boerner, S.T., Experimental investigation of packed speres under extension : application to sand box experiments, M.A. thesis, The University of Texas at Austin, pp 244, 1989.

Boerner, S.T., and J.G. Sclater, The deformation under extension of assemblies of steel balls in contact: application to sandbox models, (in preparation for submission to The Journal of Geophysical Research).

SLIDE NUMBER	CONTENT OF SLIDES	
1	Title	
2	Affiliations	
3	Definition β	
4	Side View - 2D Apparatus	
5	Front View - 2D Apparatus	
6	Photo - 2D Apparatus	
7	Title: Basic 2D Experiment - Run #8	
8	$\beta = 1.00$	
9	$\beta = 1.10$	
10	$\beta = 1.15$	
11	$\beta = 1.19$	
12	$\beta = 1.24$	
13	$\beta = 1.28$	
14	Title: Basic 2D Experiment - Run #9	
15	$\beta = 1.00$	
16	$\beta = 1.10$	
17	$\beta = 1.15$	
18	$\beta = 1.19$	
19	$\beta = 1.22$	
20	Title: Dilation, Fault Blocks, Bridging - Run #10	
21	$\beta = 1.00$	- 11 hr 36 min 07 sec.
22	$\beta = 1.09$	- 12 hr. 27 min 00sec.
23	$\beta = 1.09$	- 12 hr 27 min 59 sec.
24	$\beta = 1.11$	- 12 hr 38 min 00 sec.

25 $\beta = 1.11$ - 12 hr 38 min 39 sec.

26 Title: Varying Number of Layers

27 $\beta = 1.15$ - Run #14

28 $\beta = 1.16$ - Run #12

29 $\beta = 1.16$ - Run #08

30 $\beta = 1.18$ - Run #13

31 Title: Parallel Faults, Crosscutting Faults, Blocks - Run #13

32 $\beta = 1.00$

33 $\beta = 1.05$

34 $\beta = 1.08$

35 $\beta = 1.13$

36 $\beta = 1.16$

37 $\beta = 1.21$

38 $\beta = 1.26$

39 Title: Rotation of Balls During Faulting - Run #21

40 $\beta = 1.00$

41 $\beta = 1.09$

42 $\beta = 1.16$

43 $\beta = 1.19$

44 $\beta = 1.22$

45 $\beta = 1.32$

46 $\beta = 1.35$

47 $\beta = 1.36$

48 $\beta = 1.45$

49 3D Apparatus - Side and Top View

50 Title: 3-D Single Sized Balls 1/4" - Run #23

51 $\beta = 1.00$

52 $\beta = 1.08$

53 $\beta = 1.18$

54 $\beta = 1.28$

55 $\beta = 1.46$

56 Released

57 Title: 3-D Single Sized Balls 5/16" - Run #24

58 $\beta = 1.00$

59 $\beta = 1.08$

60 $\beta = 1.21$

61 $\beta = 1.25$

62 $\beta = 1.28$

63 $\beta = 1.38$

64 $\beta = 1.47$

65 Released

66 Title: 3-D Single-Sized Balls 1/8" - Run #37

67 $\beta = 1.00$

68 $\beta = 1.08$

69 $\beta = 1.17$

70 $\beta = 1.26$

71 $\beta = 1.36$

72 $\beta = 1.46$

73 Title: Two Different Sizes - Top Lock Bottom In Place - Run #18

74 $\beta = 1.00$

75 $\beta = 1.11$

76 $\beta = 1.14$

77 $\beta = 1.24$

78 $\beta = 1.35$

79 $\beta = 1.51$

80 Title: Two Different Sizes - Top Lock Bottom in Place - Run #31

81 $\beta = 1.00$

82 $\beta = 1.05$

83 $\beta = 1.08$

84 $\beta = 1.17$

85 $\beta = 1.21$

86 $\beta = 1.27$

87 $\beta = 1.45$

88 Title: Plan View-Sideways Motion, Dropping Faults, Curved Faults - Run #30

89 $\beta = 1.00$ Plan

90 $\beta = 1.00$ Side

91 $\beta = 1.08$ Plan

92 $\beta = 1.08$ Side

93 $\beta = 1.19$ Plan

94 $\beta = 1.19$ Side

95 $\beta = 1.23$ Plan

96 $\beta = 1.23$ Side

97 $\beta = 1.38$ Plan

98 $\beta = 1.38$ Perspective view

99 Title: Plan View - Cross Packing - Run #28

100 $\beta = 1.00$ Plan

101 $\beta = 1.00$ Side

102 $\beta = 1.27$ Plan

103 $\beta = 1.27$ Side

104 Title: Three Sizes, $\pm 25\%$ Range, Random Packing - Run #19

105 $\beta = 1.00$

106 $\beta = 1.18$

107 Title: Three Sizes, $\pm$25% Range,Random Packing - Run #22

108 $\beta = 1.00$

109 $\beta = 1.19$

110 Title: Three Sizes, $\pm$25% Range, Distributed (1/4:1/2:1/4), Random Packing - Run #25

111 $\beta = 1.00$

112 $\beta = 1.19$

113 Title: Three Sizes, $\pm$6% Range, Distributed (1/4:1/2:1/4) Closely Packed - Run #32

114 $\beta = 1.00$

115 $\beta = 1.17$

116 Title: Three Sizes, $\pm$6% Range, Distributed (1/4:1/2:1/4) Locked in Place By Upper Layer - Run #33

117 $\beta = 1.00$

118 $\beta = 1.17$

119 Title: Three Sizes, $\pm$6% Range, Distributed (1/4:1/2:1/4) Locked in Place by Upper Layers- Run #34

120 $\beta = 1.00$

121 $\beta = 1.18$

122 Title: Three Sizes, $\pm$6% Range, Distributed (1/4:1/2:1/4) 1/8" balls over sheet, Locked in place by upper layers of 5/16" balls-Run #36

123 $\beta = 1.00$

124 $\beta = 1.09$

125 $\beta = 1.18$

126 $\beta = 1.21$

127 $\beta = 1.24$

A SET OF EXPERIMENTS ON STEEL BALLS UNDER EXTENSION: A SLIDE SHOW

JOHN G. SCLATER

AND

SEAN T. BOERNER

slide 1

In Affiliation With

The Department of Geological Sciences

The Institute for Geophysics

and

The Bureau of Economic Geology

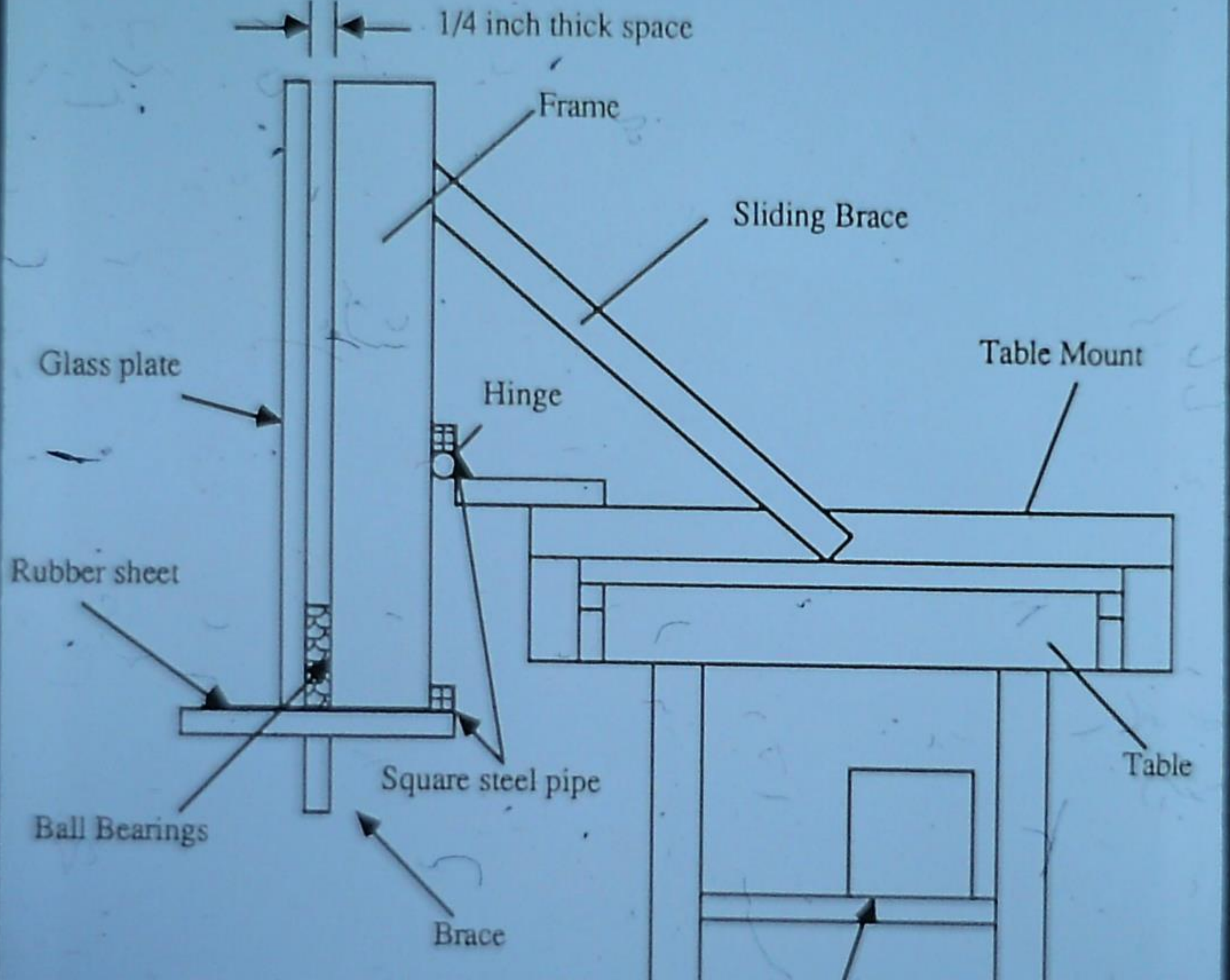
The University of Texas at Austin

Between

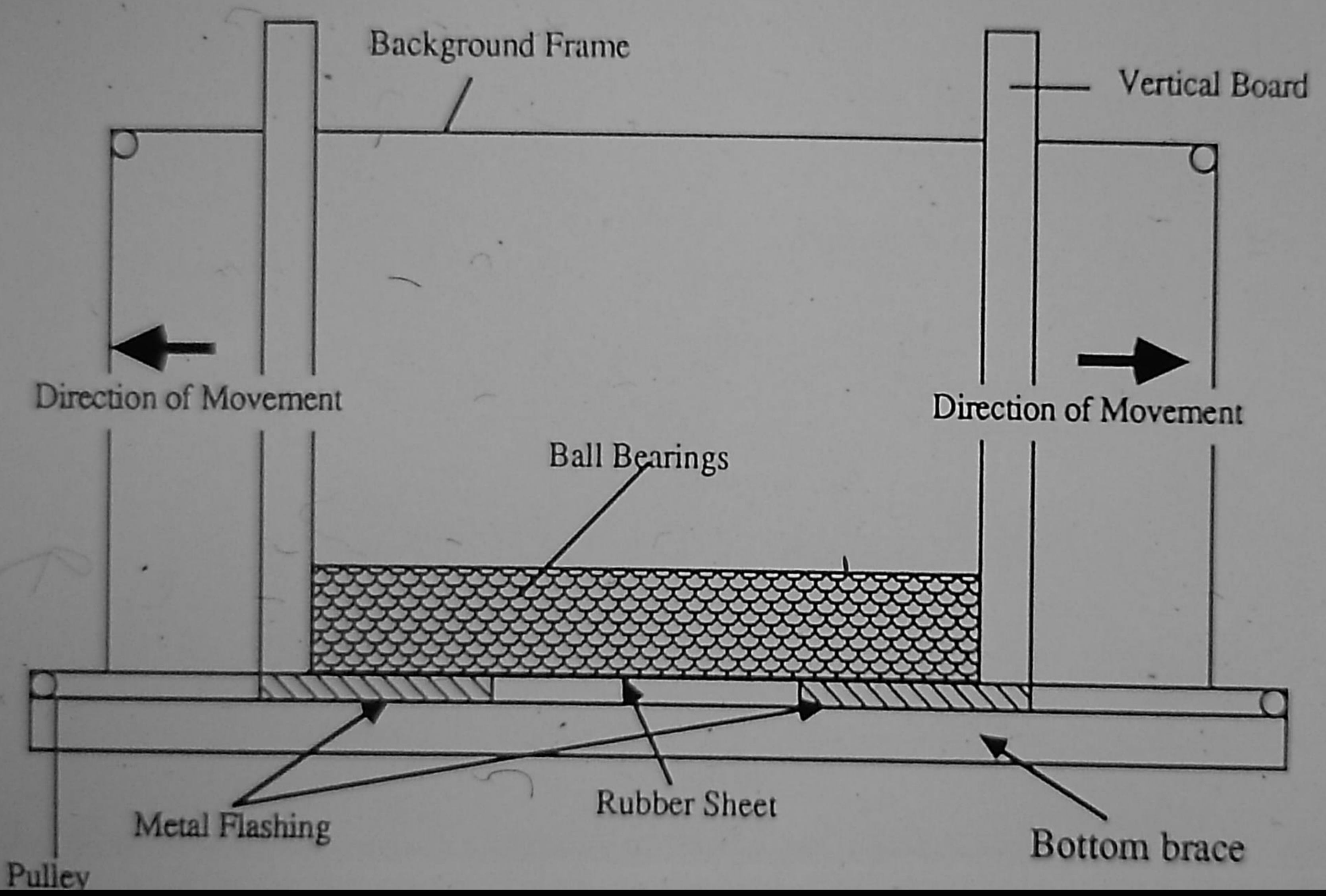
MEASUREMENT OF EXTENSION

$$= \frac{\text{Length at Time of Snapshot}}{\text{Initial Length}}$$

SIDE VIEW 2D APPARATUS



FRONT VIEW 2D APPARATUS




Run #
Time

BASIC 2D EXPERIMENT

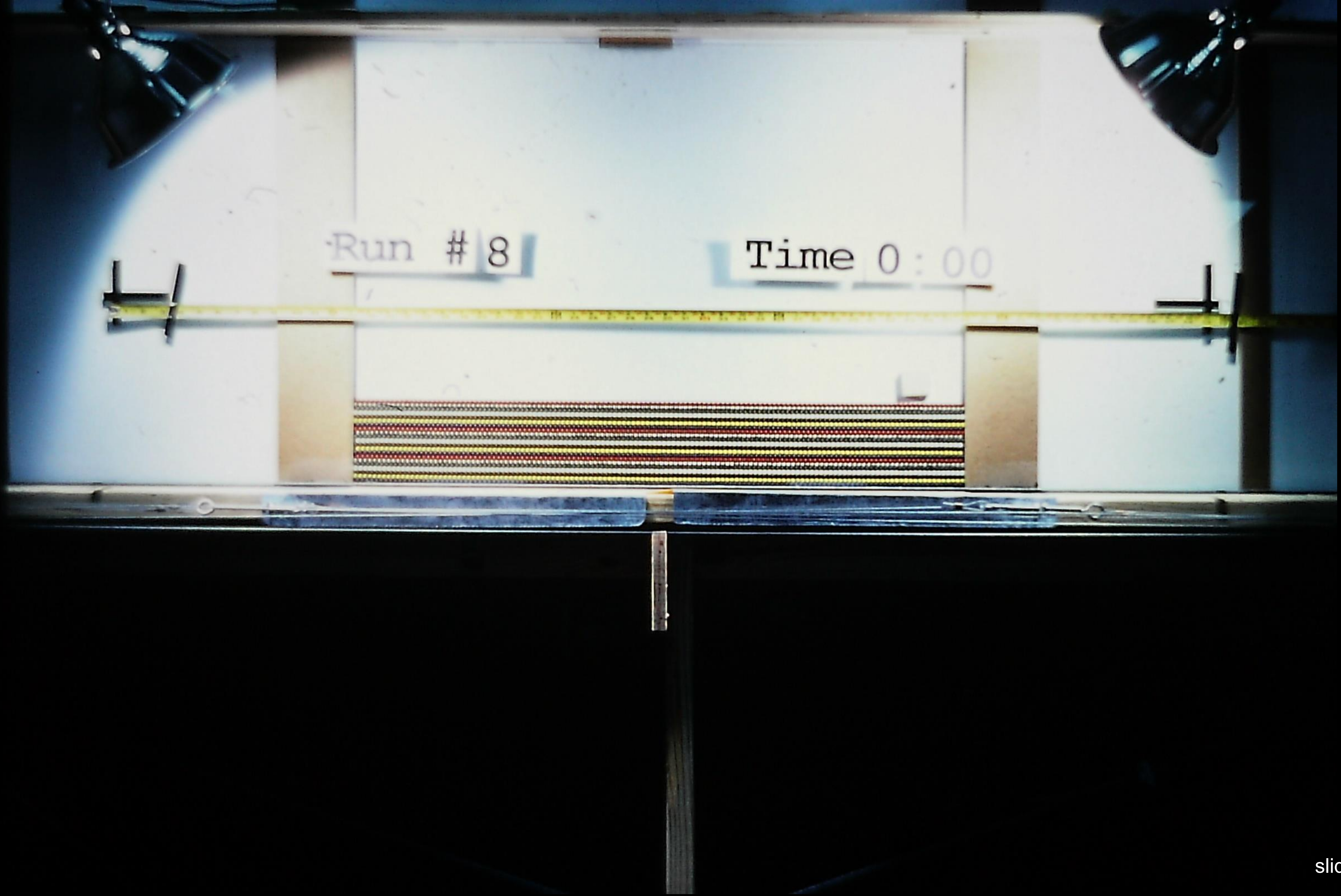
Run #8

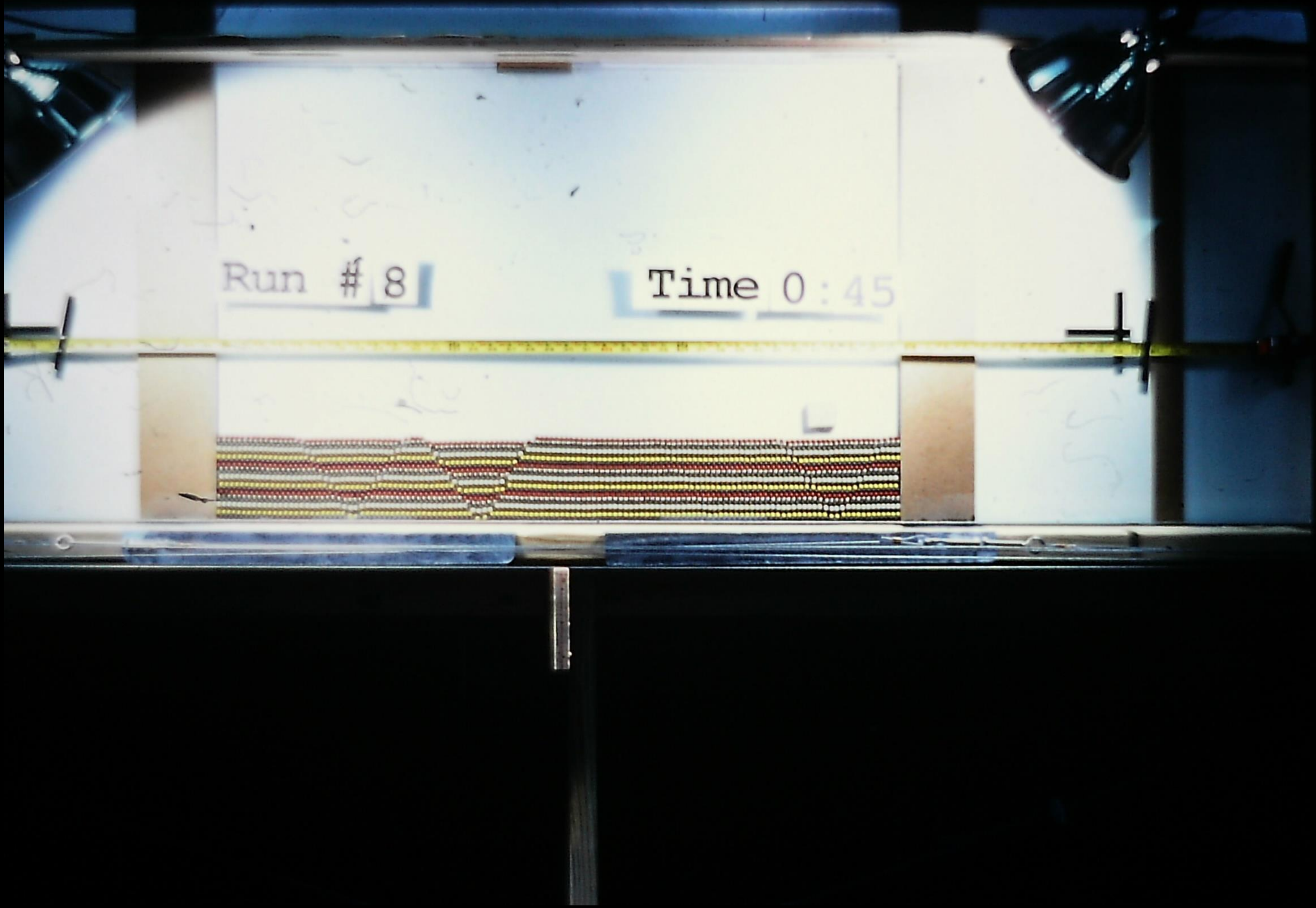
22 Layers

2D Close-Packed Hexagonal

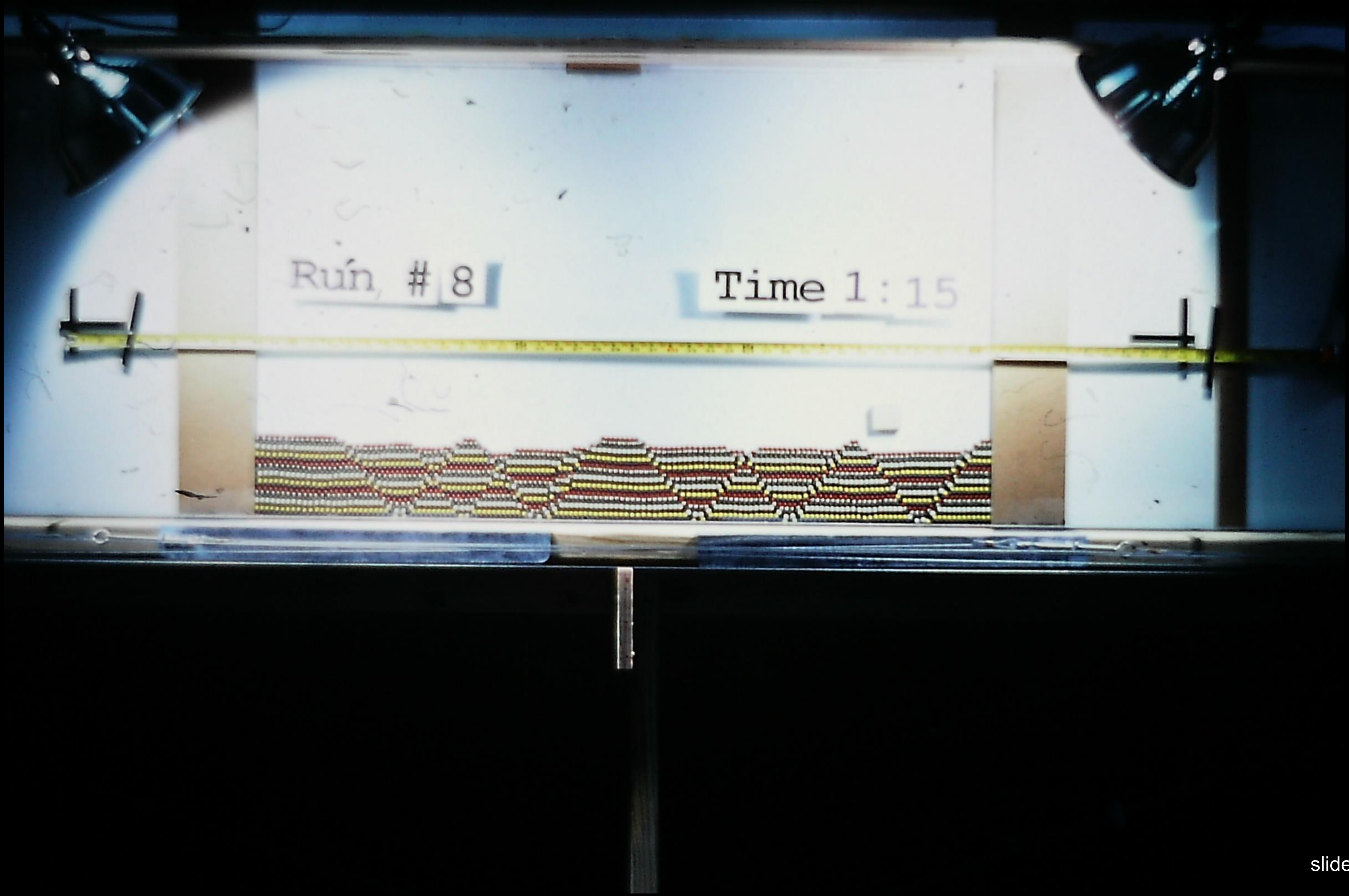
13.4 cm/hr

β = 1.00, 1.10, 1.15, 1.19, 1.24, 1.28


Run # 8
Time 0 : 00


Run # 8
Time 0:45


Run # 8
Time 1:00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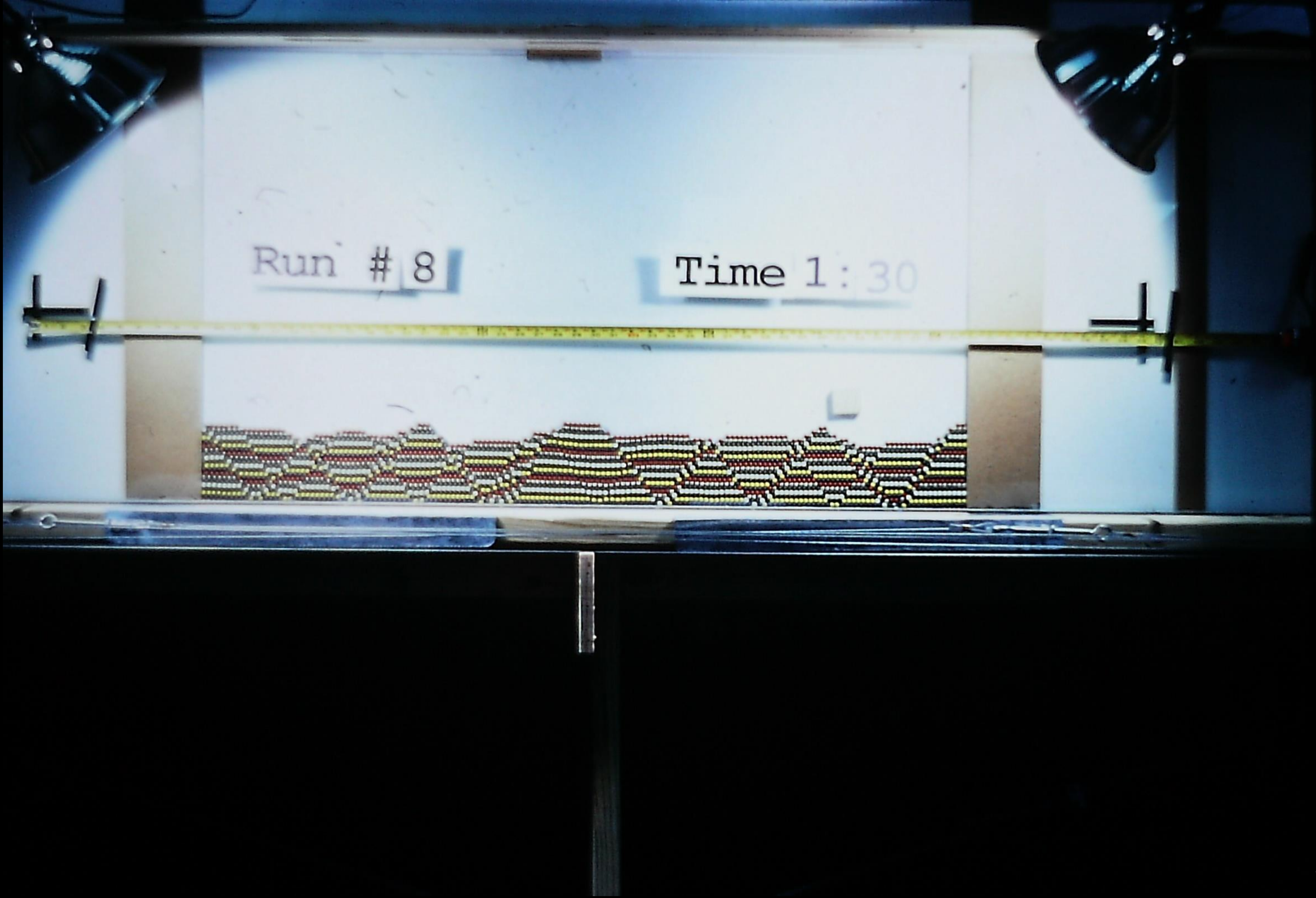
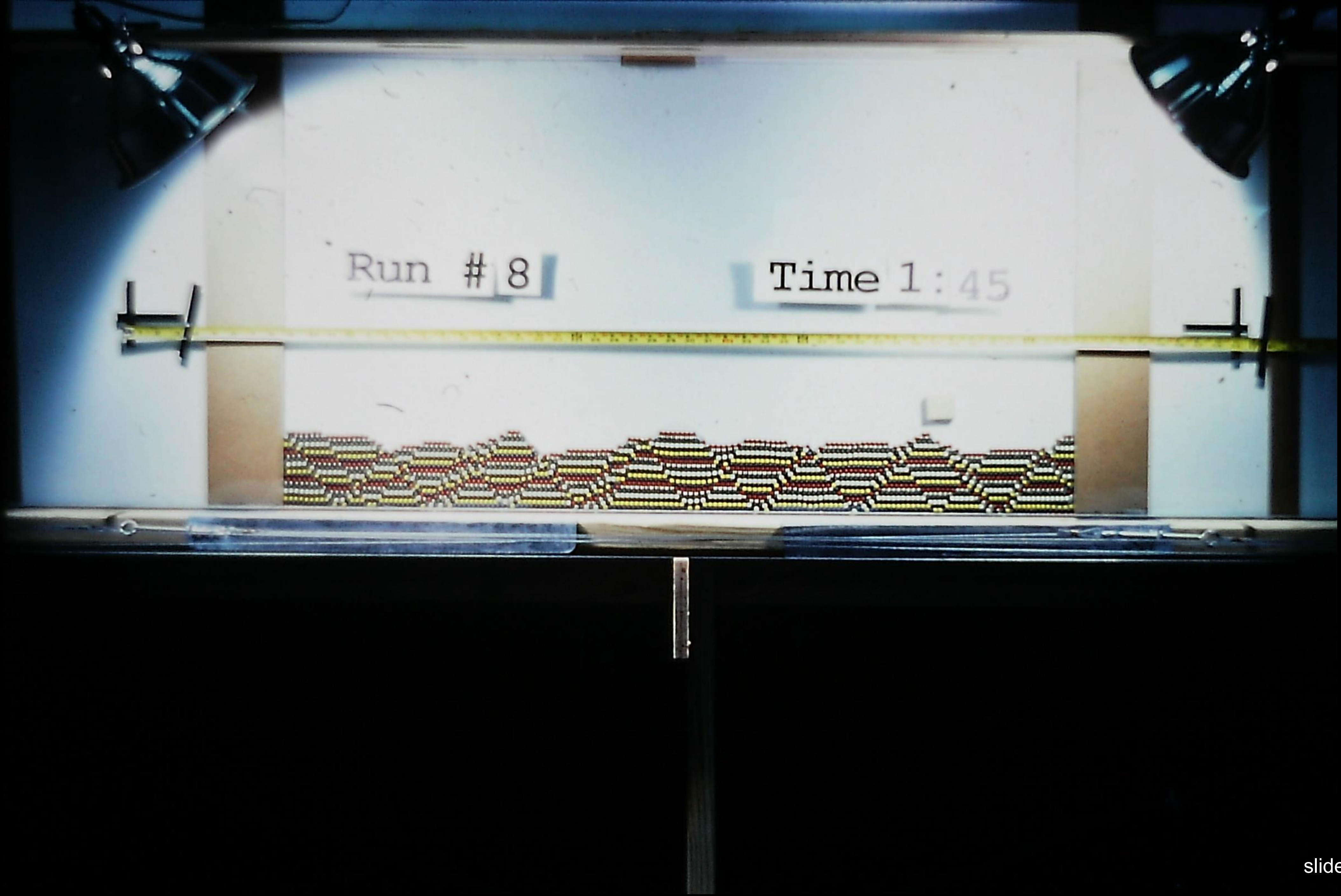
Time 1:15


Run # 8
Time 1:30


Run # 8
Time 1:45

BASIC 2D EXPERIMENT

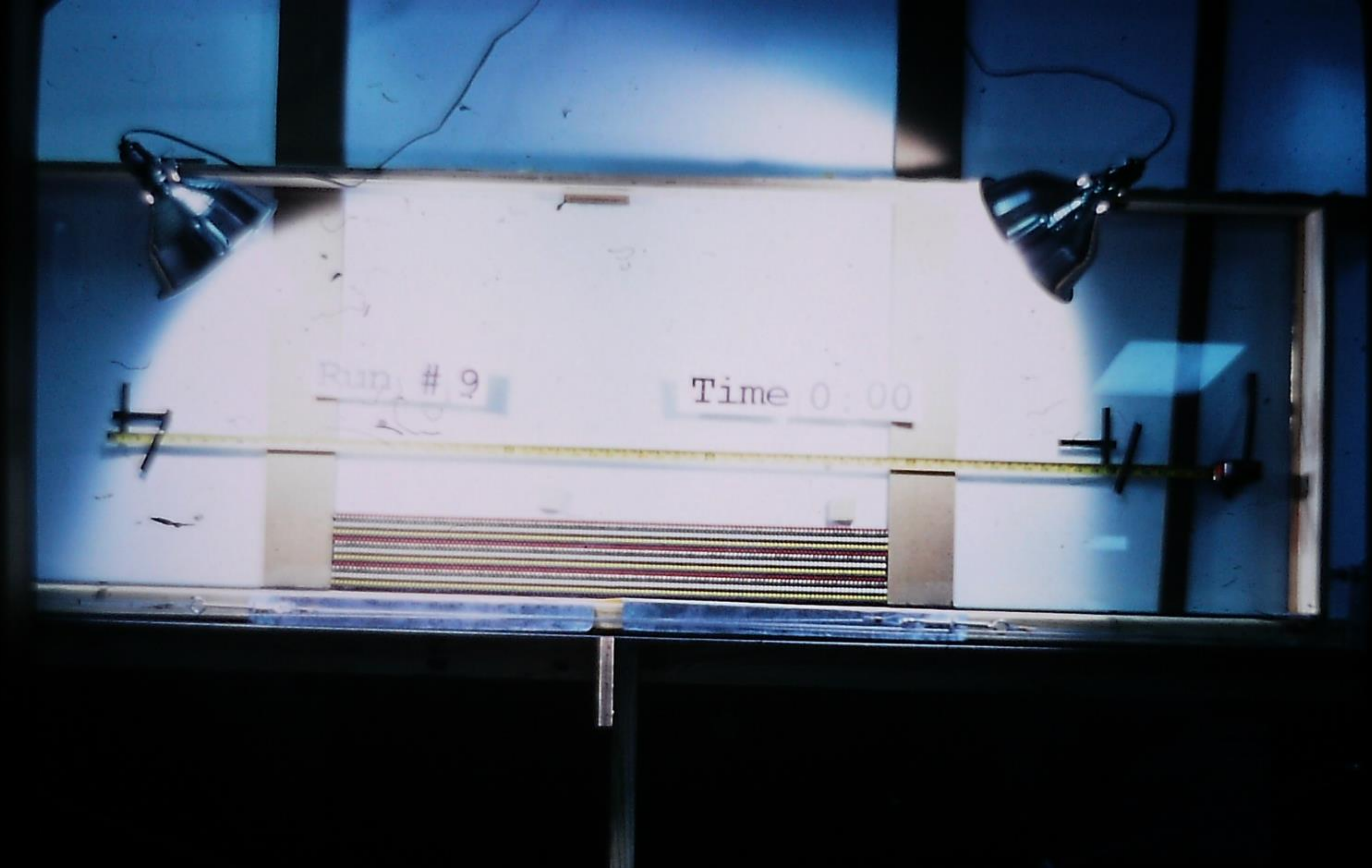
Run #9

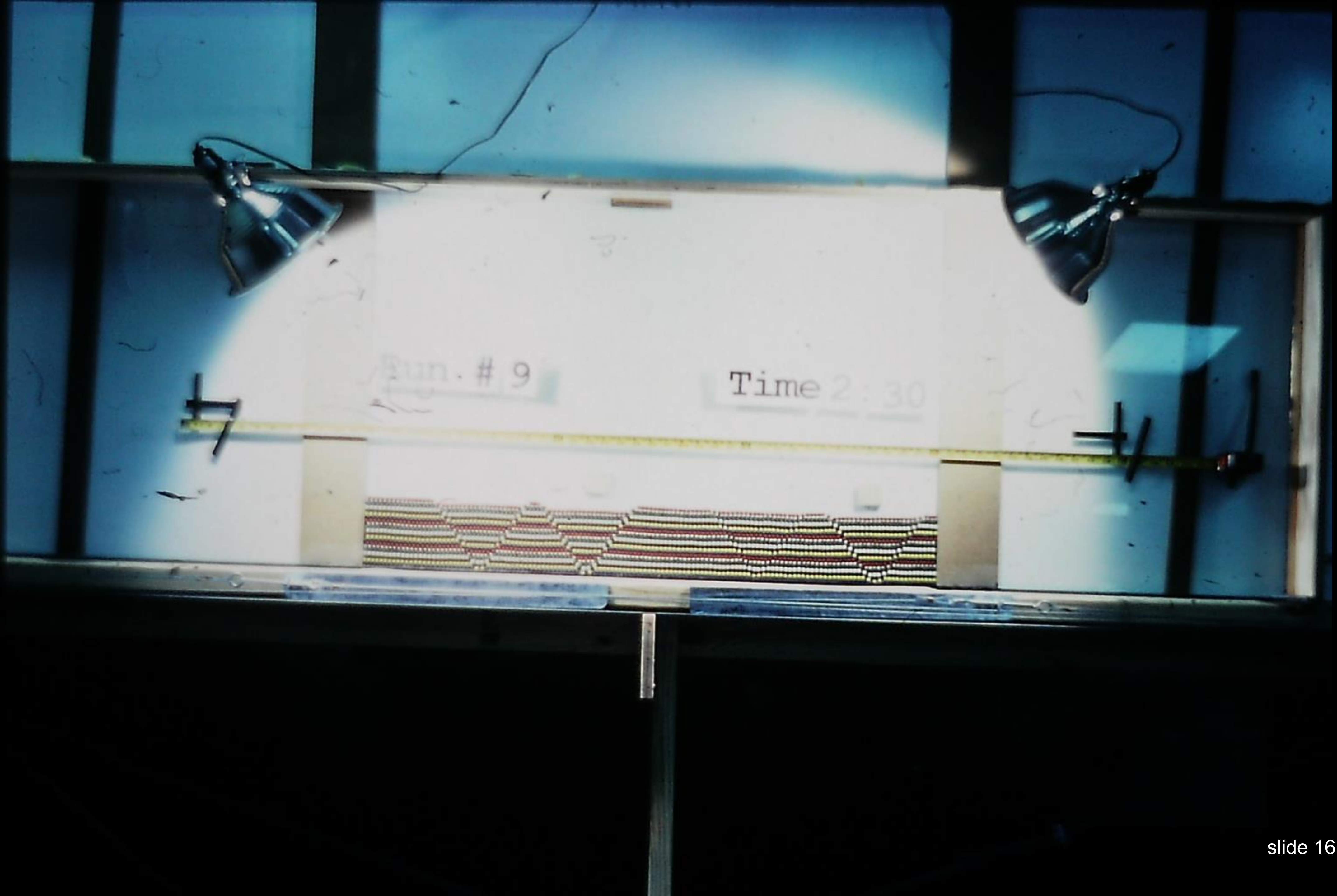
22 Layers

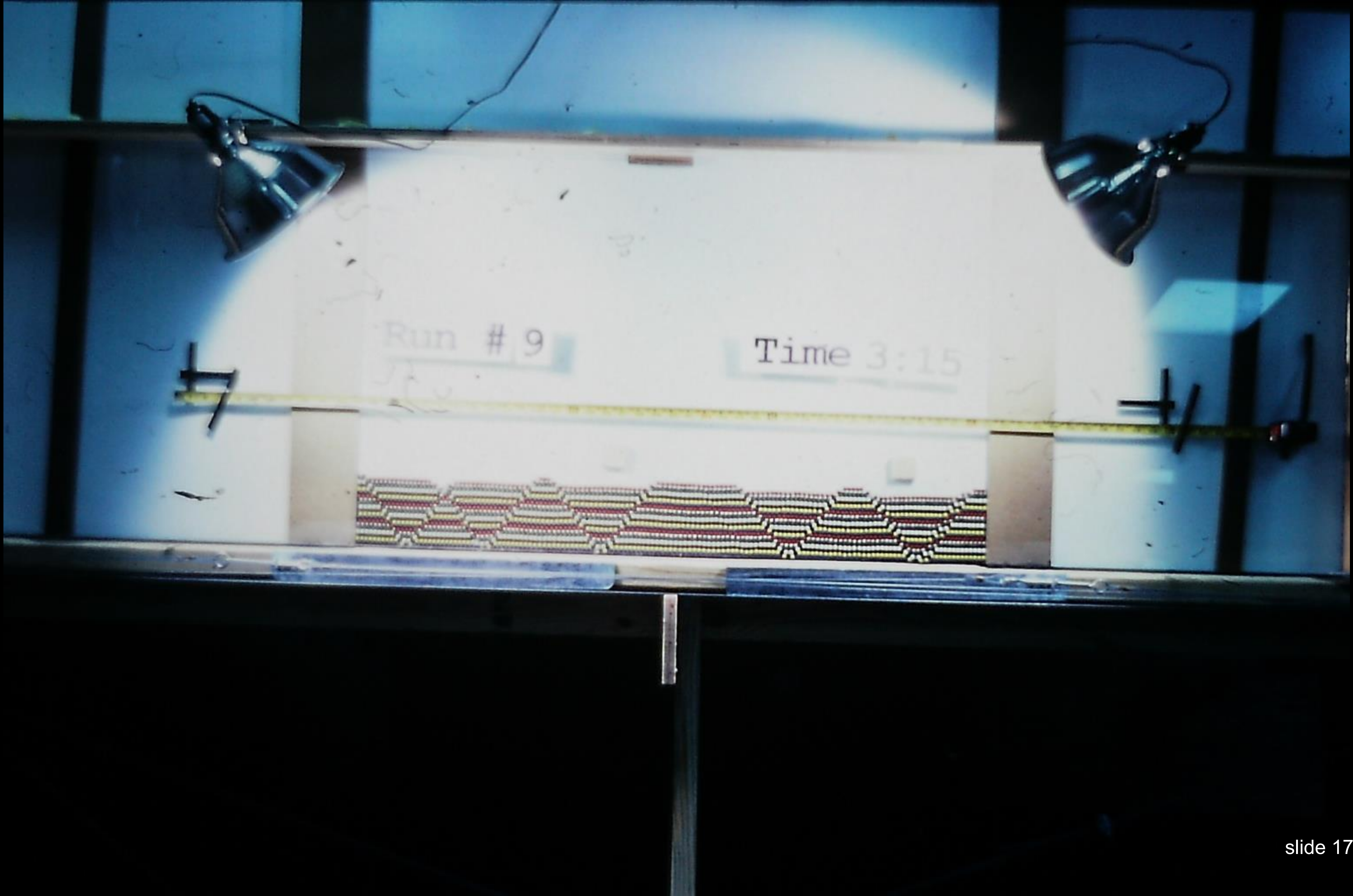
2D Close-Packed Hexagonal

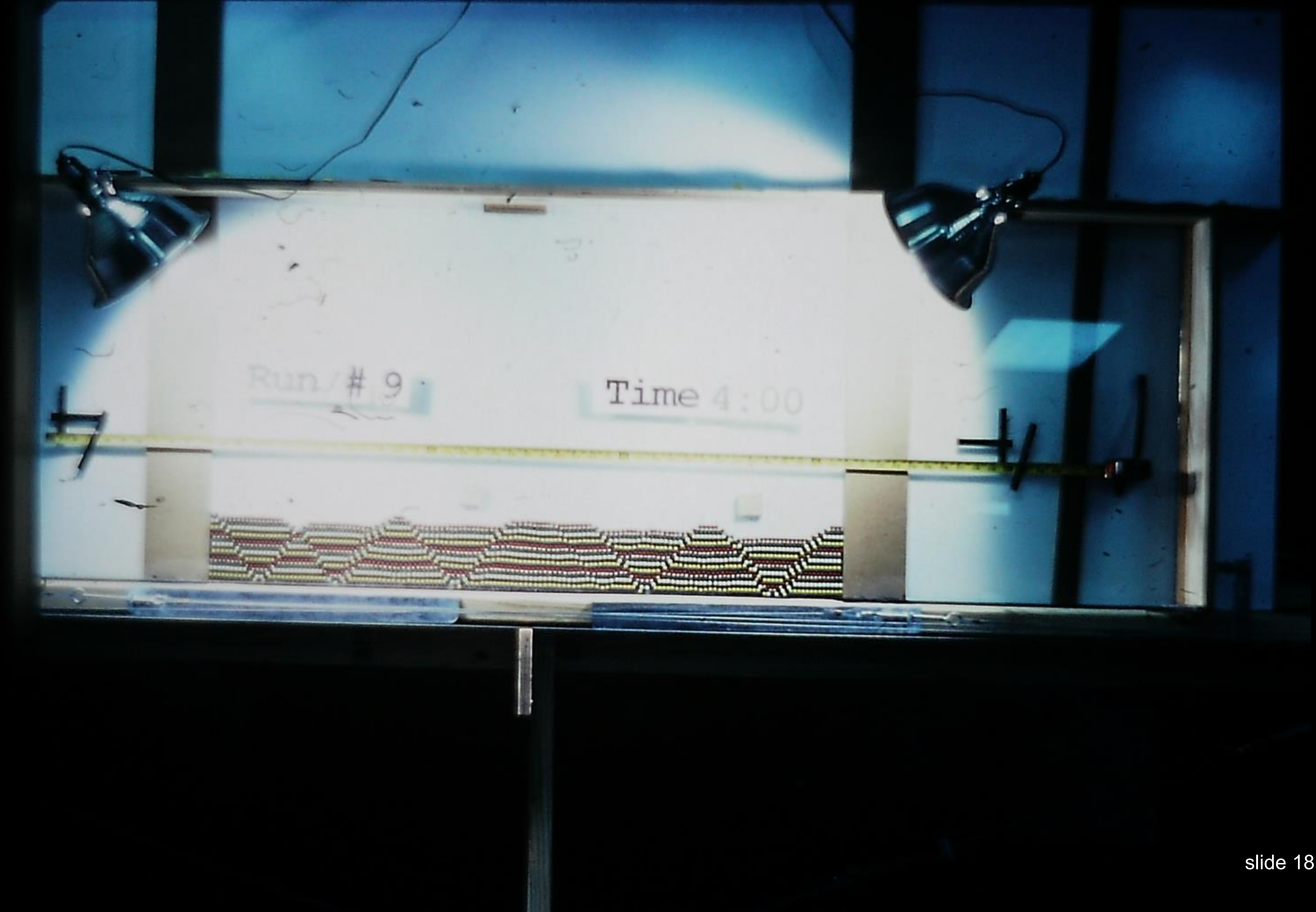
4.2 cm/hr

β = 1.00, 1.10, 1.15, 1.19, 1.22

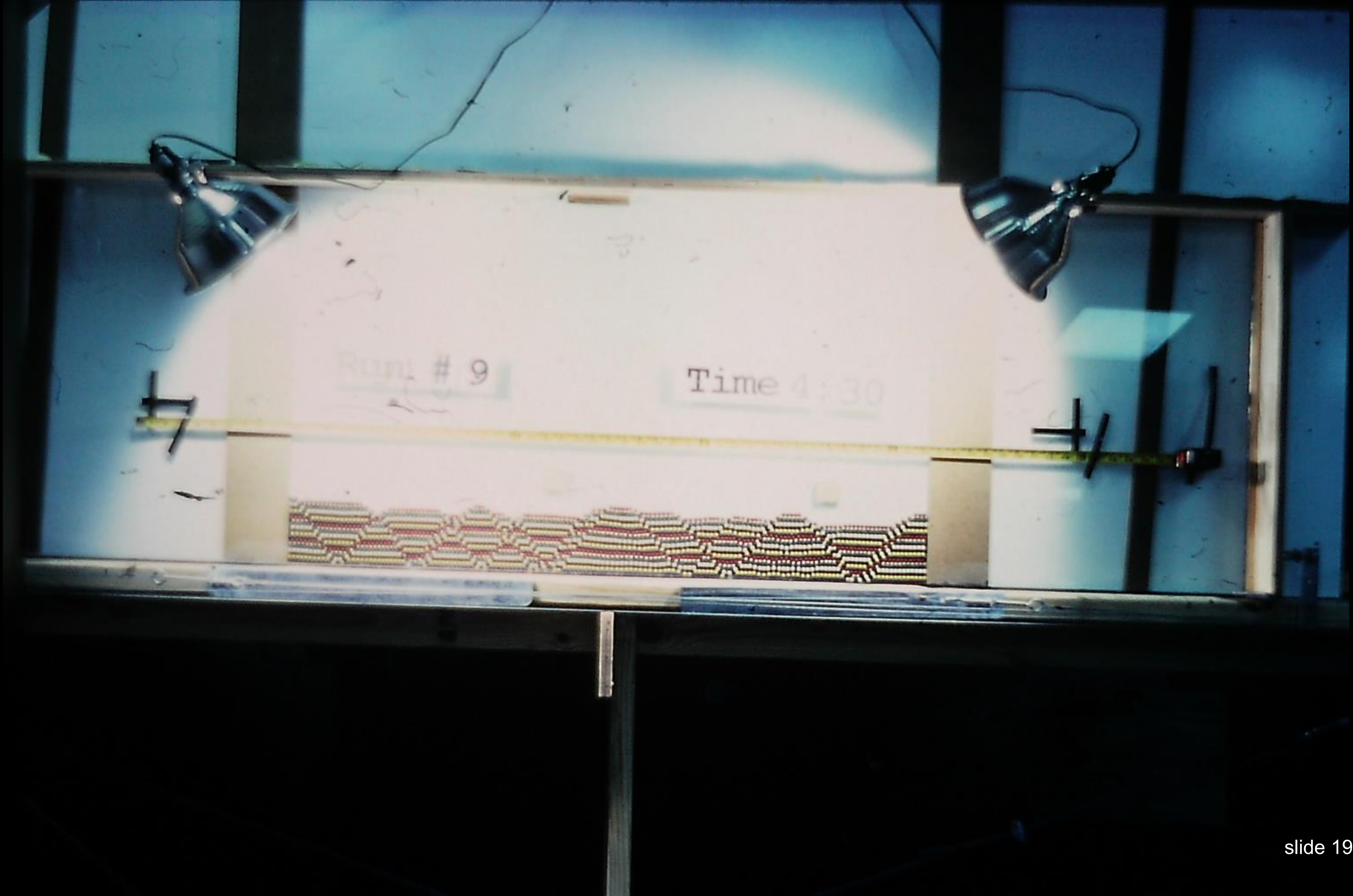

Run # 9
Time 0:00


Run. # 9
Time 2:30


Run # 9
Time 3:15



Run # 9
Time 4:00


Run # 9
Time 4:30

DILATION, FAULT BLOCKS, BRIDGING

Run #10

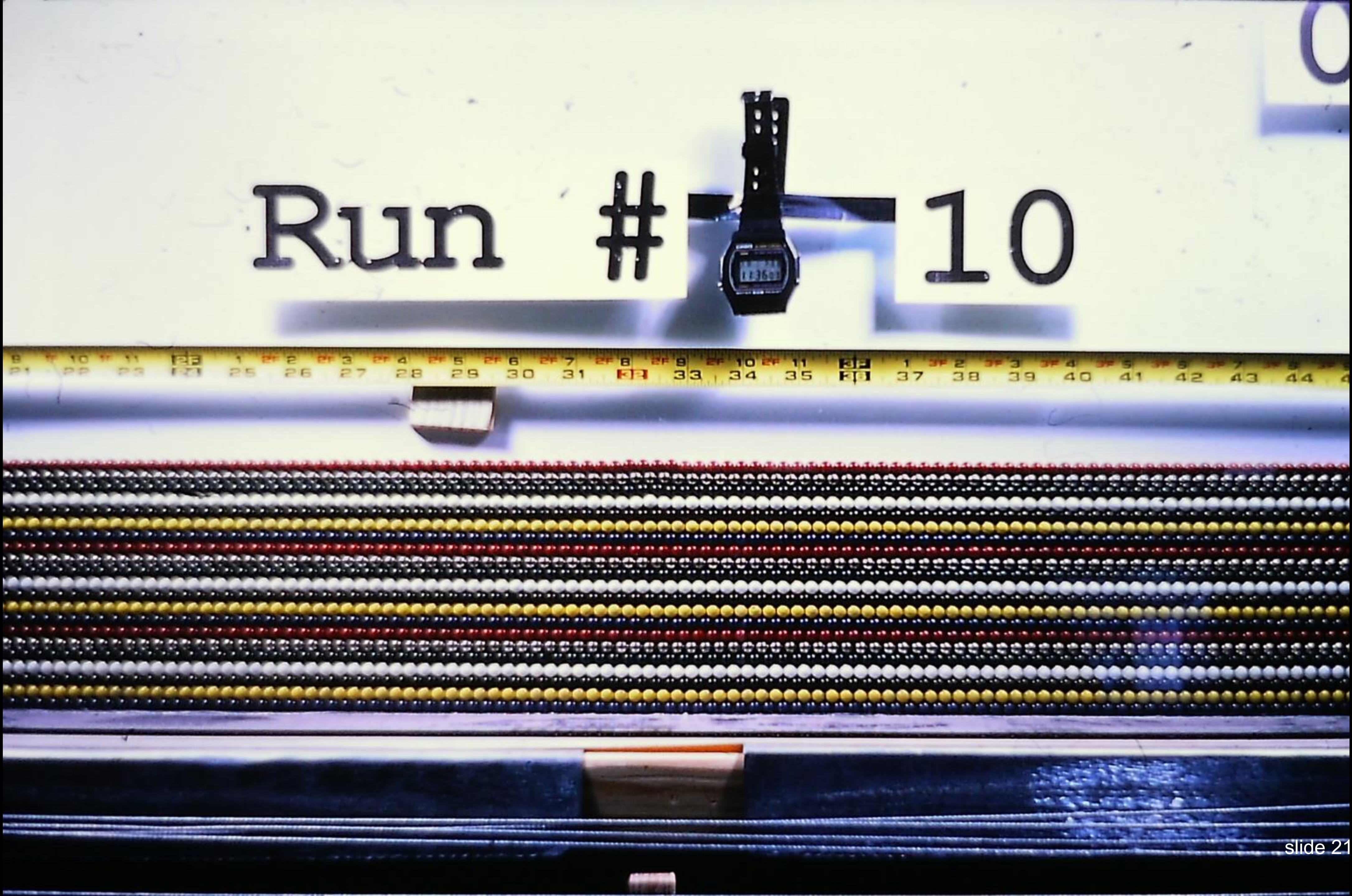
22 Layers

2D Close-Packed Hexagonal

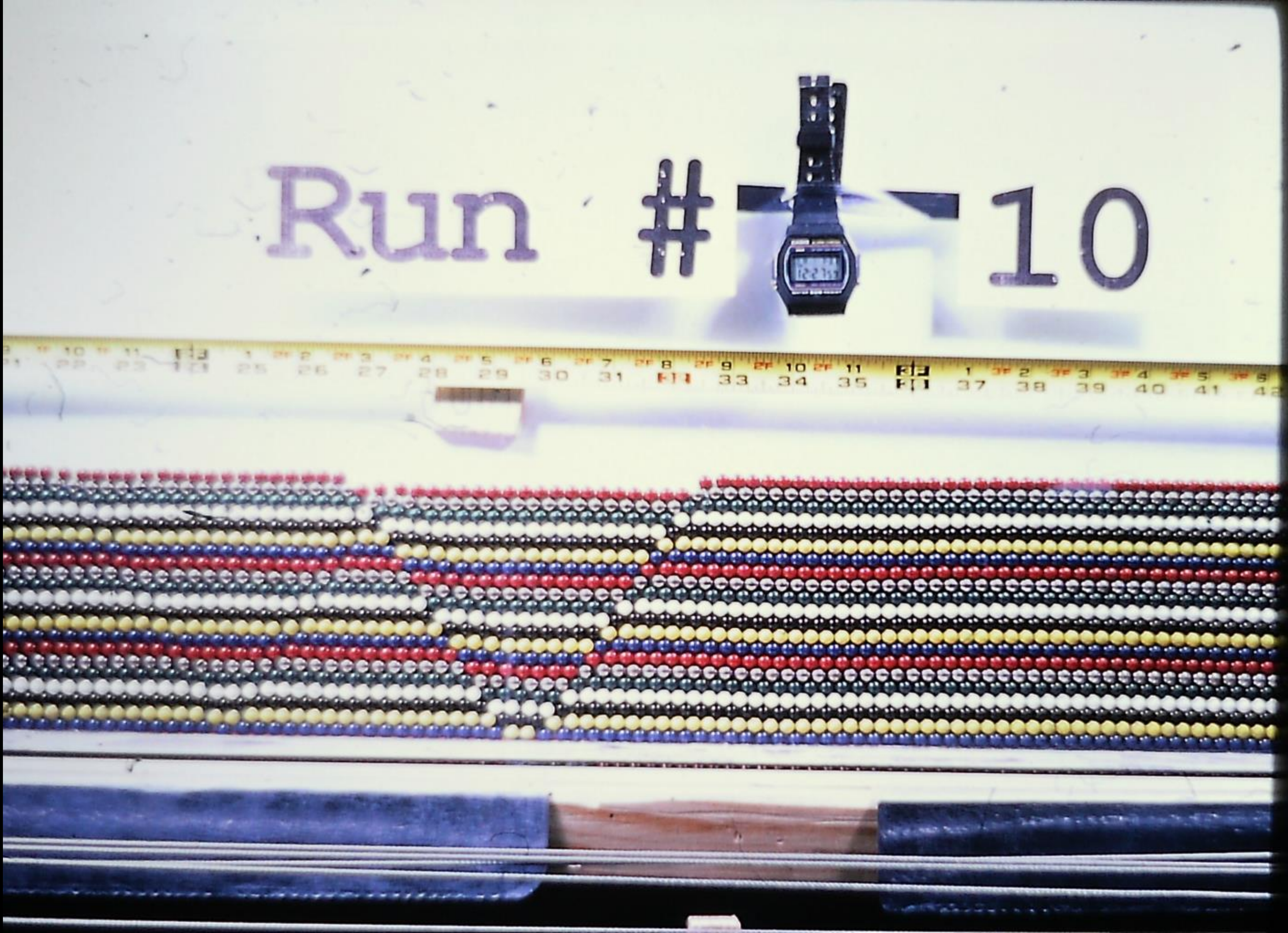
10.5 cm/hr

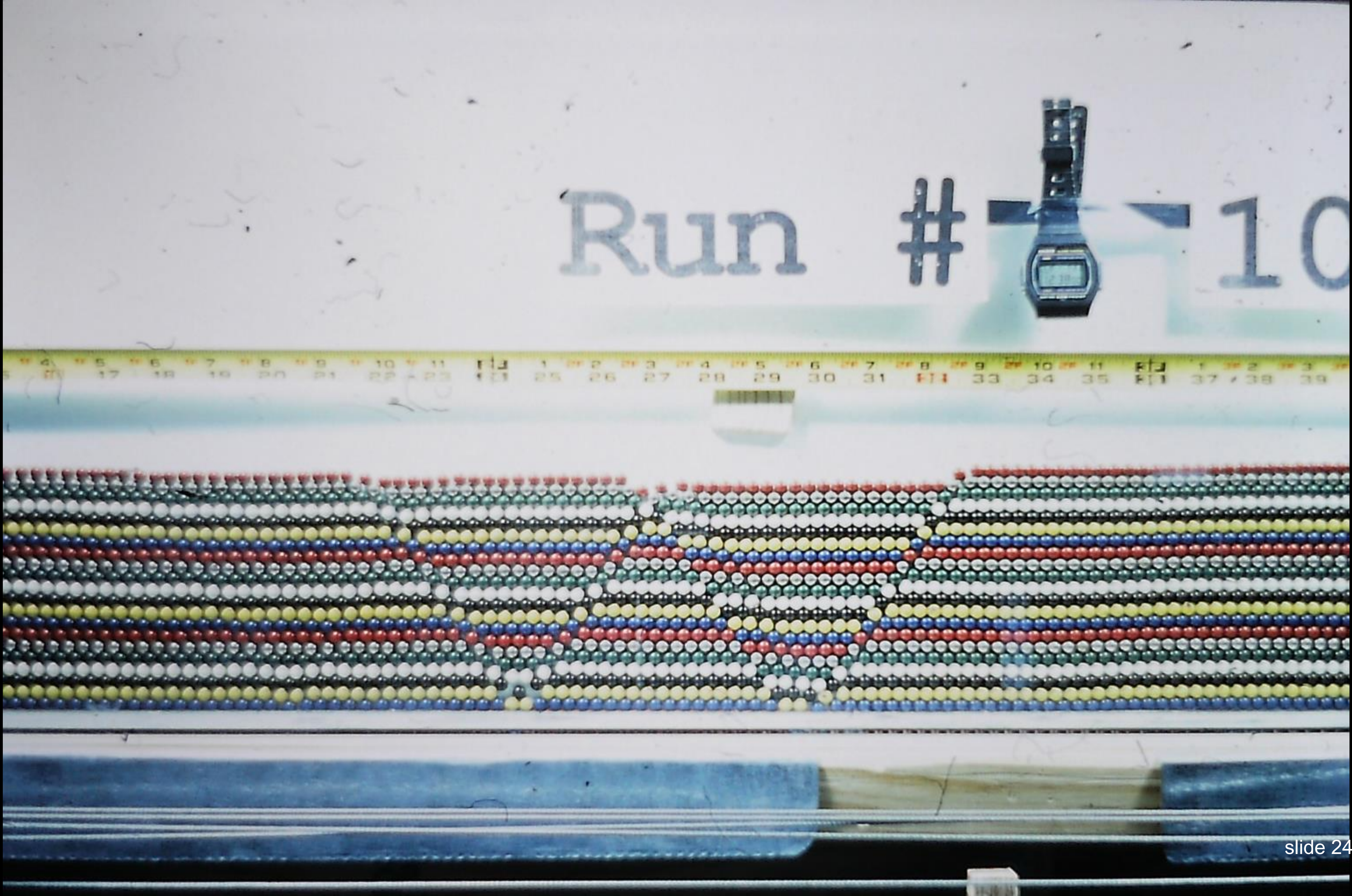
ime = 11:36:07,12:27:00,12:27:59,12:38:00,12:38:39

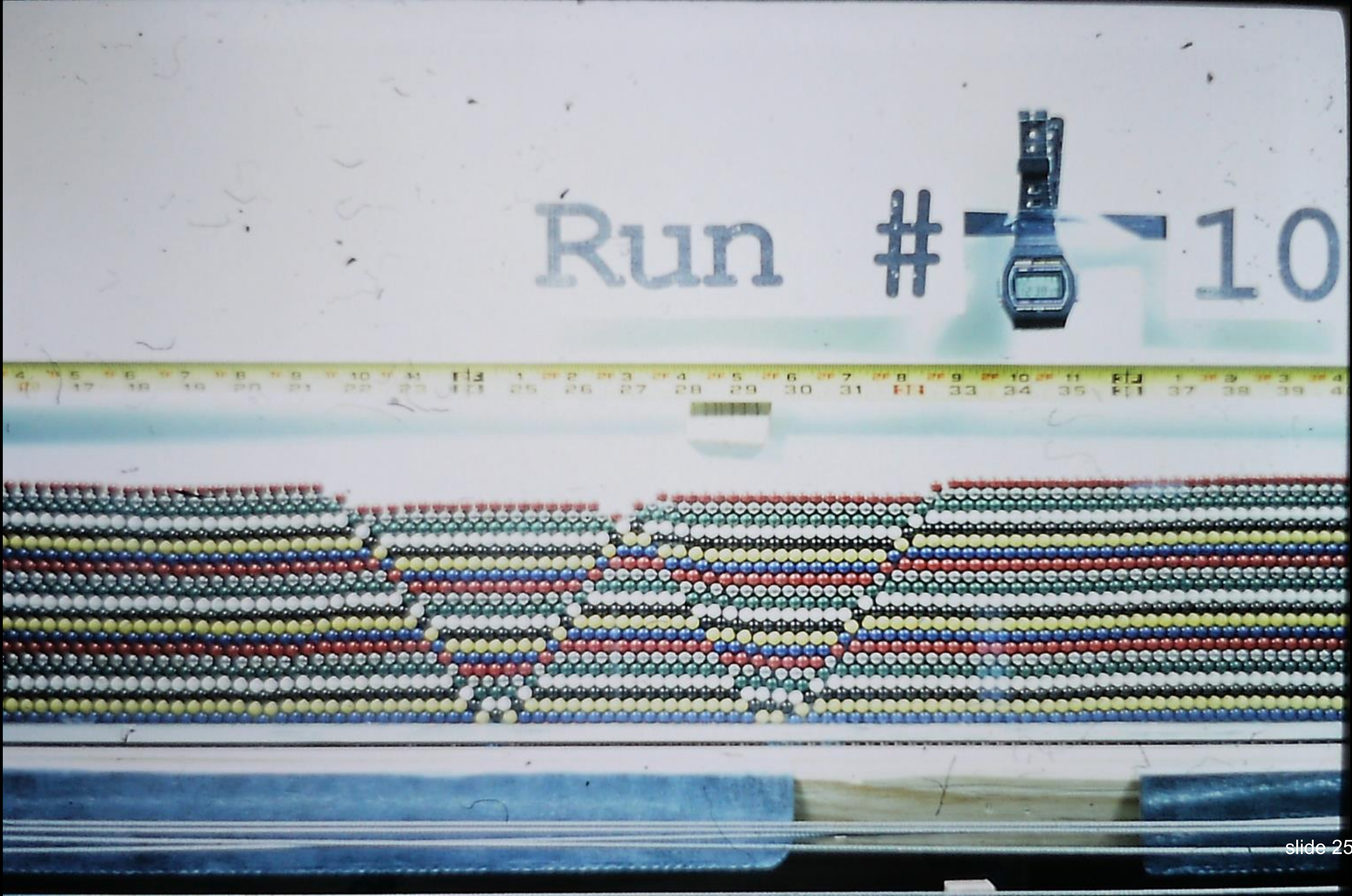
β = 1.00, 1.09, 1.09, 1.11, 1.11


Run # 10

Run #
10


Run # 10


Run # 10


Run #
10

VARYING THE NUMBER OF LAYERS

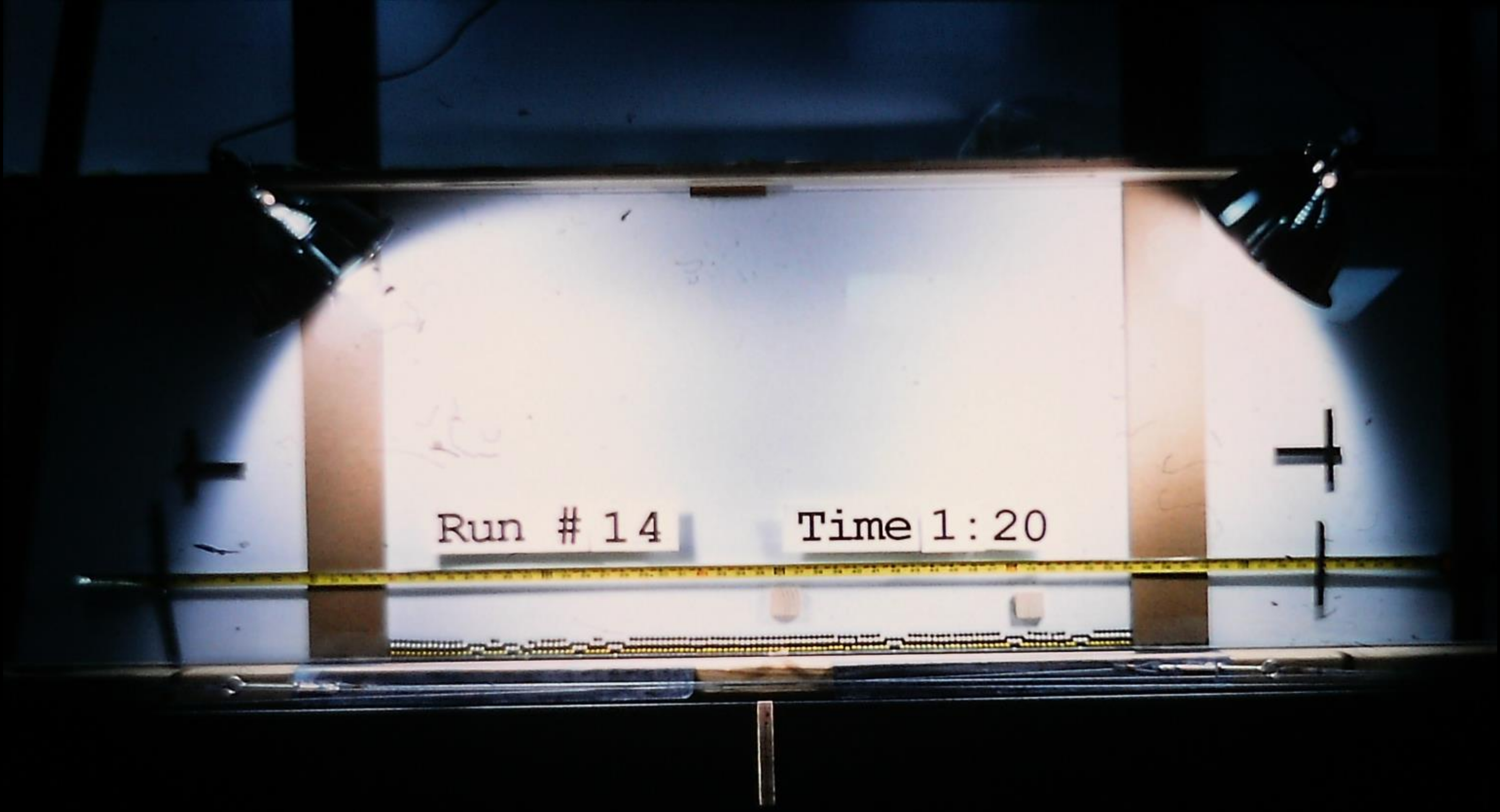
Run #14, 12, 8, 13

5, 11, 22, and 34 Layers

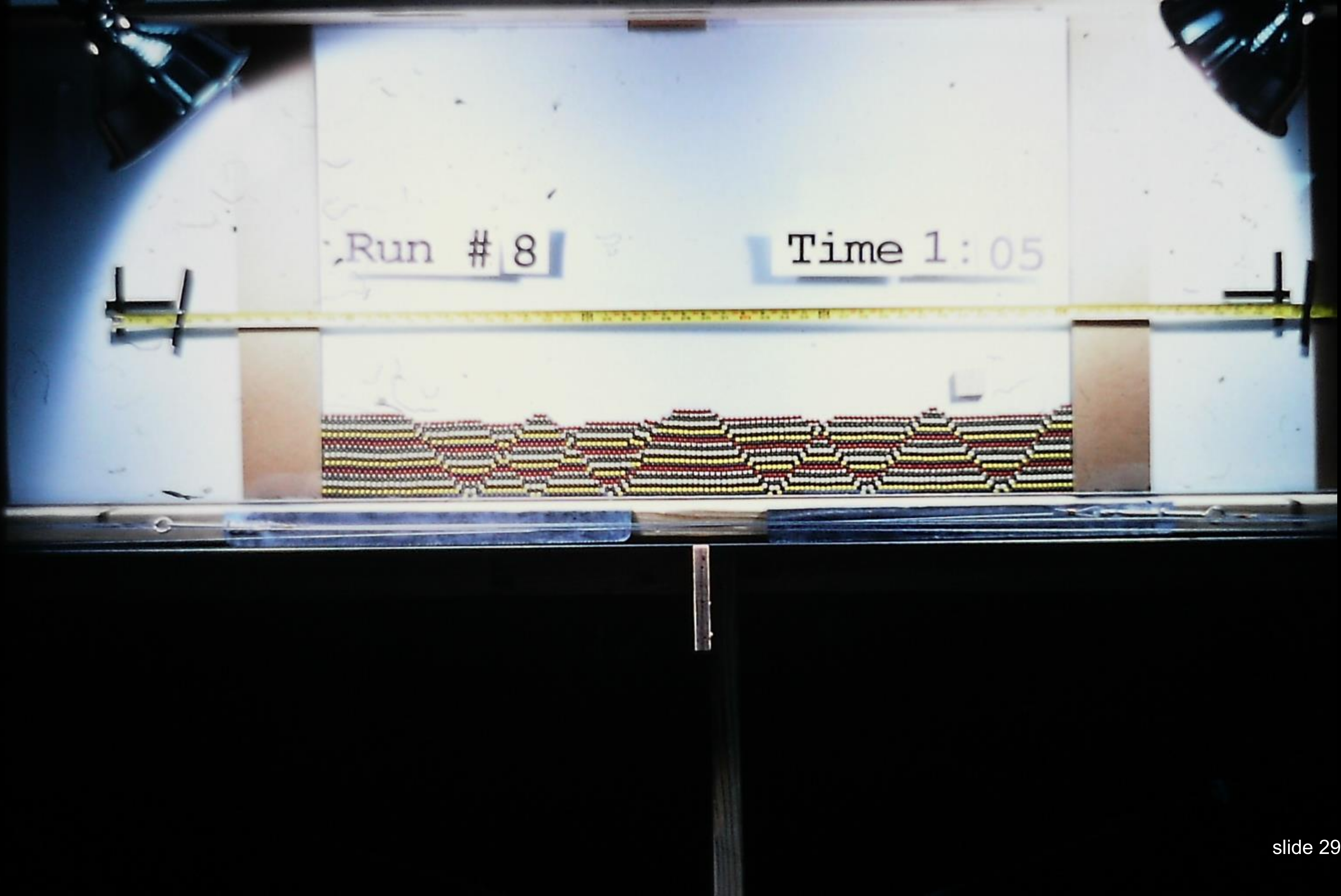
2D Close-Packed Hexagonal

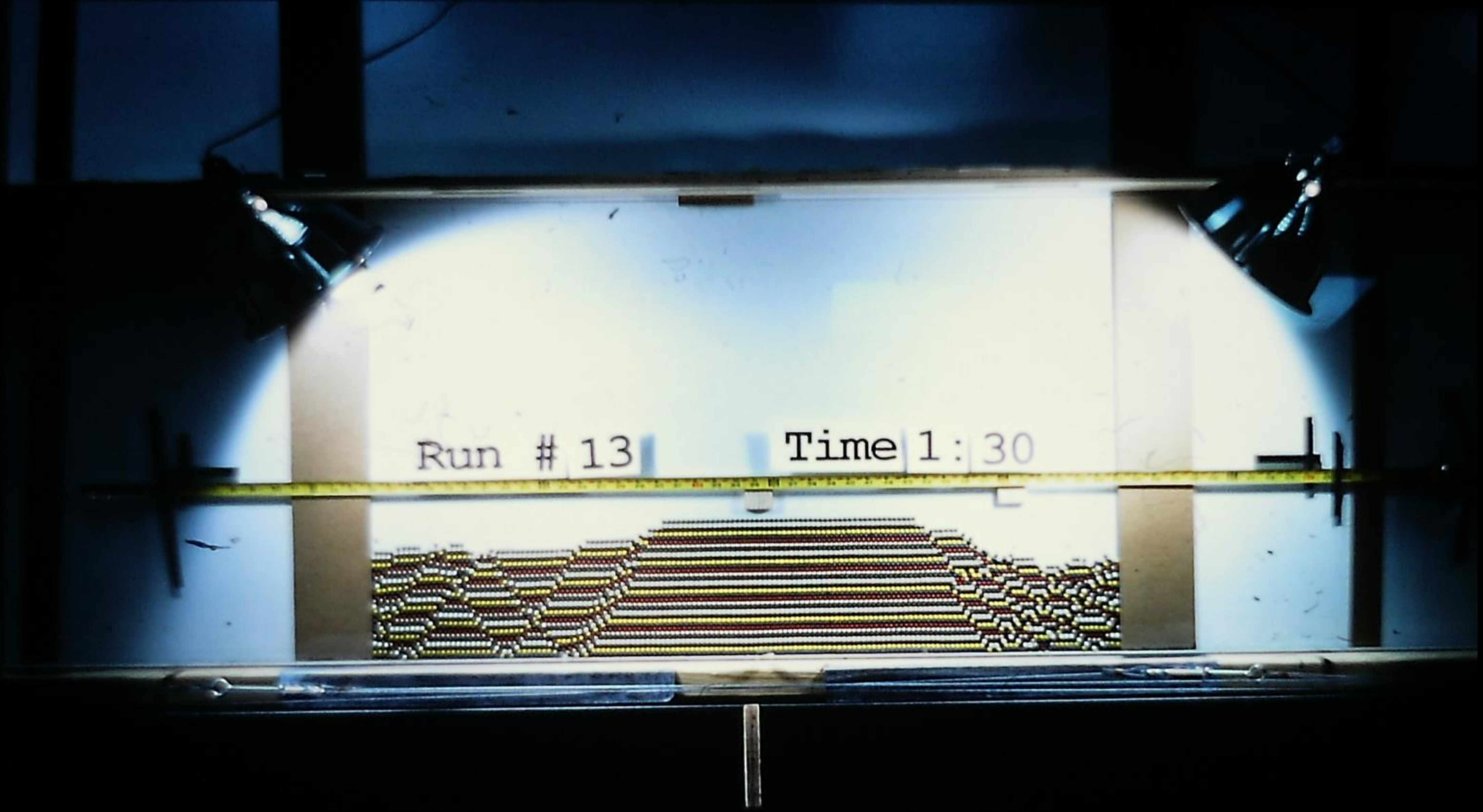
10.8 - 13.4 cm/hr

$1.15 \leq \beta \leq 1.18$


Run # 14
Time 1:20


Run # 12
Time 1:30


Run # 8
Time 1:05


Run # 13
Time 1: 30

PARALLEL FAULTS, CROSS-CUTTING FAULTS, BLOCKS

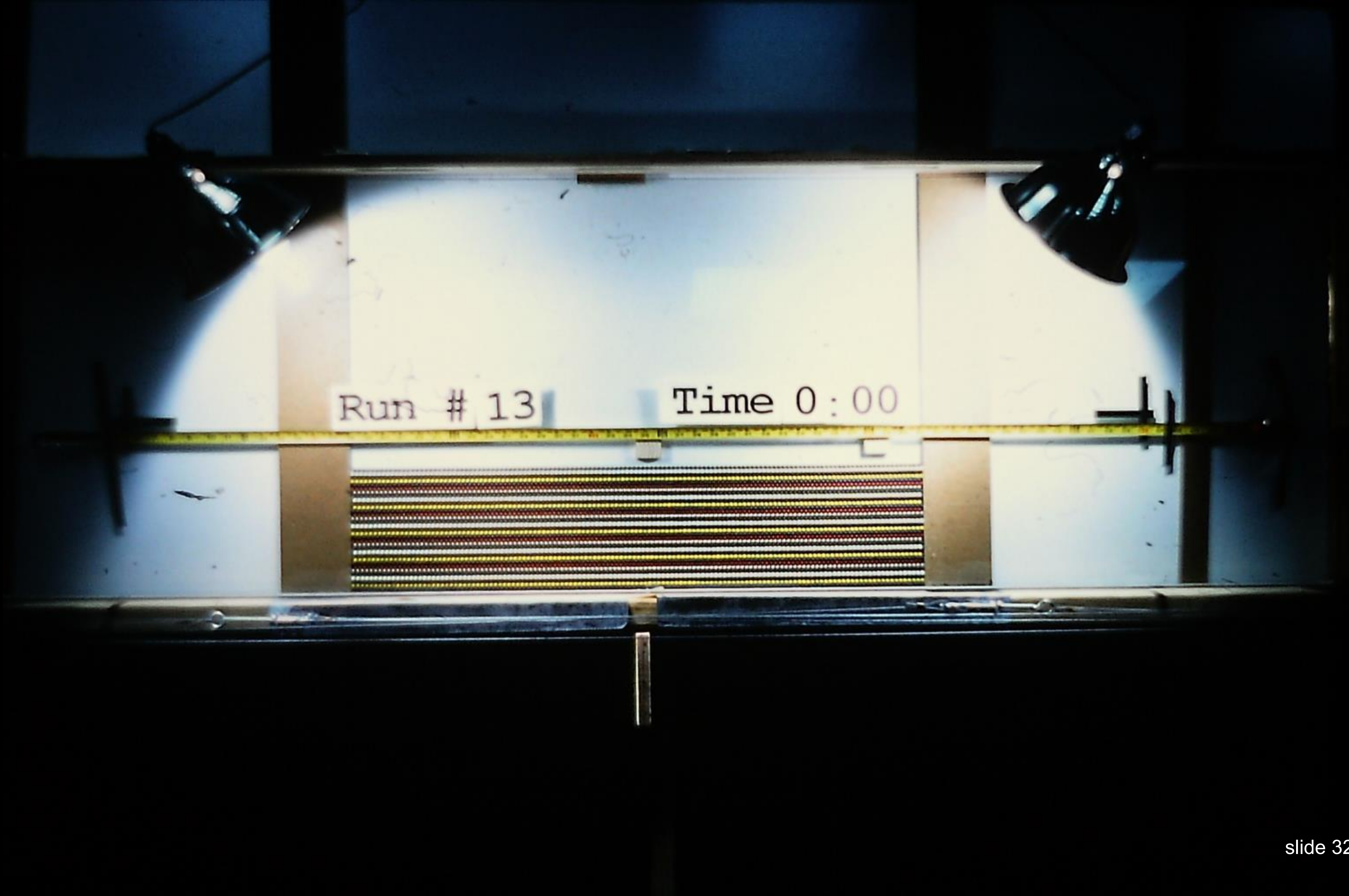
Run #13

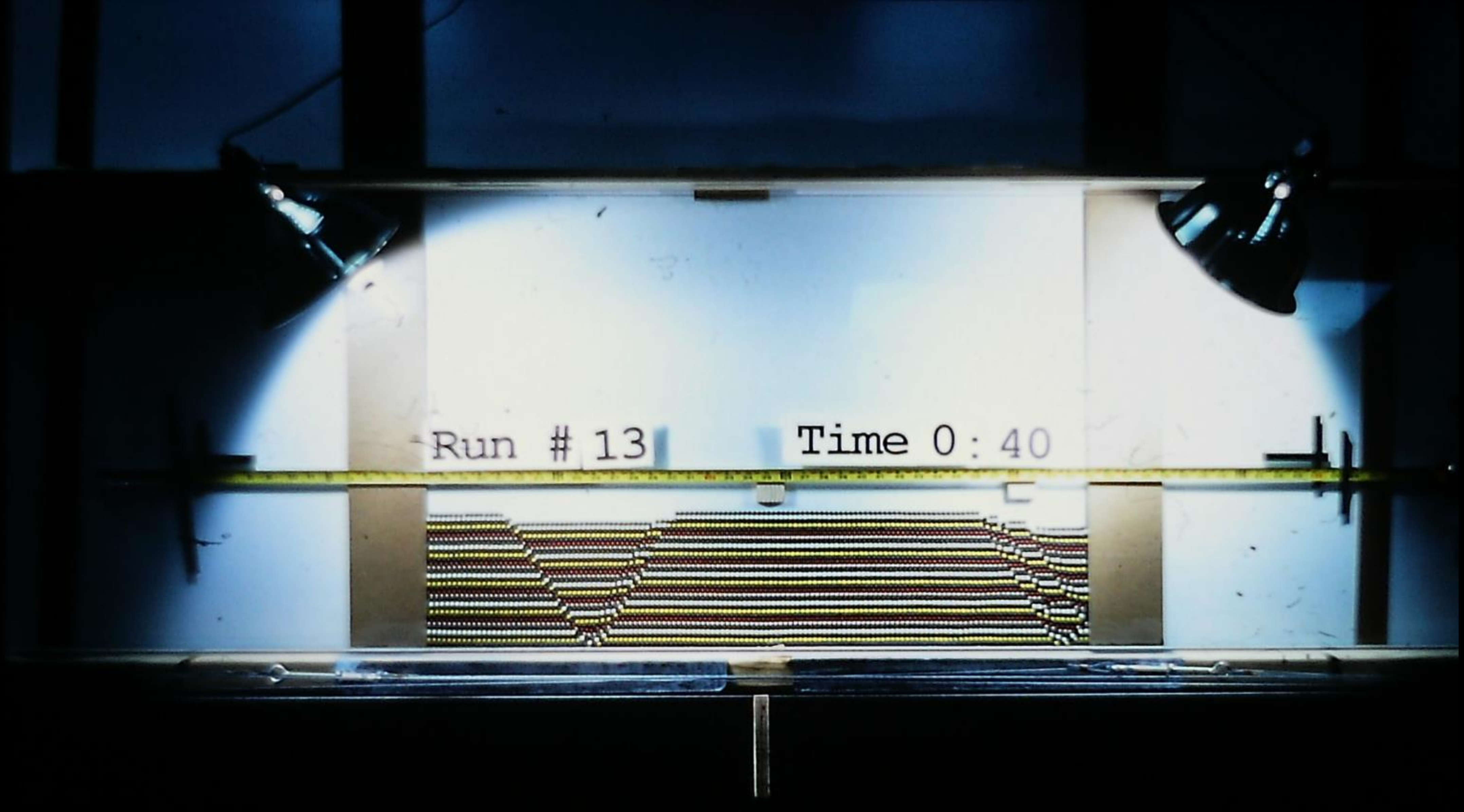
34 Layers

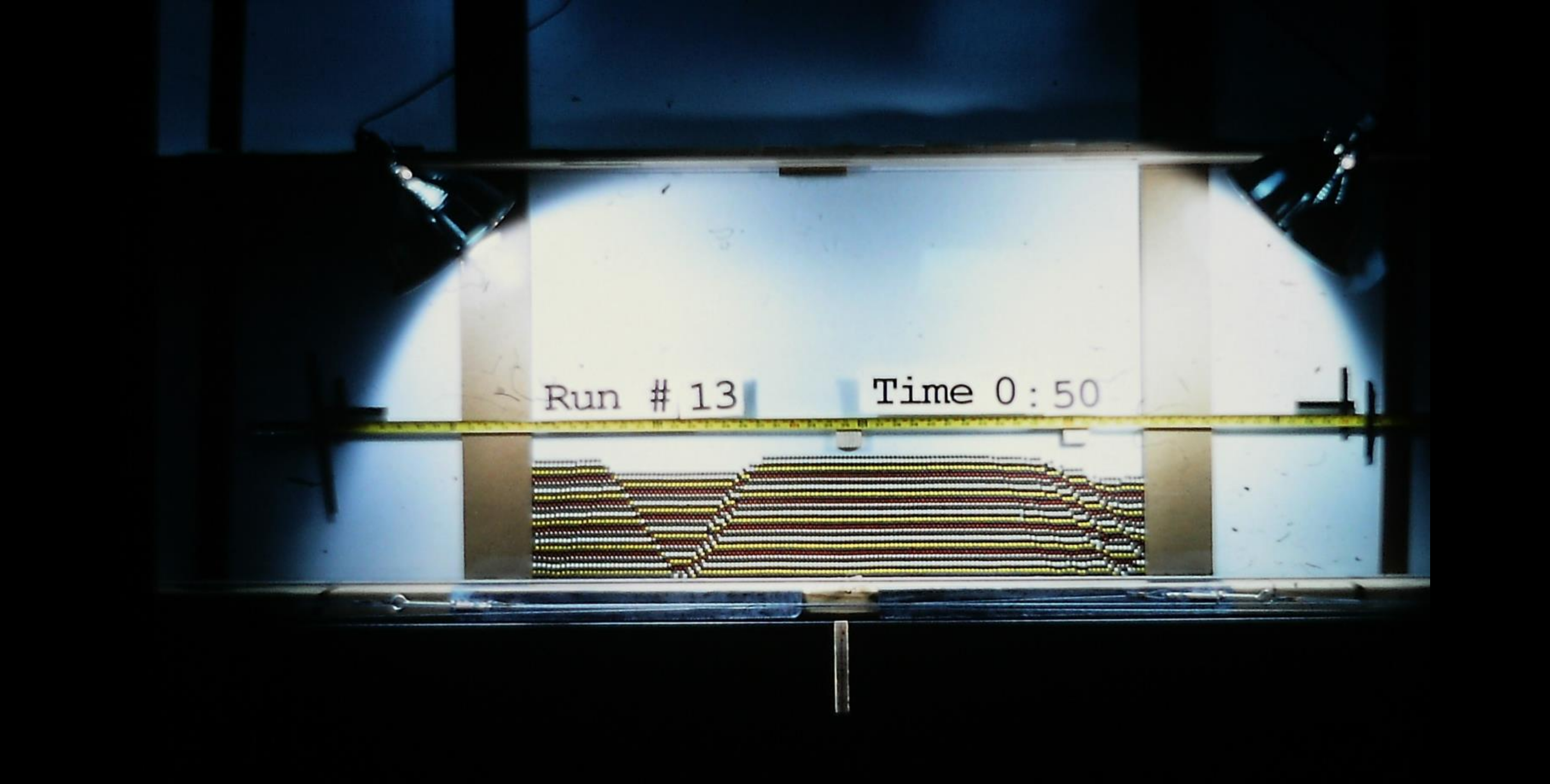
2D Close-Packed Hexagonal

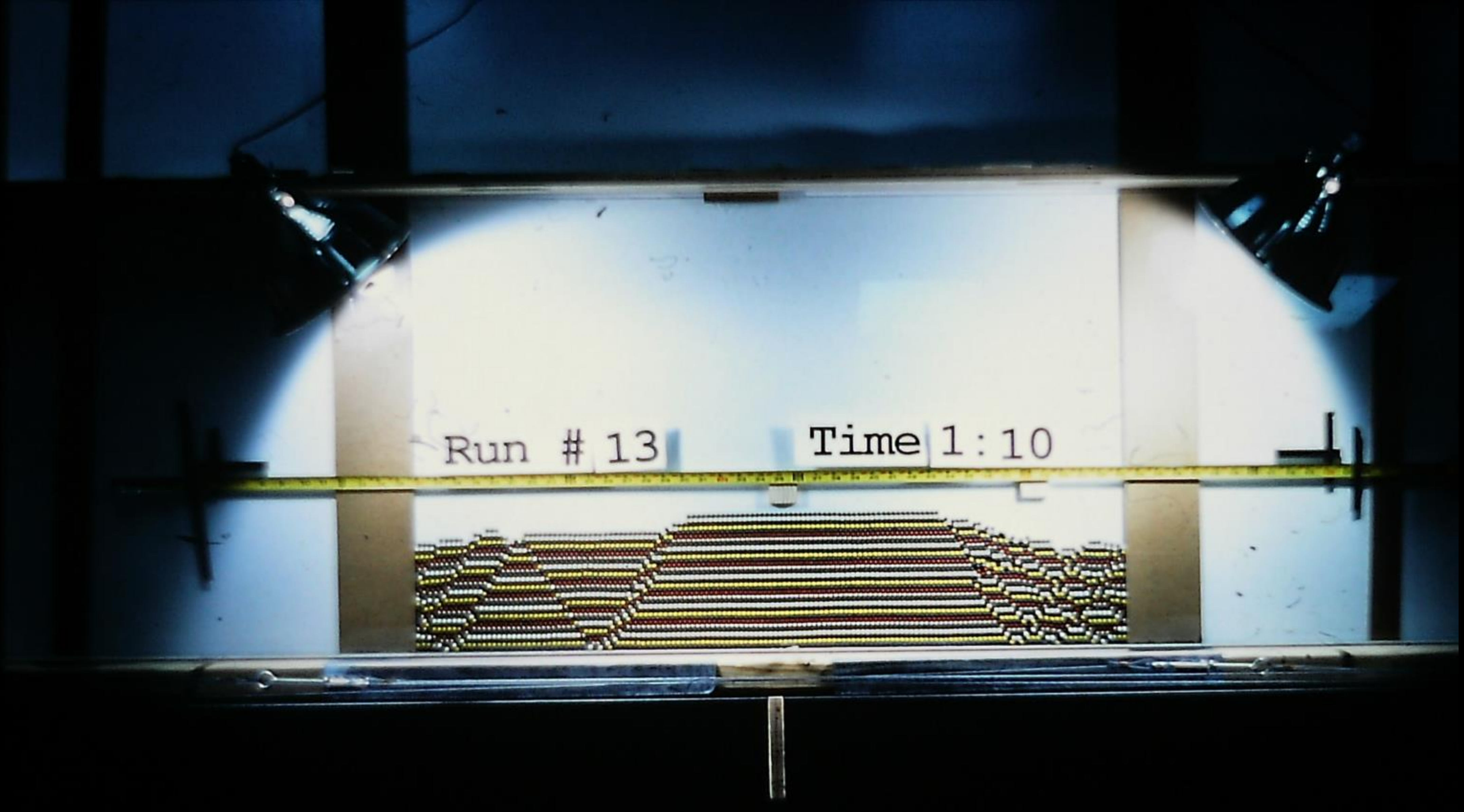
11.4 cm/hr

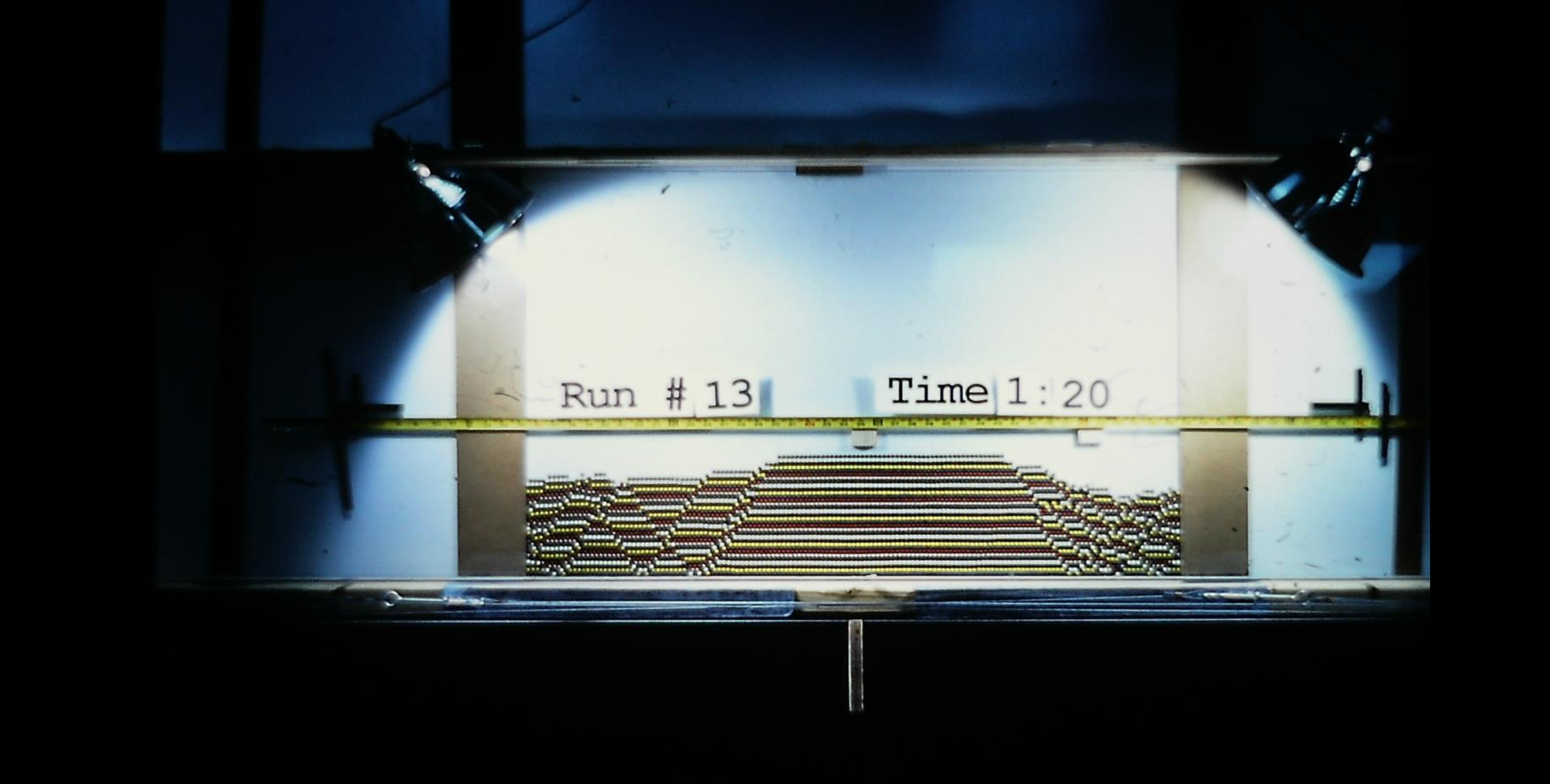
β = 1.00, 1.05, 1.08, 1.13, 1.16, 1.21, 1.24

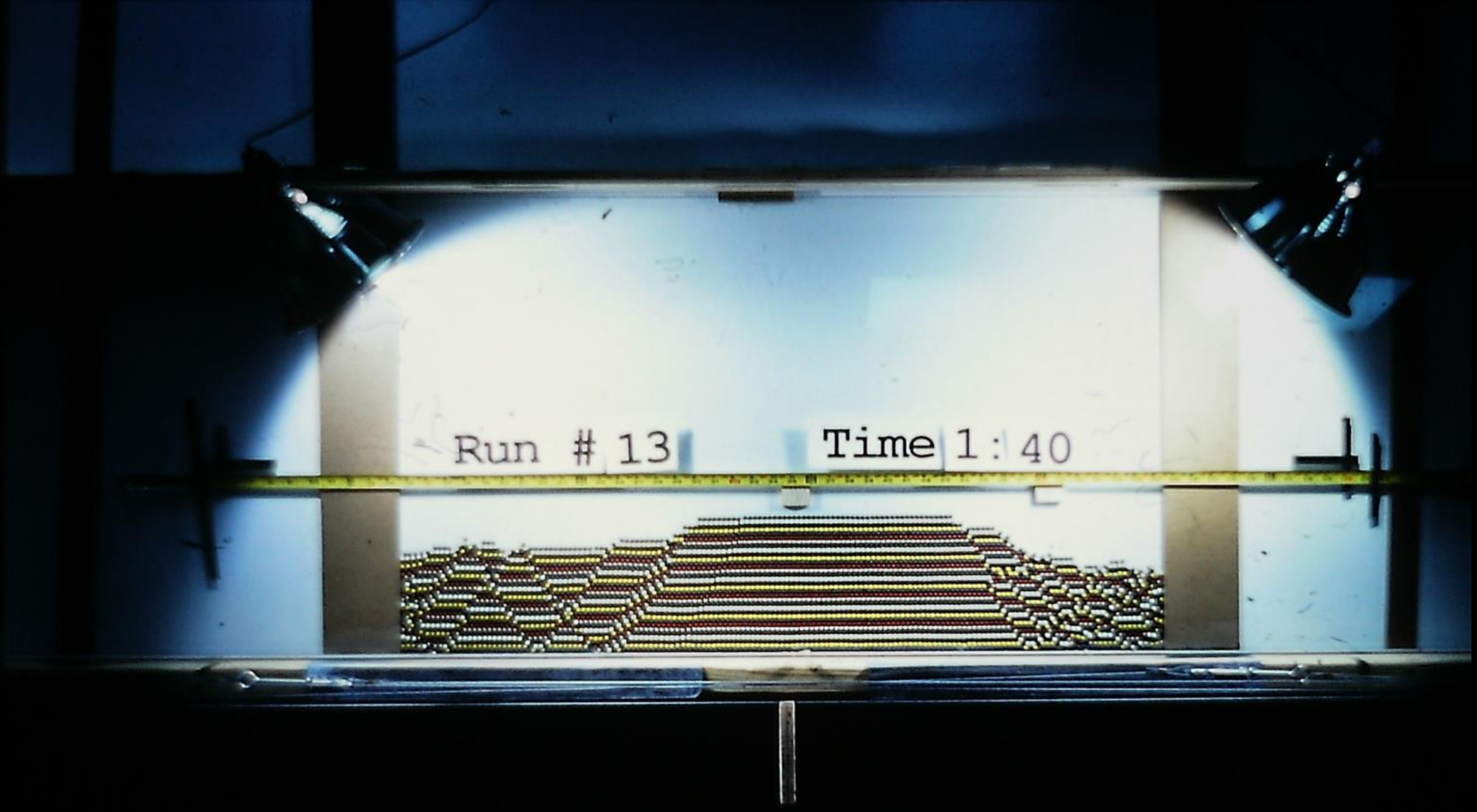

Run # 13
Time 0:00

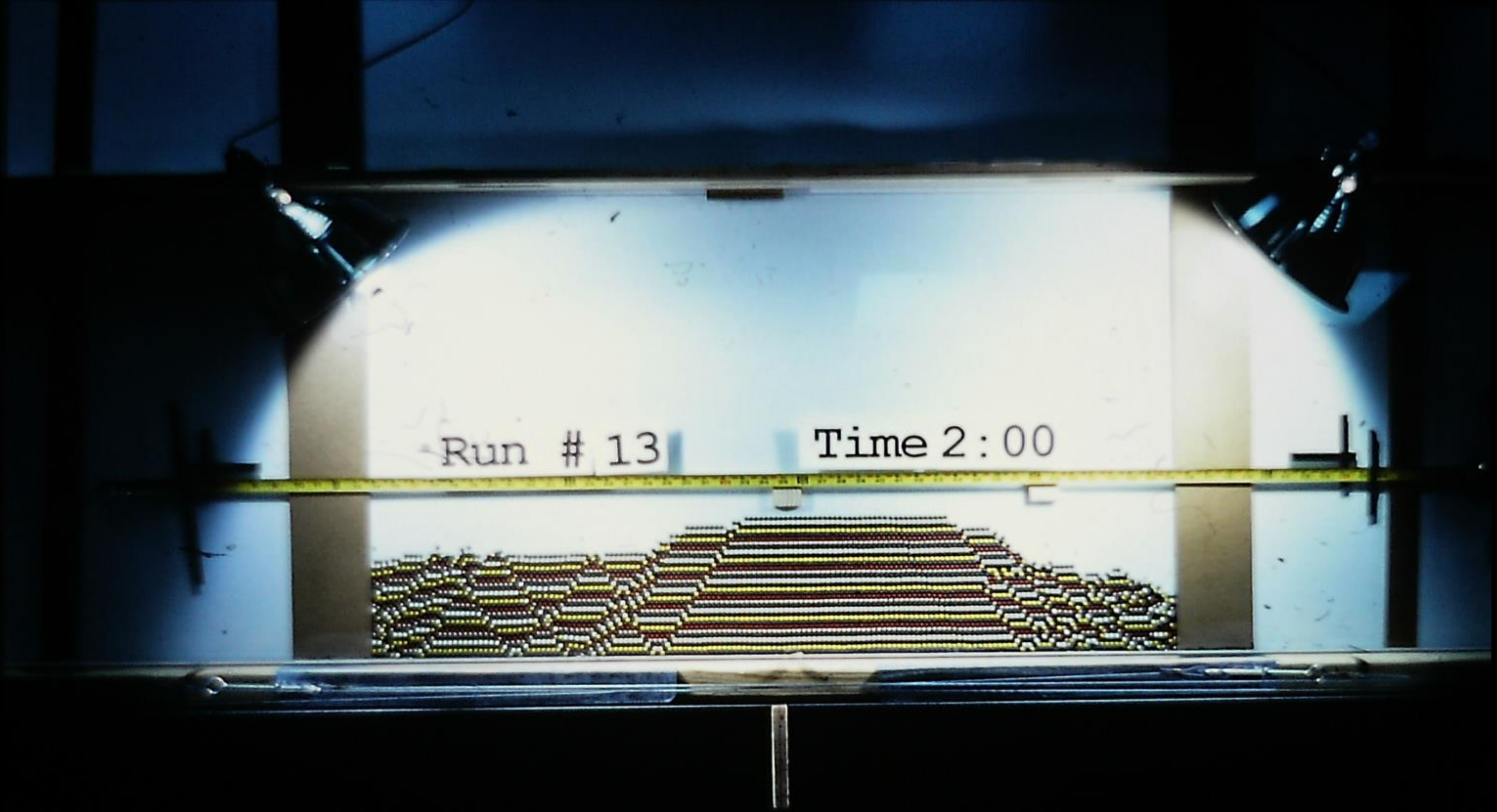

Run # 13
Time 0: 40


Run # 13
Time 0:50


Run # 13
Time 1:10


Run # 13
Time 1:20


Run # 13
Time 1:40


Run # 13
Time 2:00

ROTATION OF BALLS DURING FAULTING

Run #21

5 Layers 1" Balls

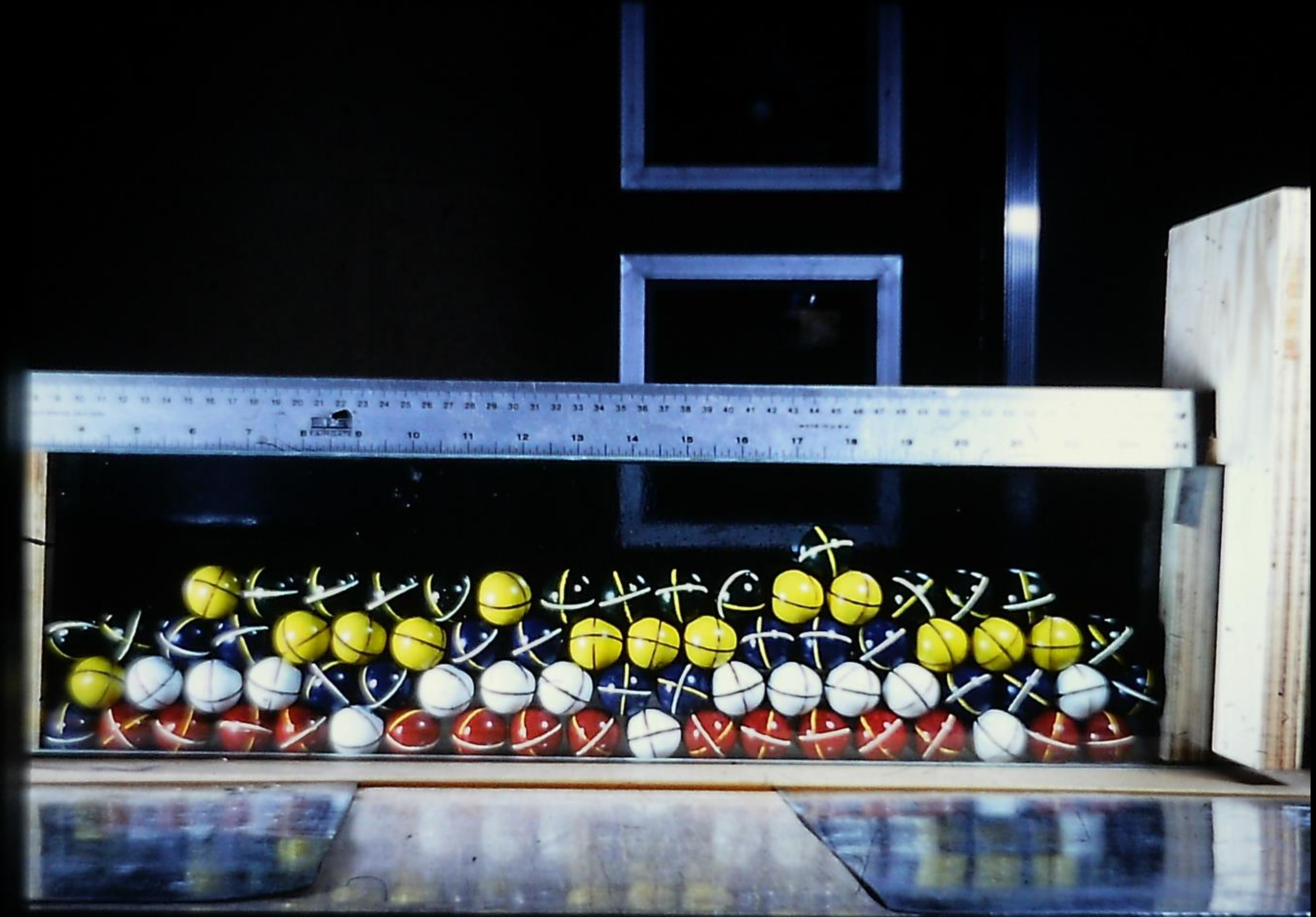
2D Close-Packed Hexagonal

7.4 cm/hr

β = 1.00, 1.09, 1.16, 1.19, 1.22, 1.32, 1.35, 1.36, 1.45

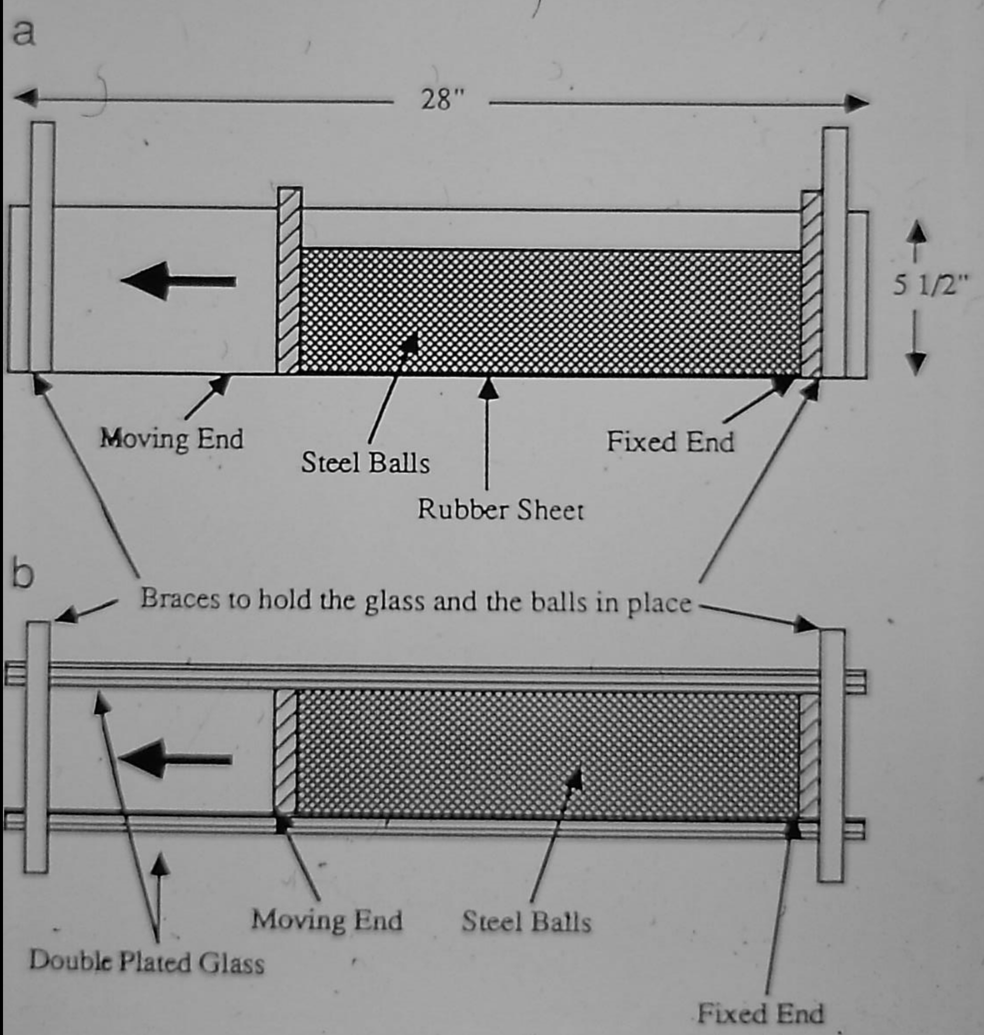
slide 42

slide 44



3D APPARATUS

SIDE & TOP VIEW



3D EXPERIMENT, SINGLE-SIZED BALLS

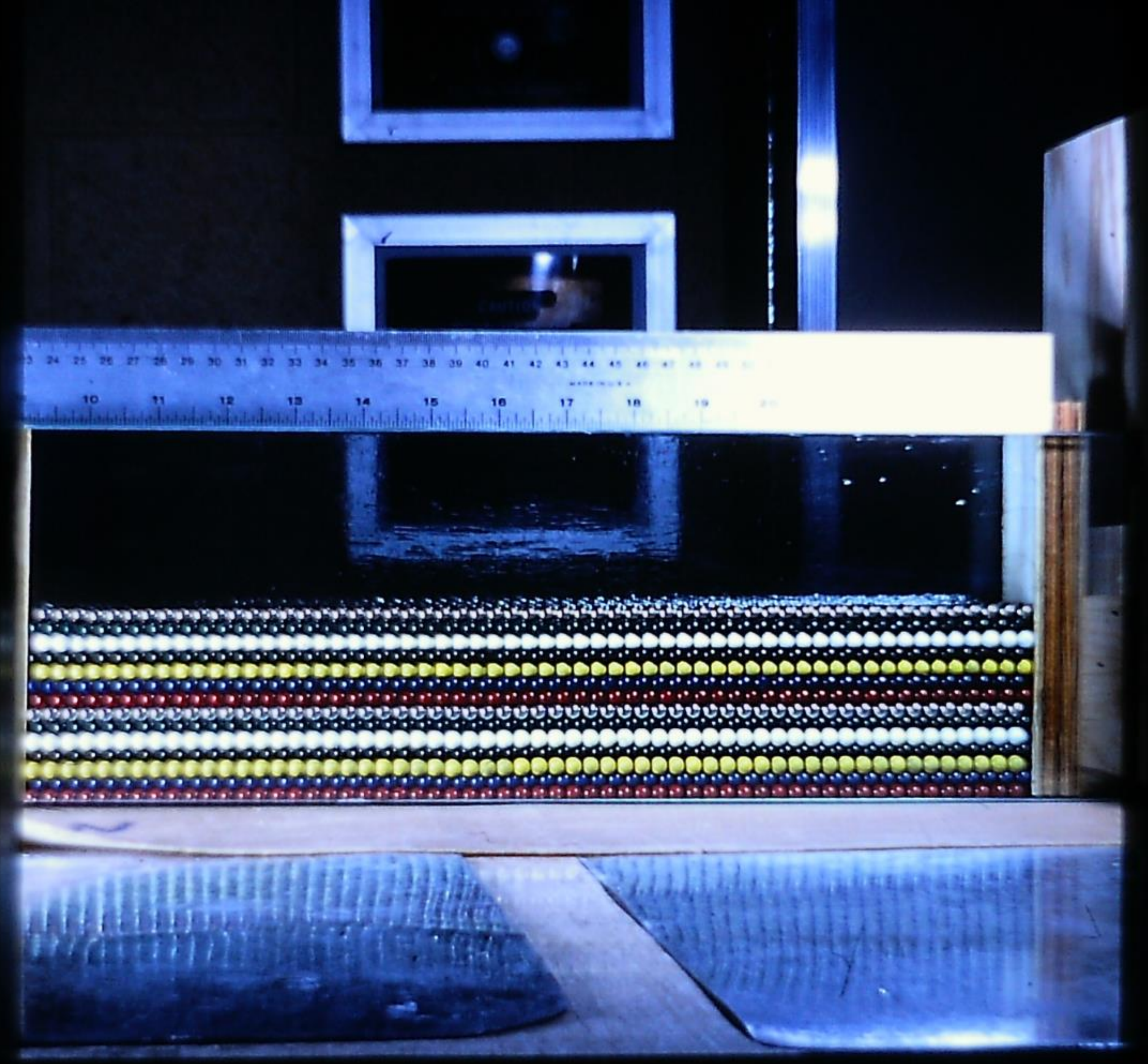
Run #23

14 Layers, 1/4" Balls

Attempted 3D Close-Packed Hexagonal

7.0 cm/hr

β = 1.00, 1.08, 1.18, 1.28, 1.46, released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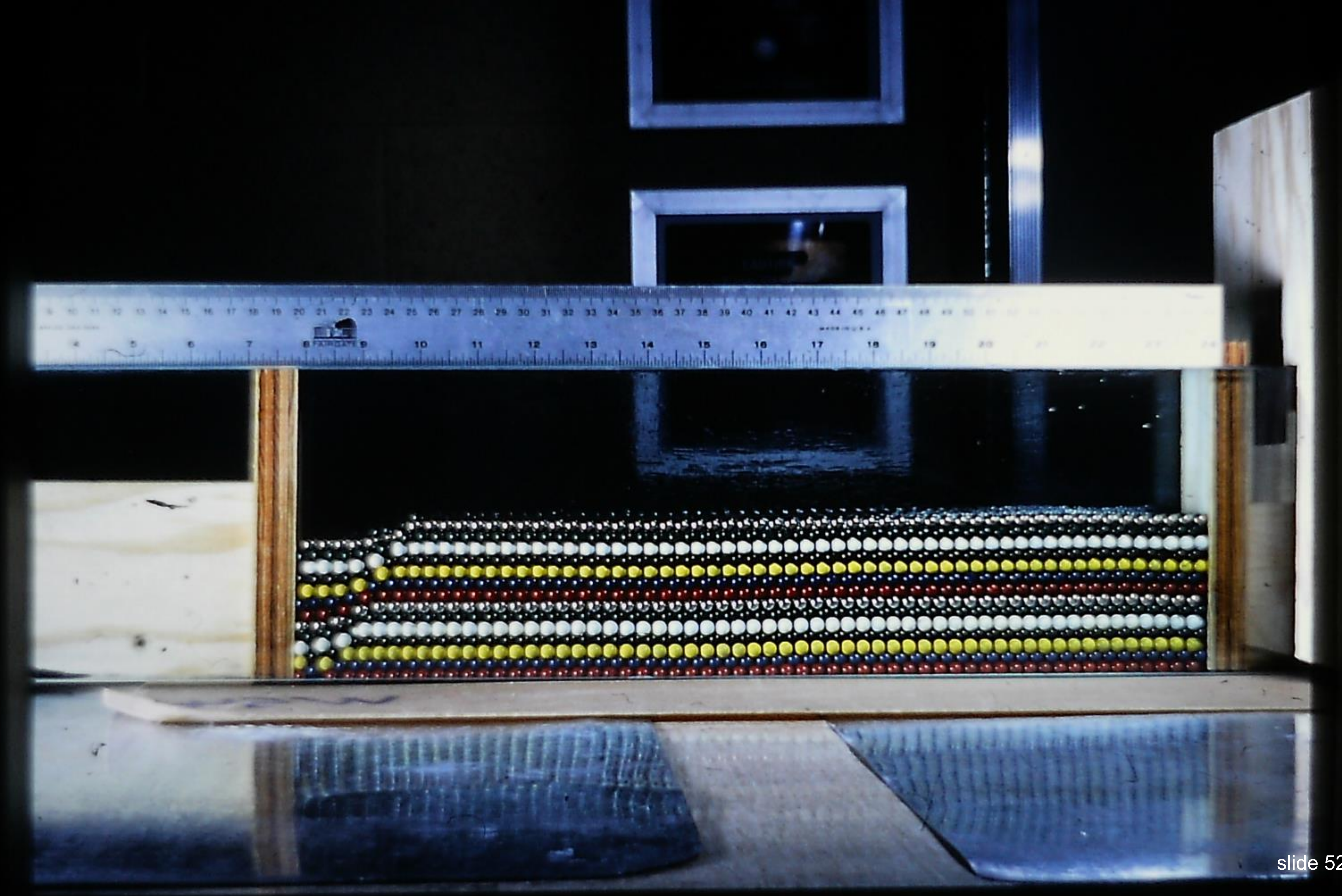
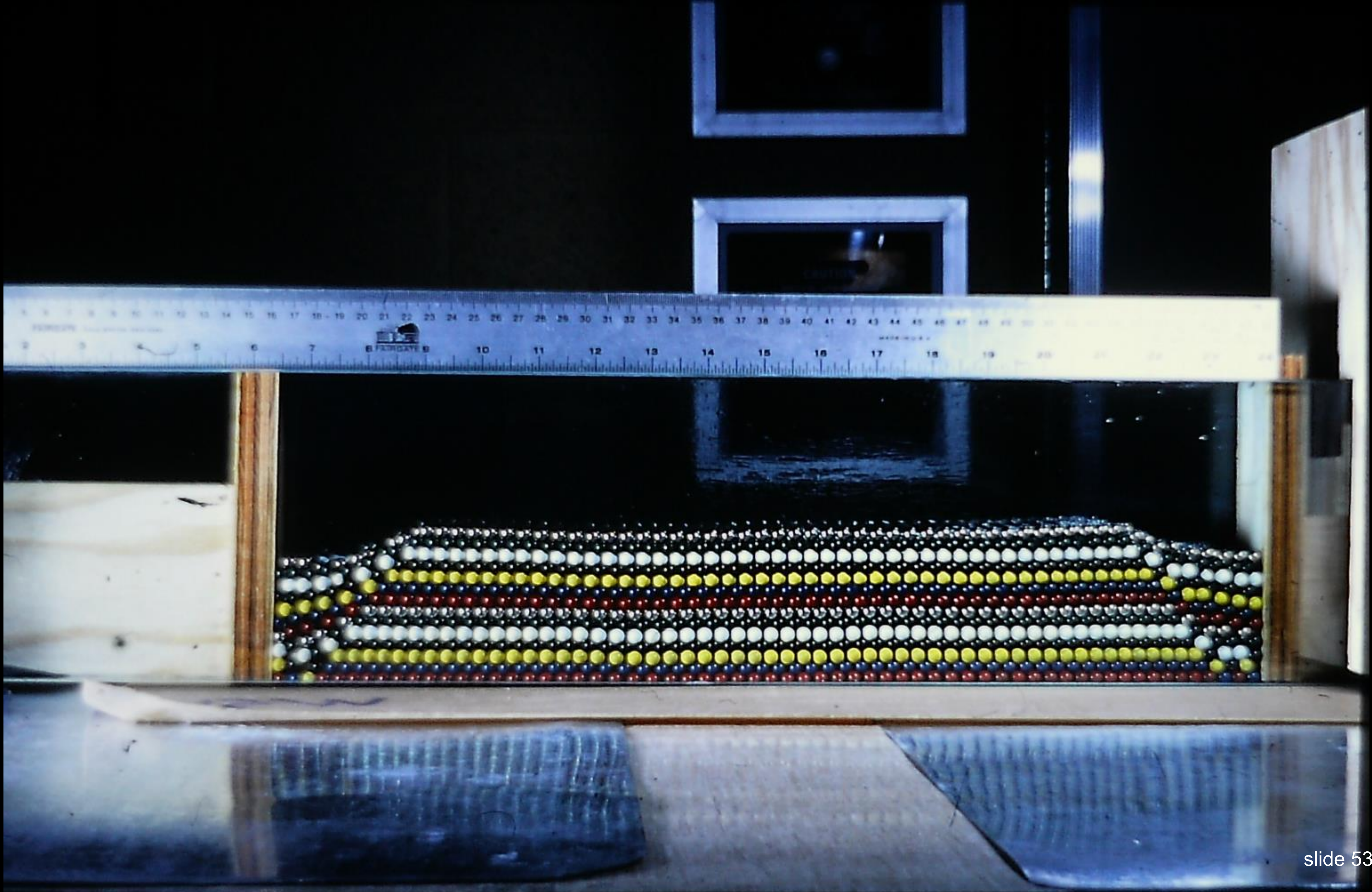
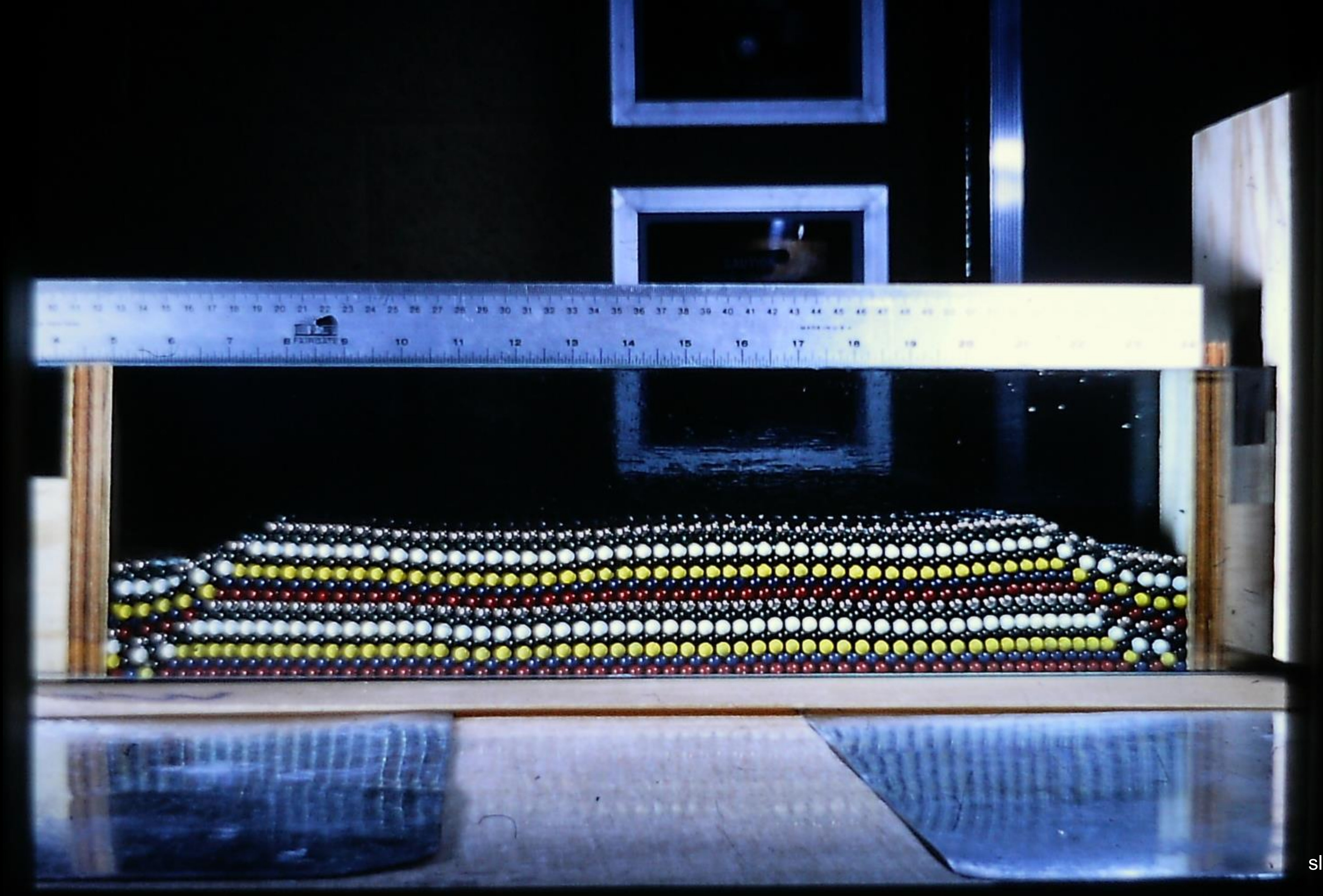
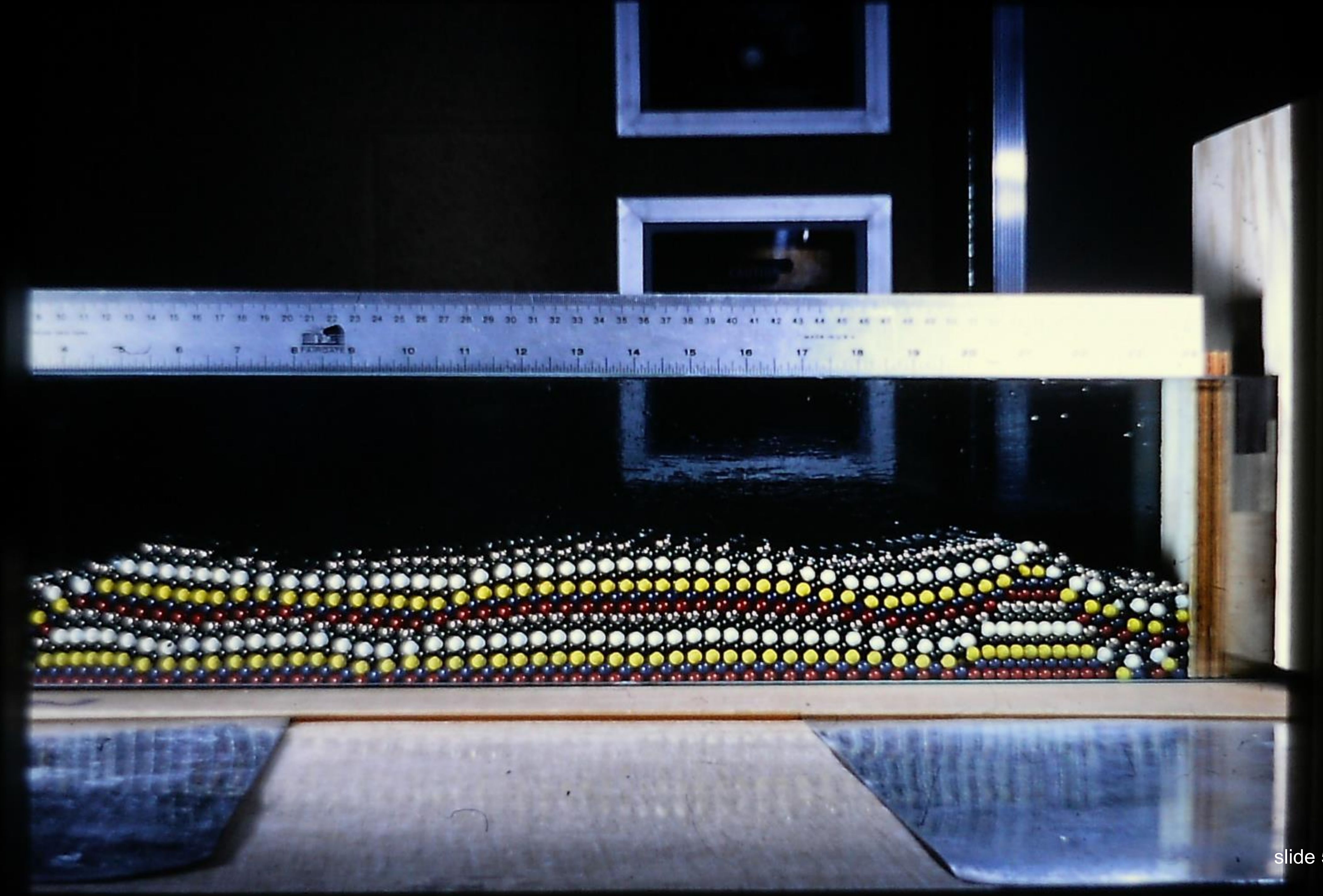


slide 52

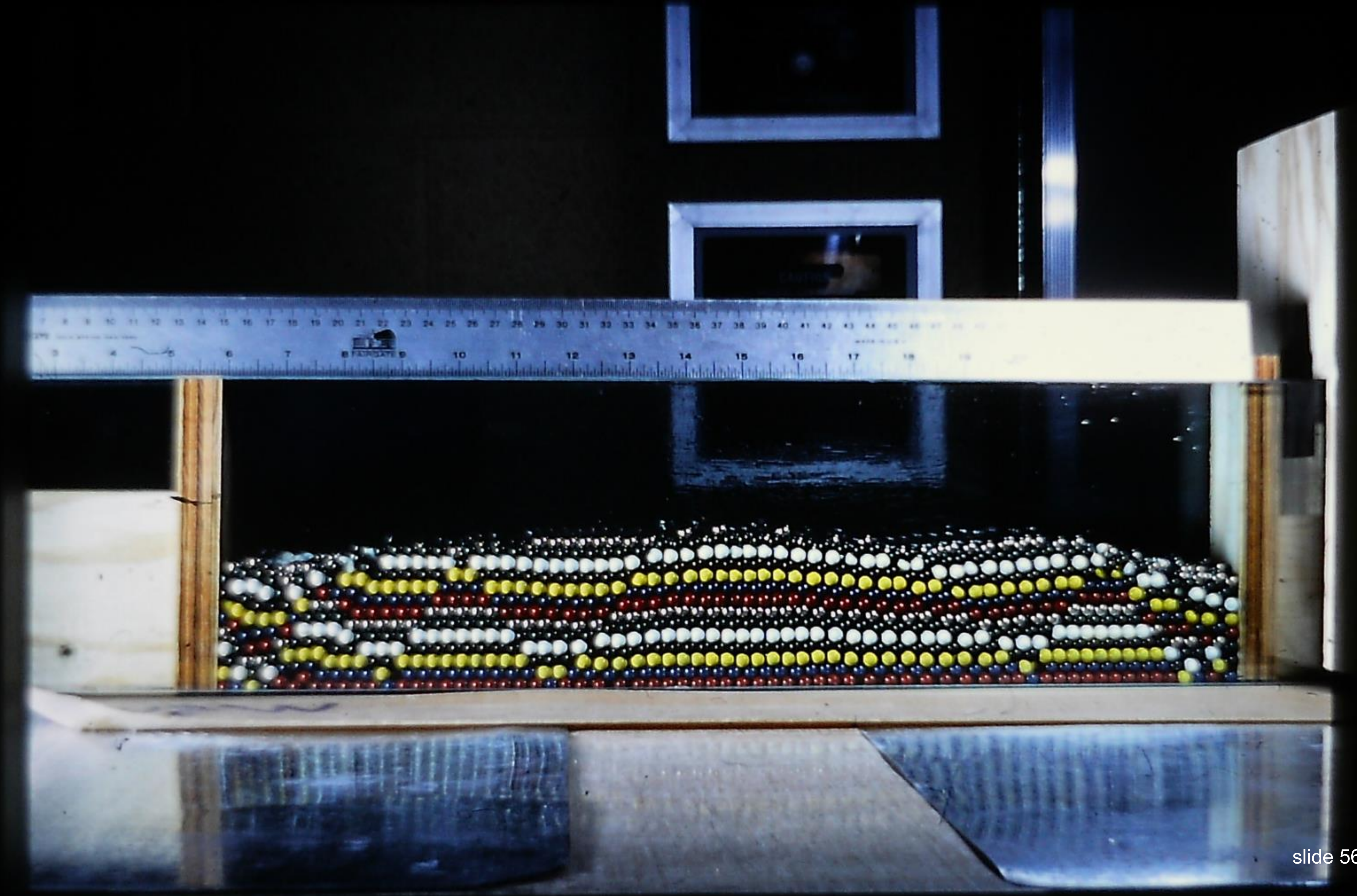




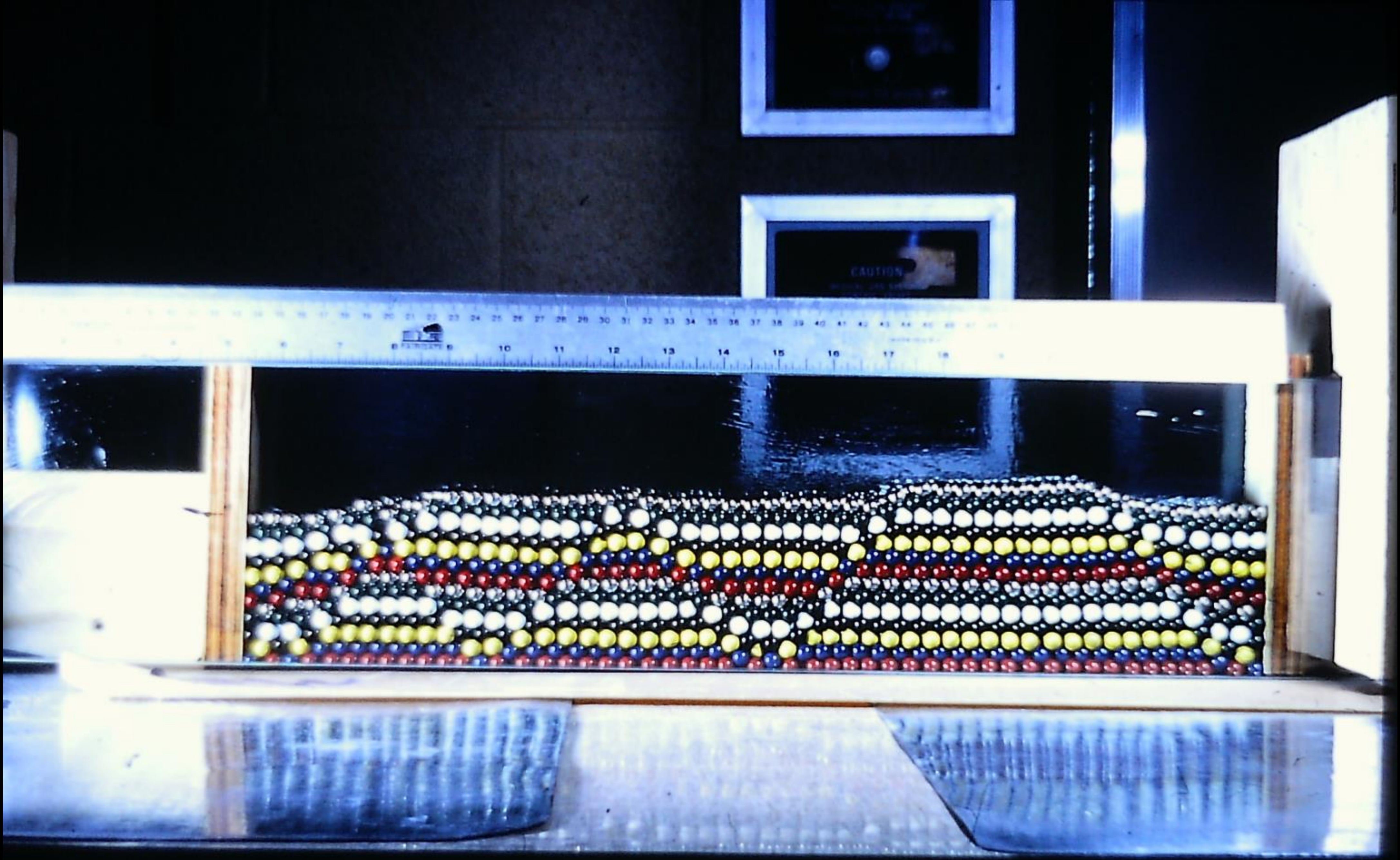
slide 54



slide 55



slide 56


CAUTION

3D EXPERIMENT, SINGLE-SIZED BALLS

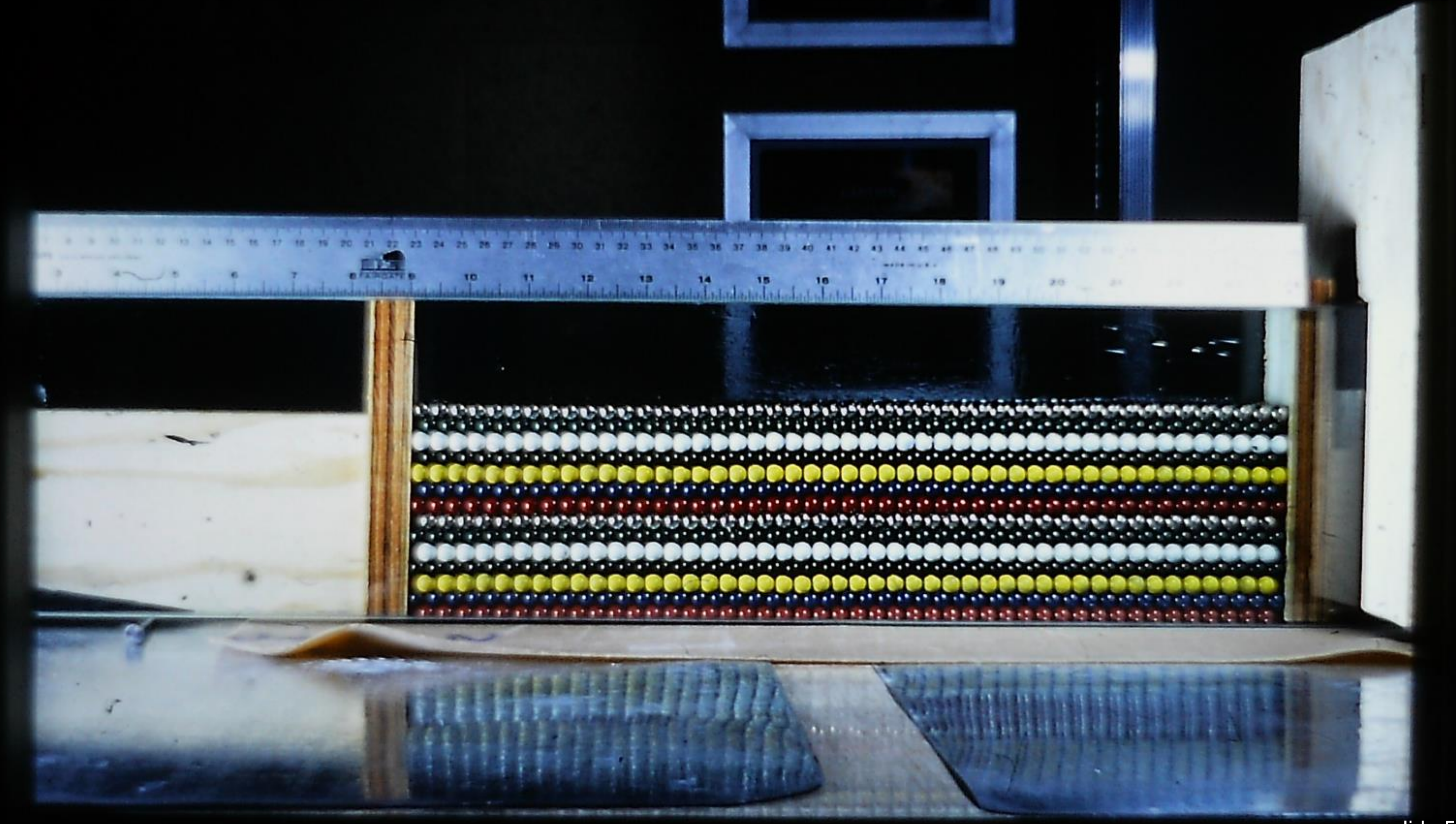
Run #24

14 Layers, 5/16" Balls

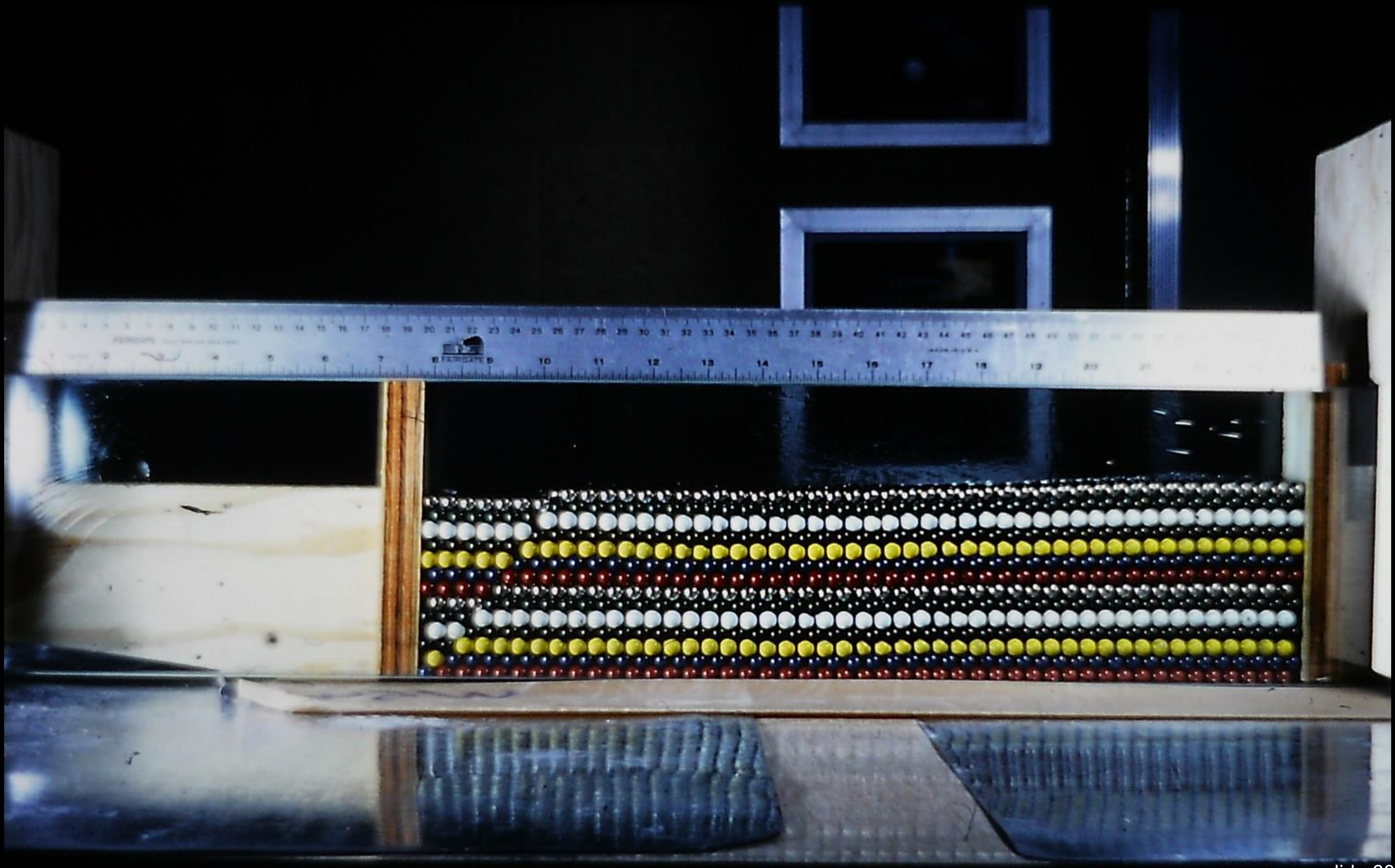
3D Close-Packed Hexagonal

7.1 cm/hr

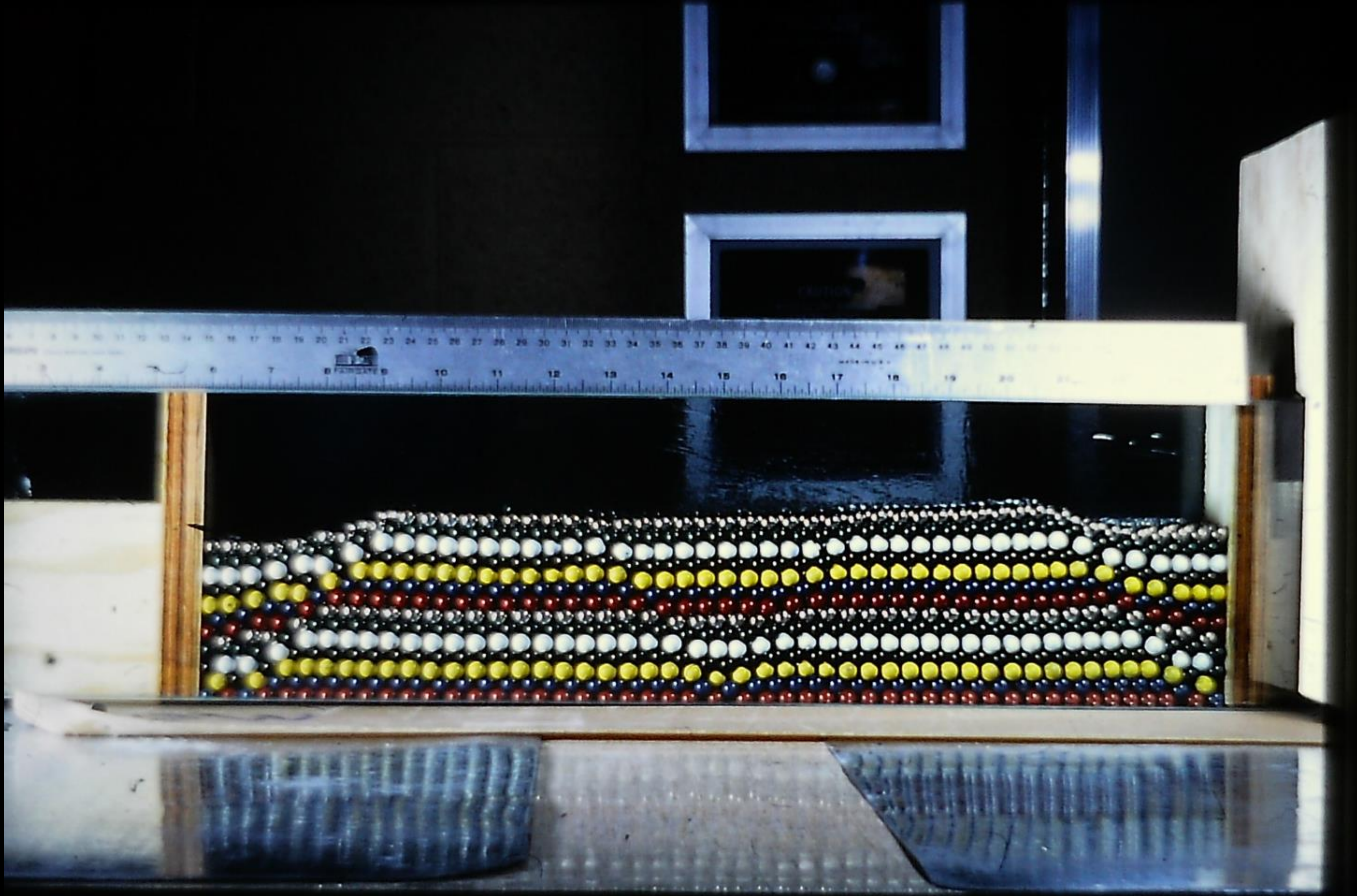
= 1.00, 1.08, 1.21, 1.25, 1.28, 1,38, 1.47, released

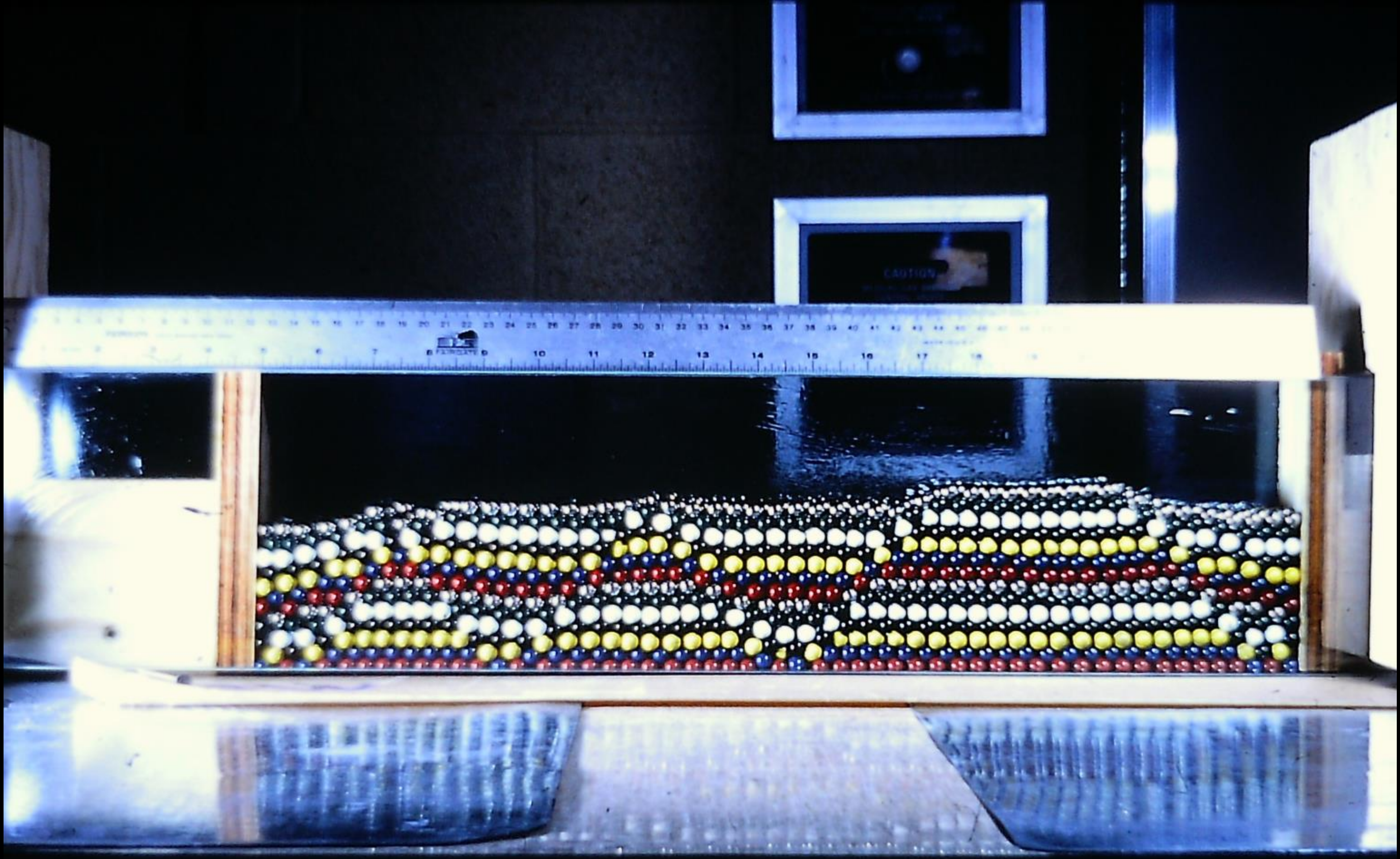


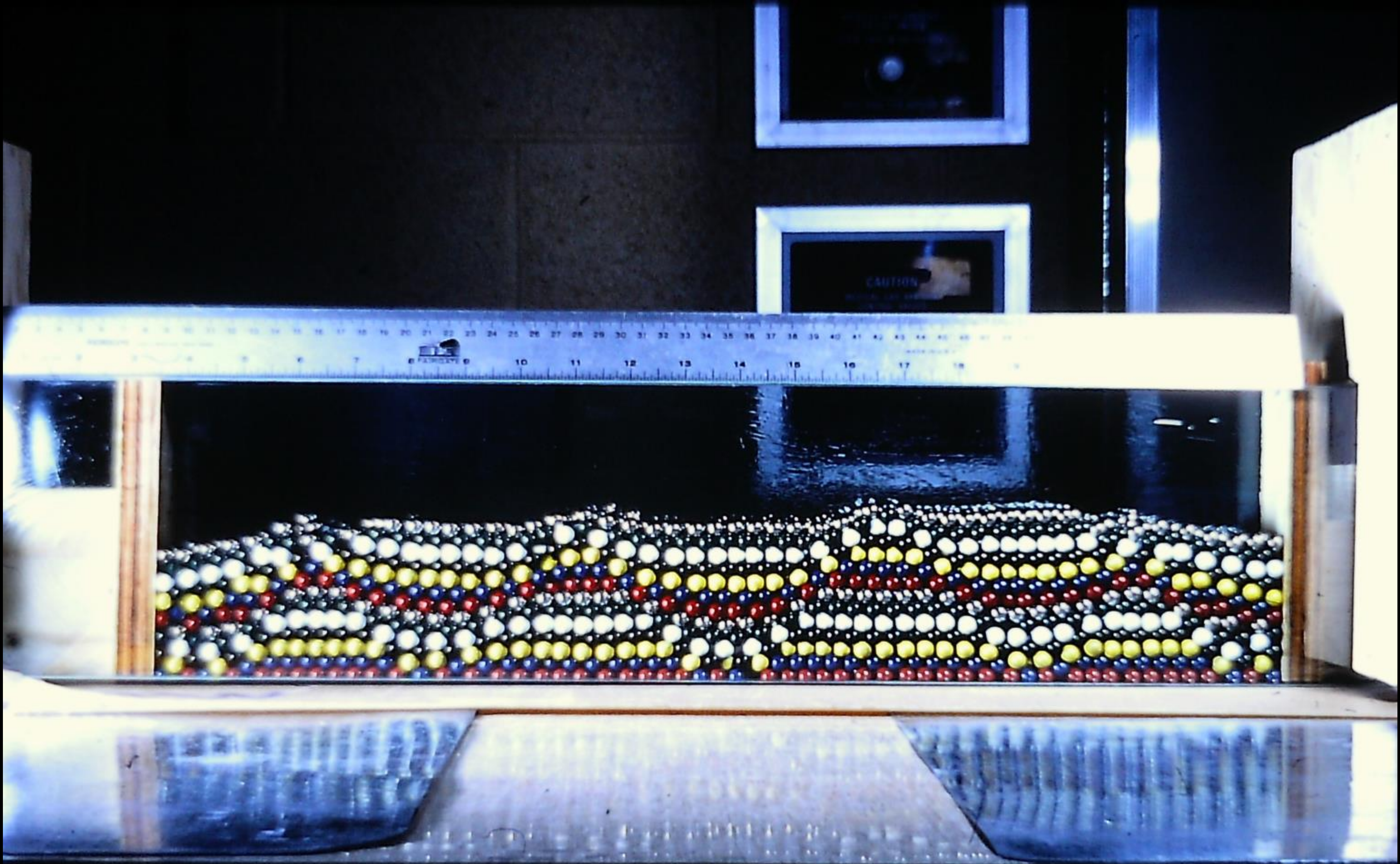
slide 59

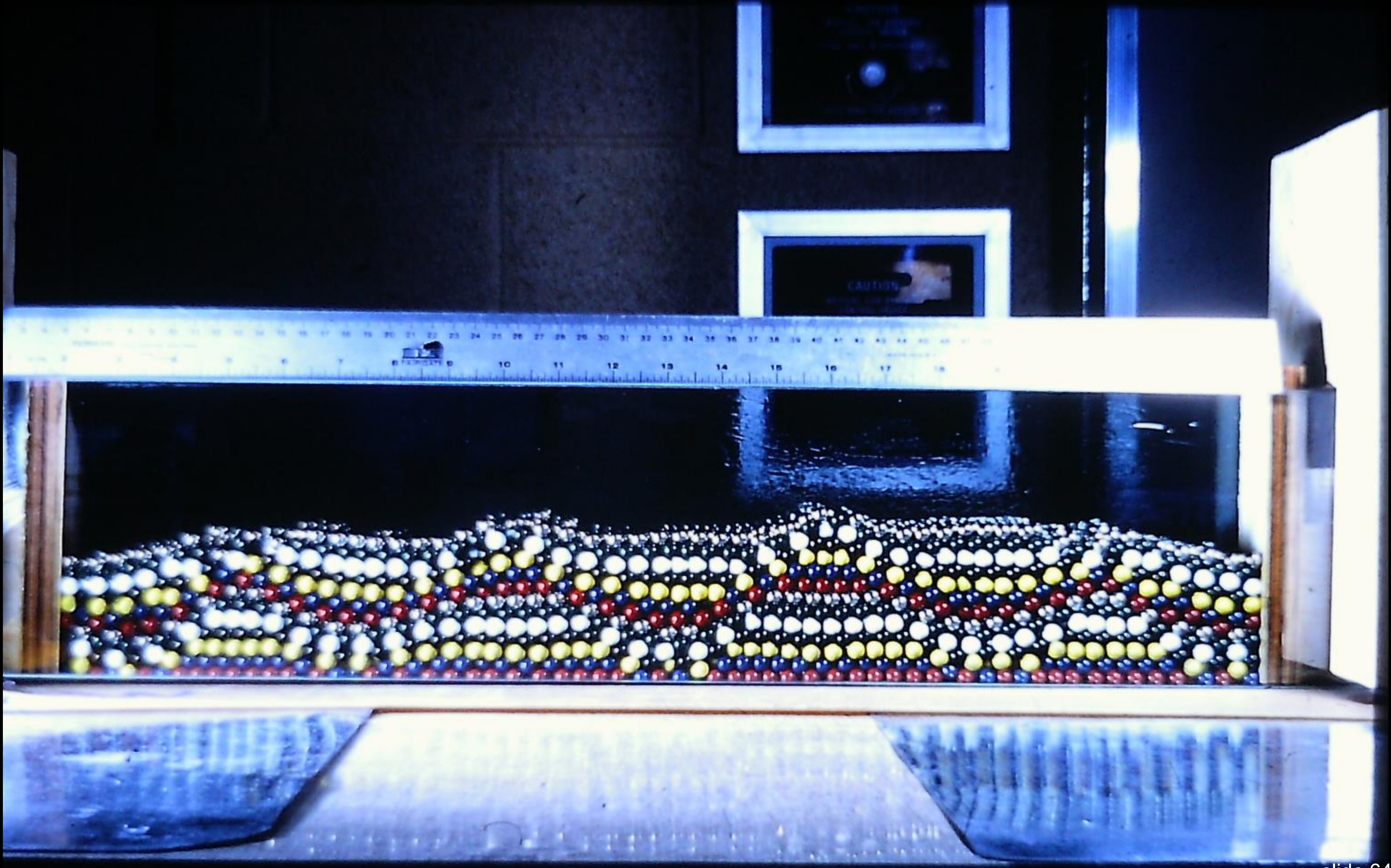


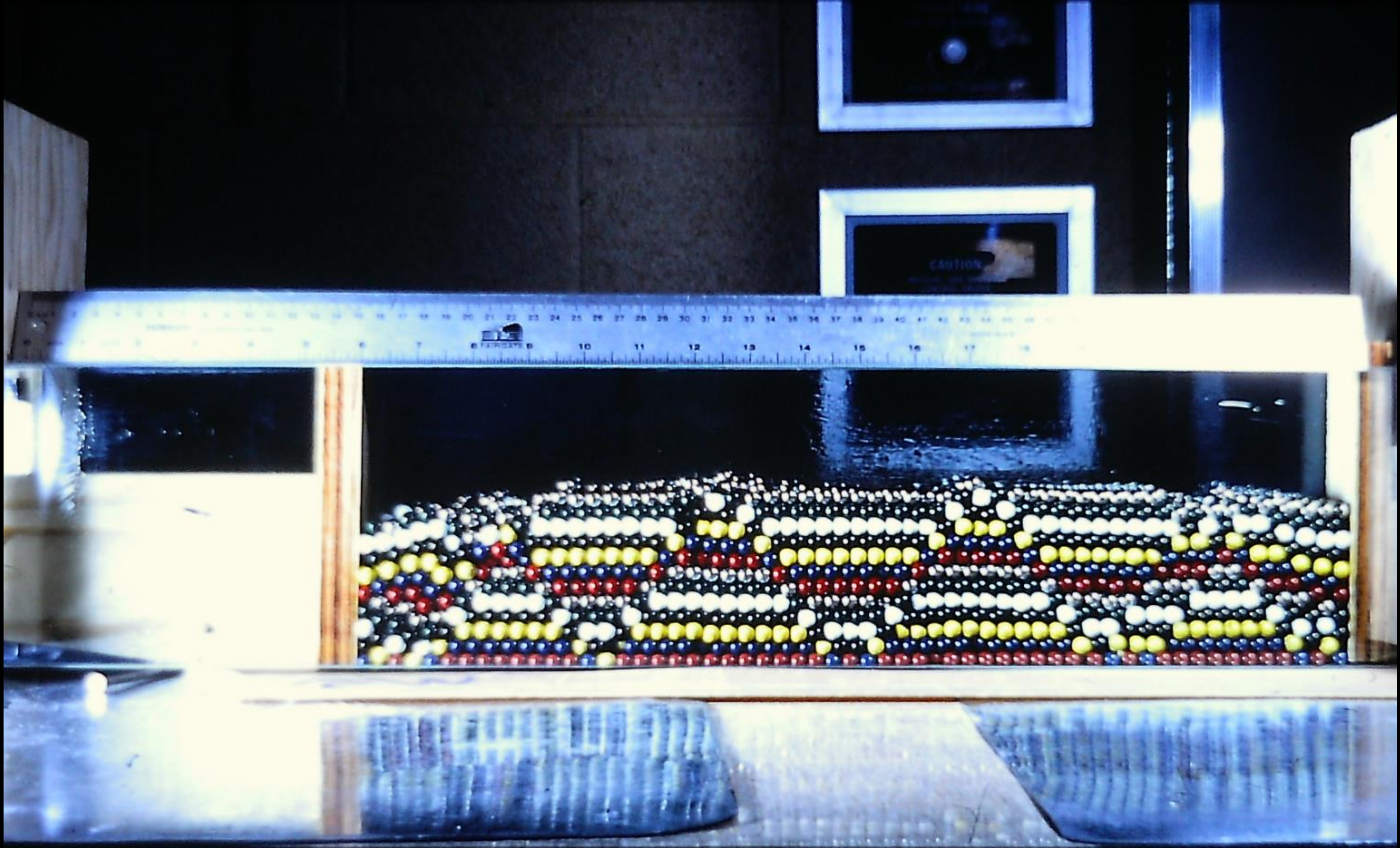
slide 60











3D EXPERIMENT, SINGLE-SIZED BALLS

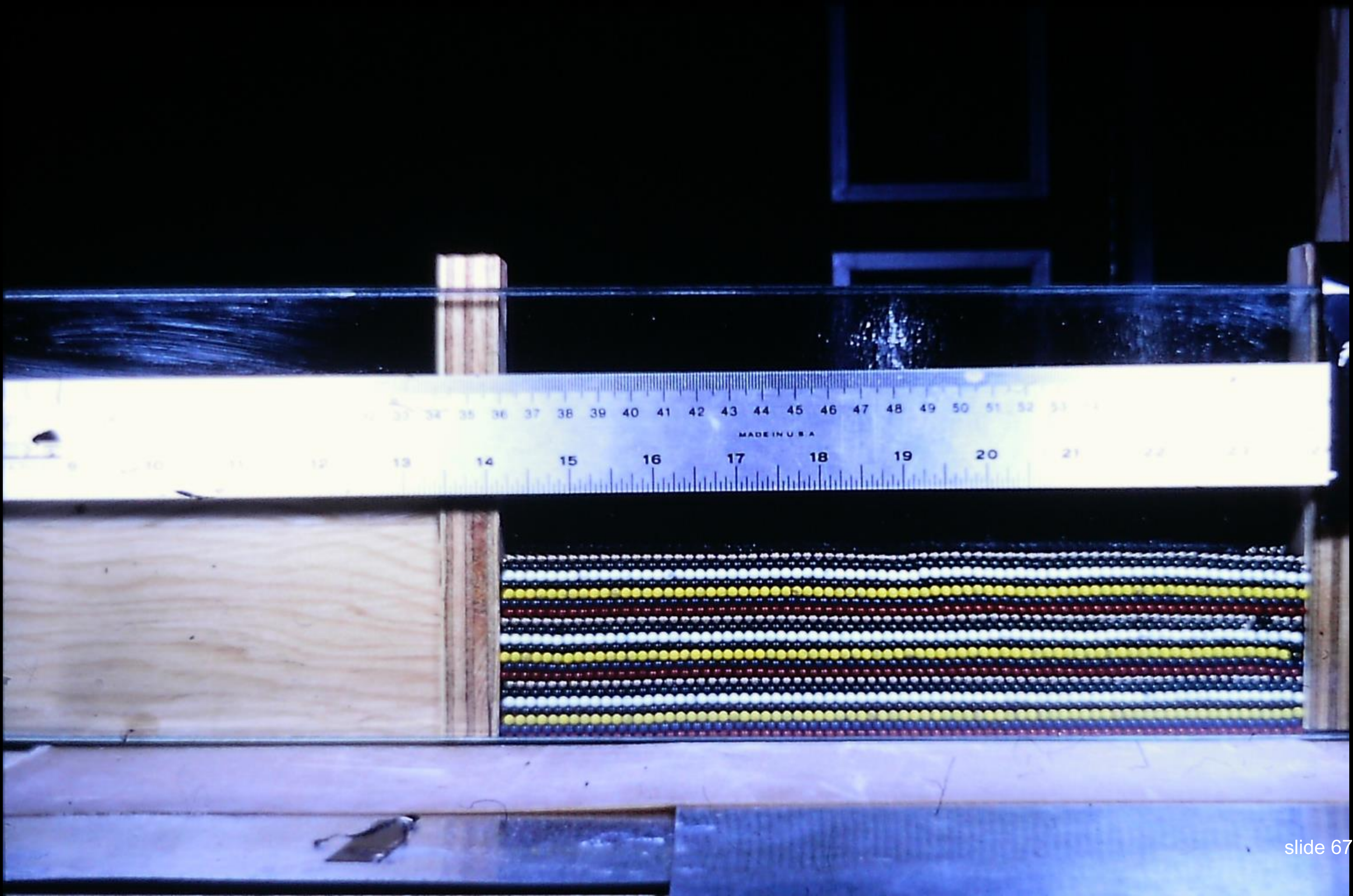
Run #37

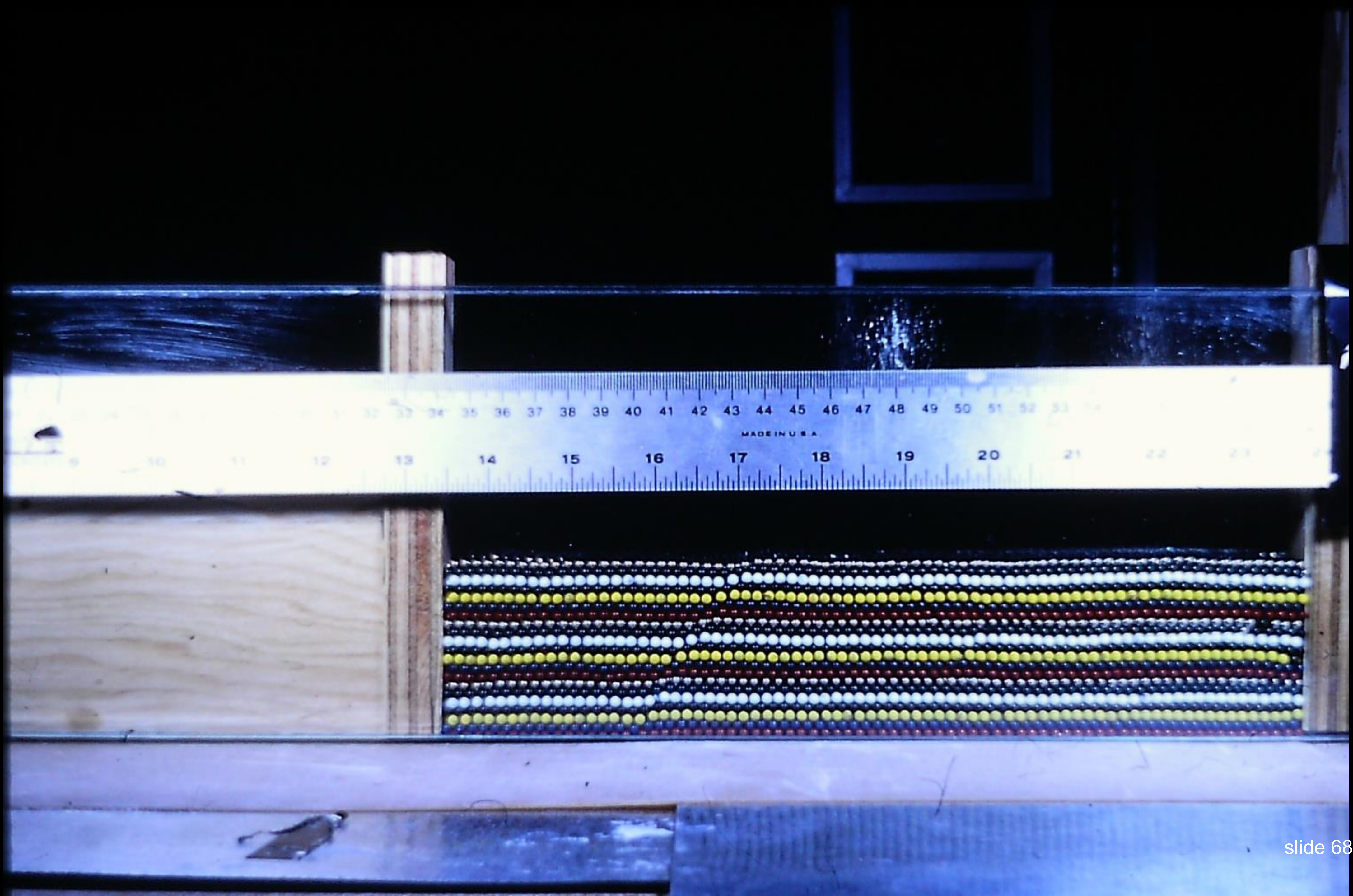
21 Layers, 1/8" Balls

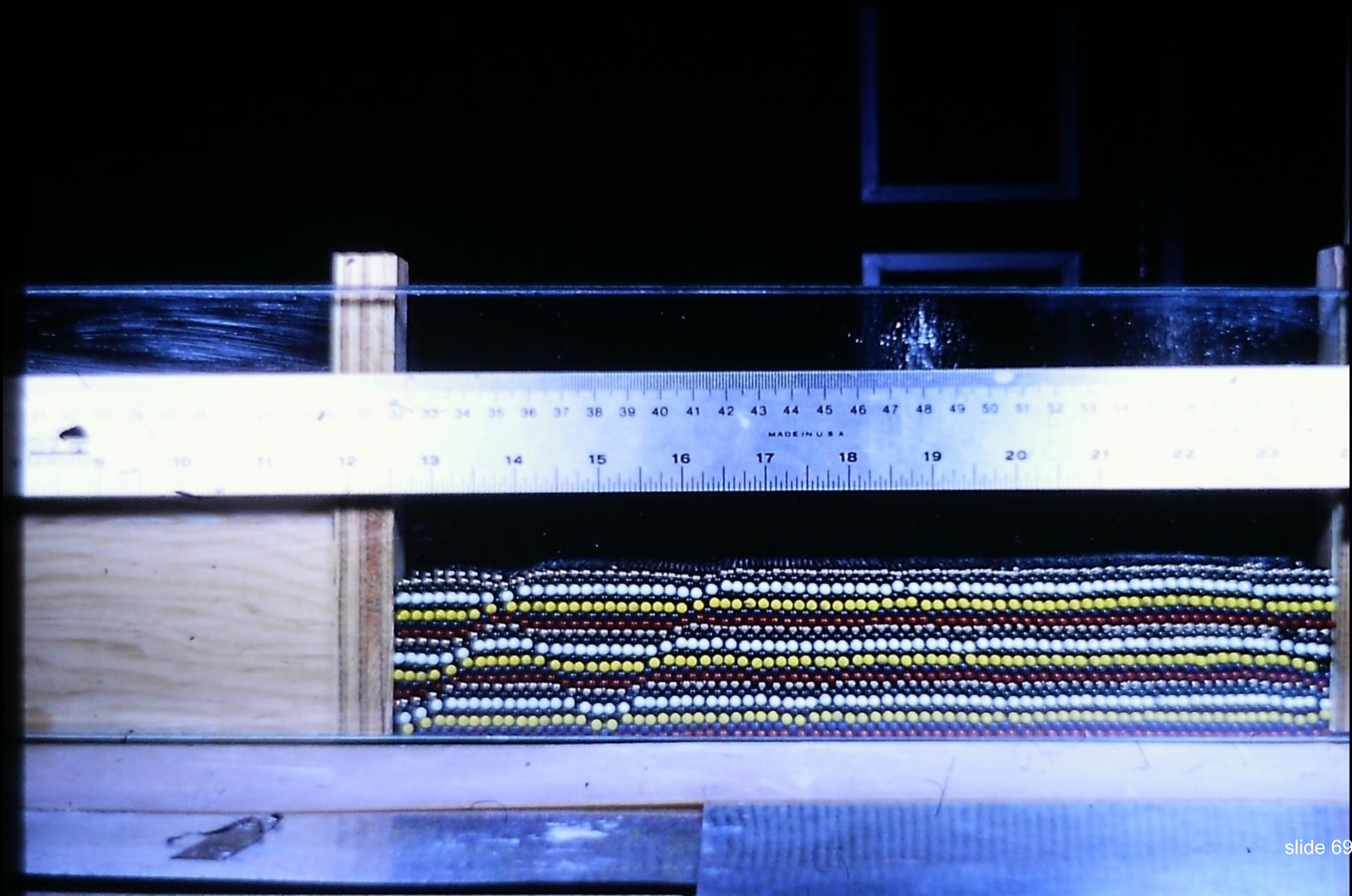
3D Close-Packed Hexagonal

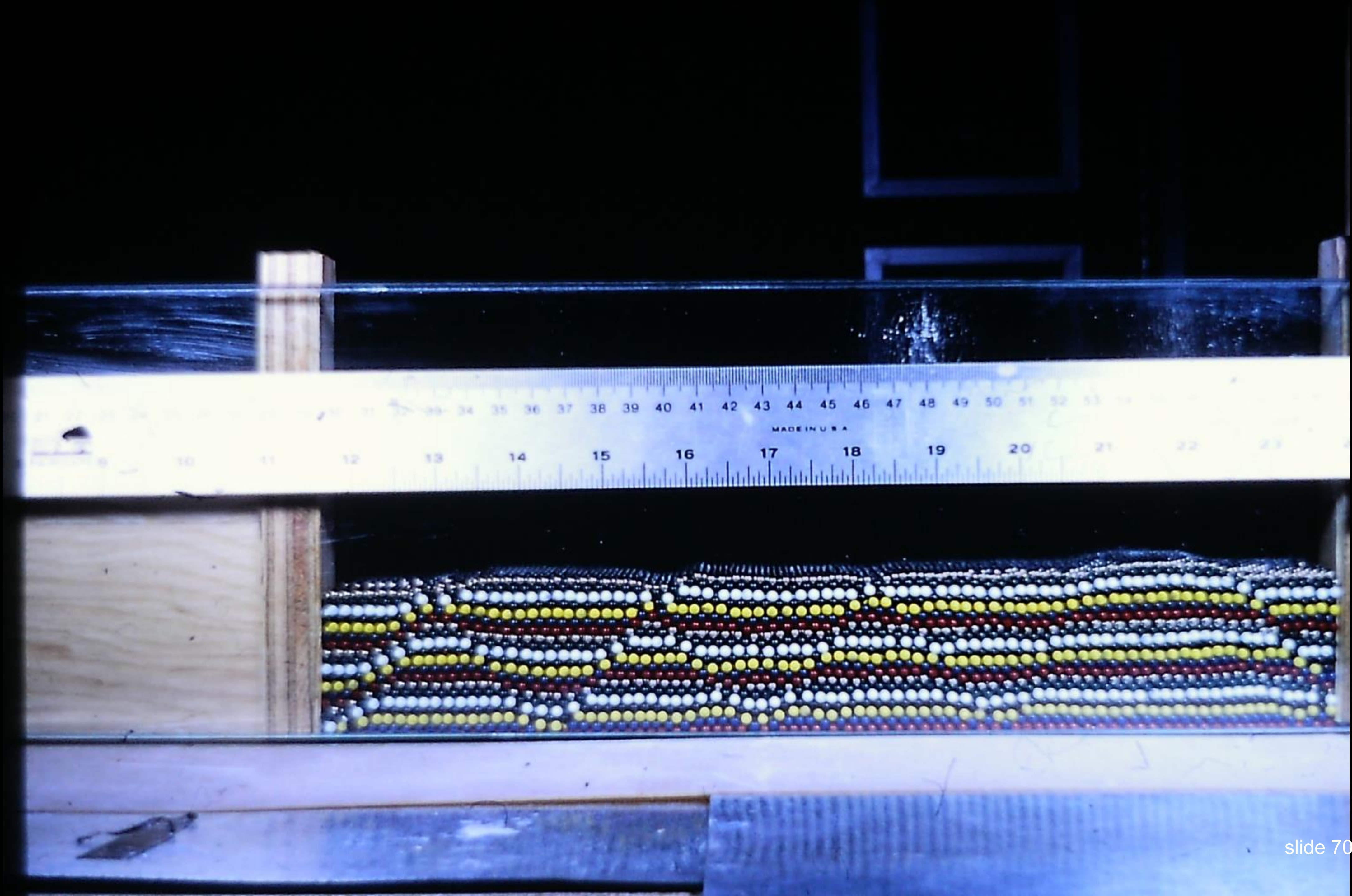
7.2 cm/hr

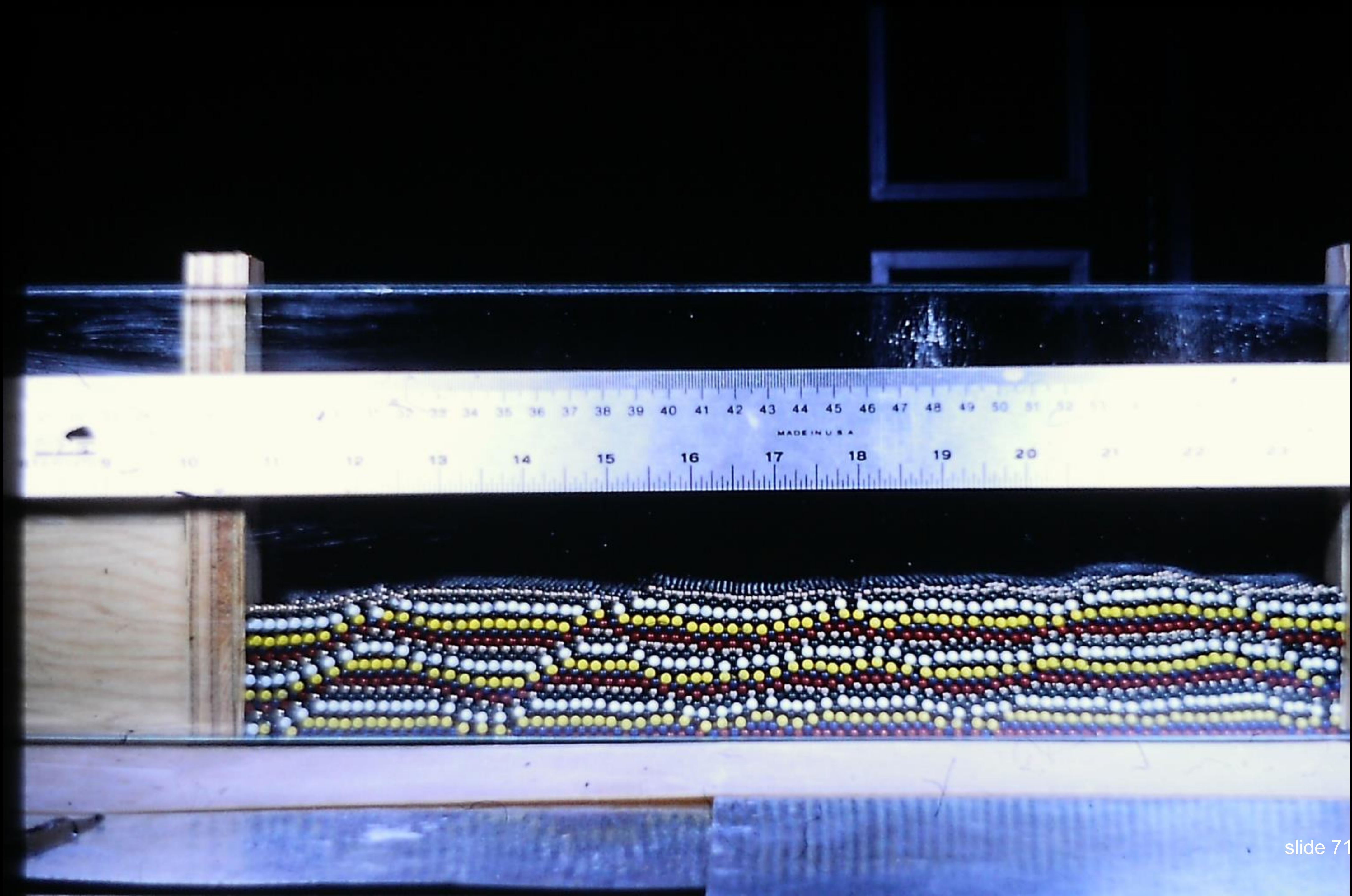
β = 1.00, 1.08, 1.17, 1.26, 1.36, 1.46

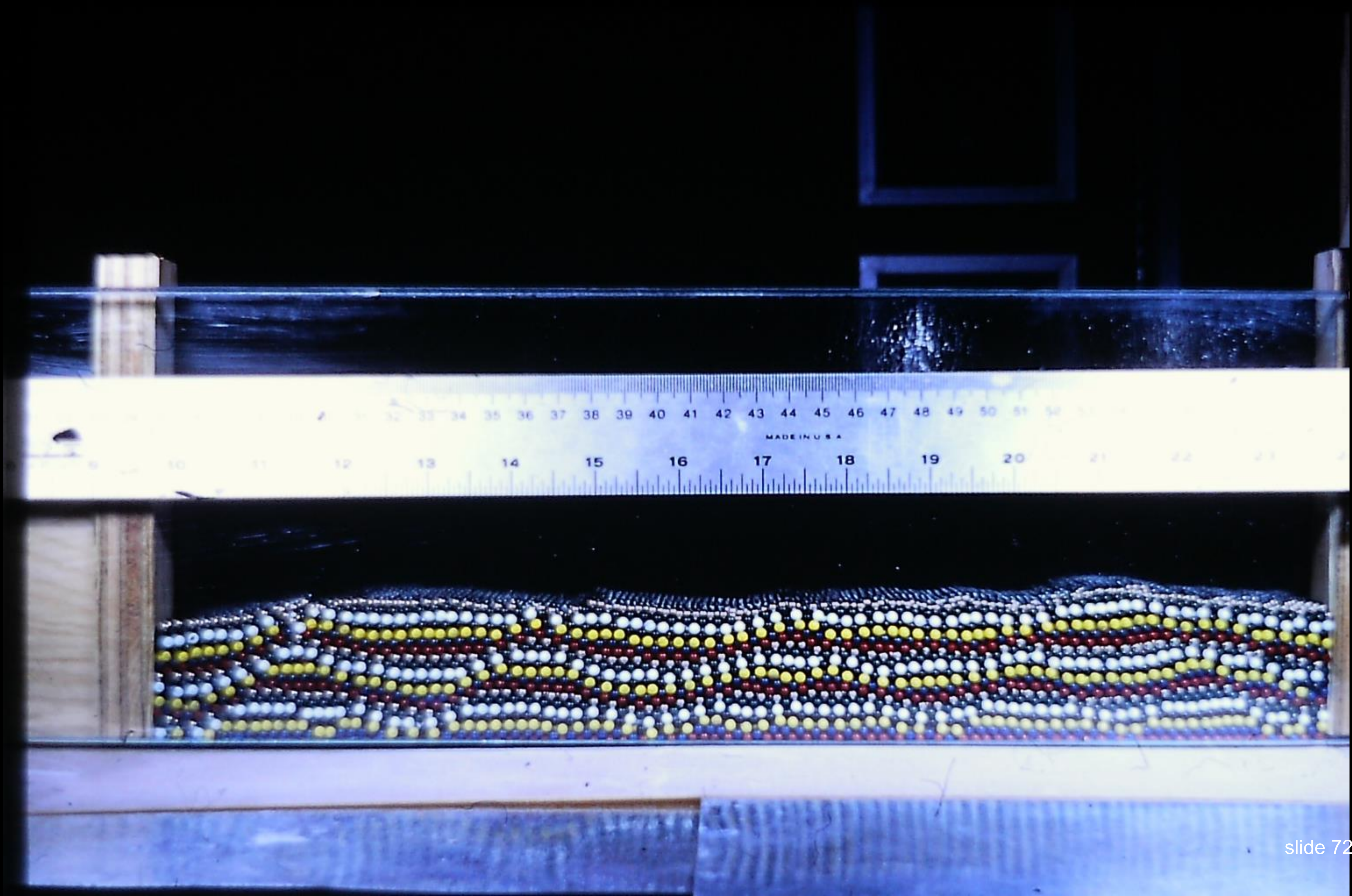

38 39 40 41 42 43 44 45 46 47 48 49 50
MADE IN U.S.A.
14 15 16 17 18 19 20








34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
13 14 15 16 17 18 19 20


34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
MADE IN U.S.A
13 14 15 16 17 18 19 20

TWO DIFFERENT SIZES, TOP LOCK BOTTOM IN PLACE

Run #18

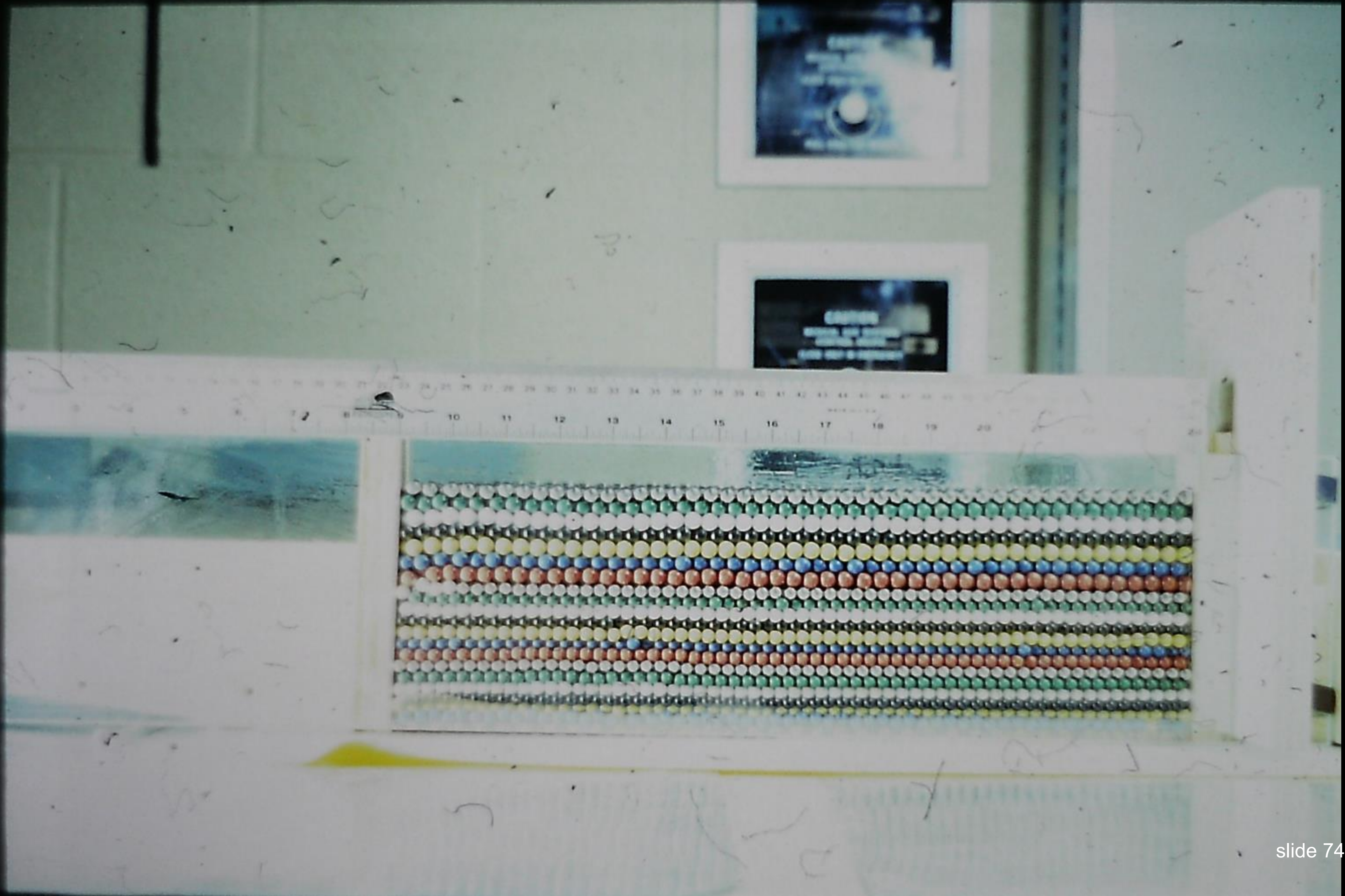
14 Layers, 1/4" Topped By

7 Layers 5/16" Balls

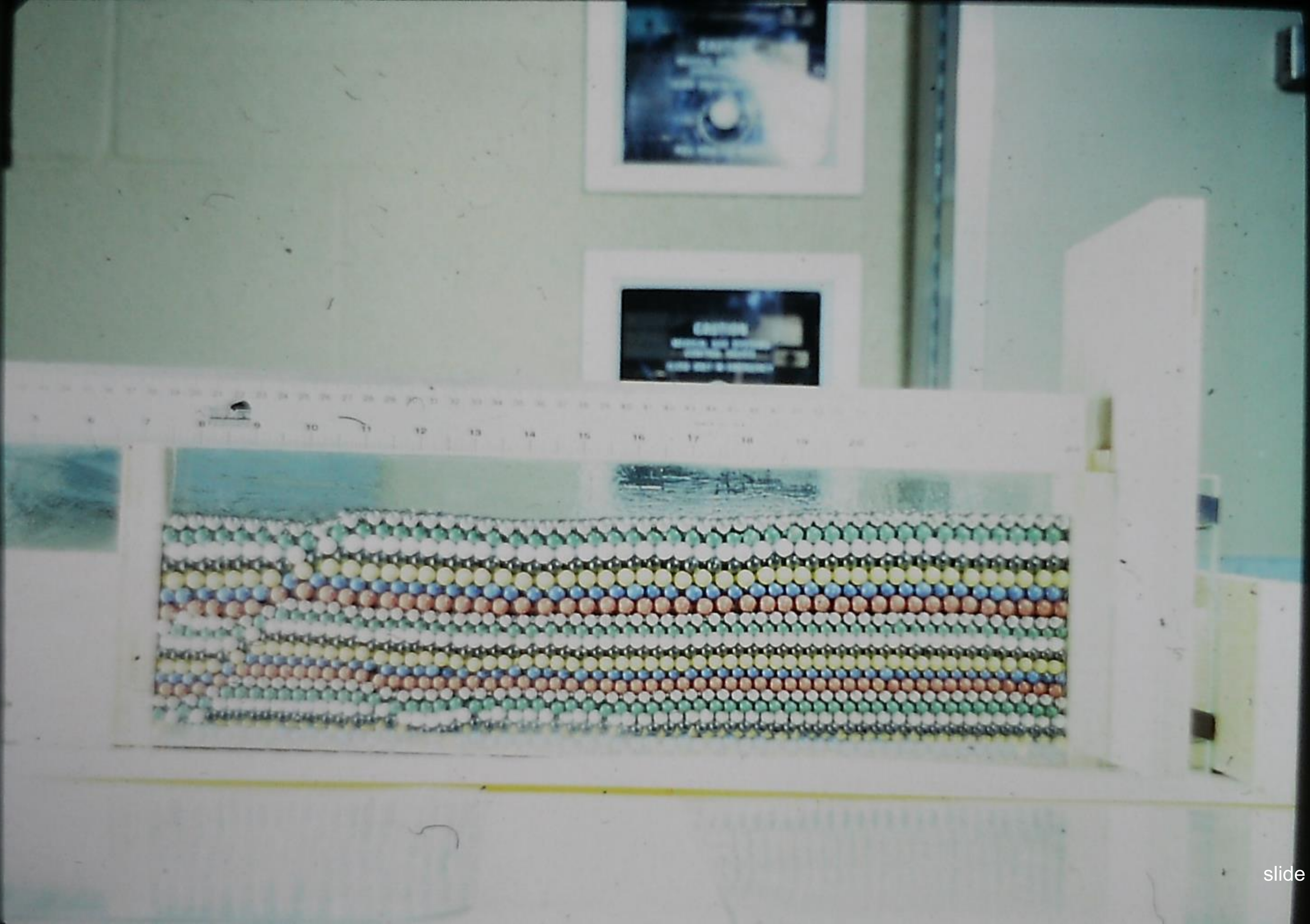
Attempted 3D Close-Packed Hexagonal

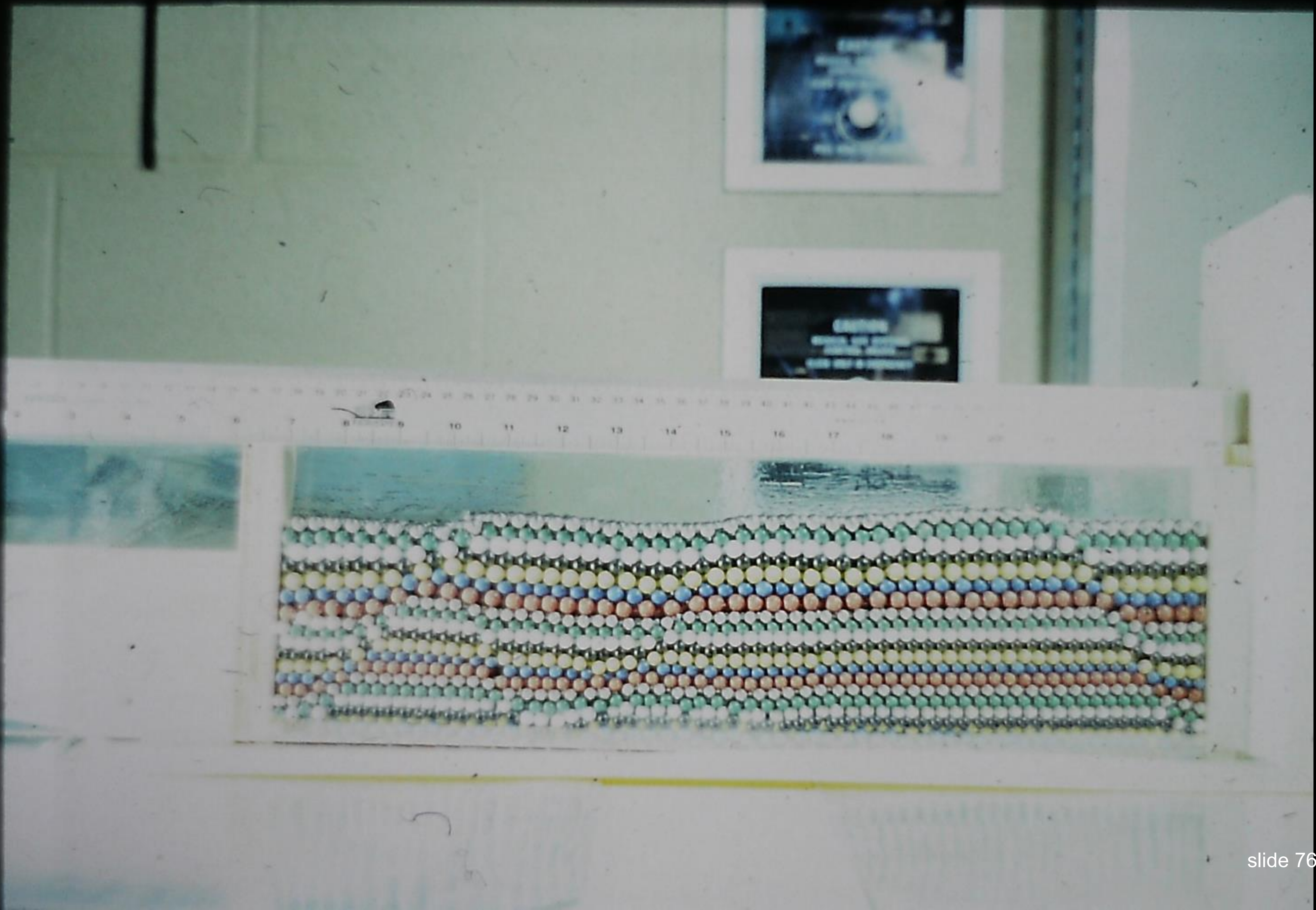
7.1 cm/hr

β = 1.00, 1.11, 1.14, 1.24, 1.35, 1.51

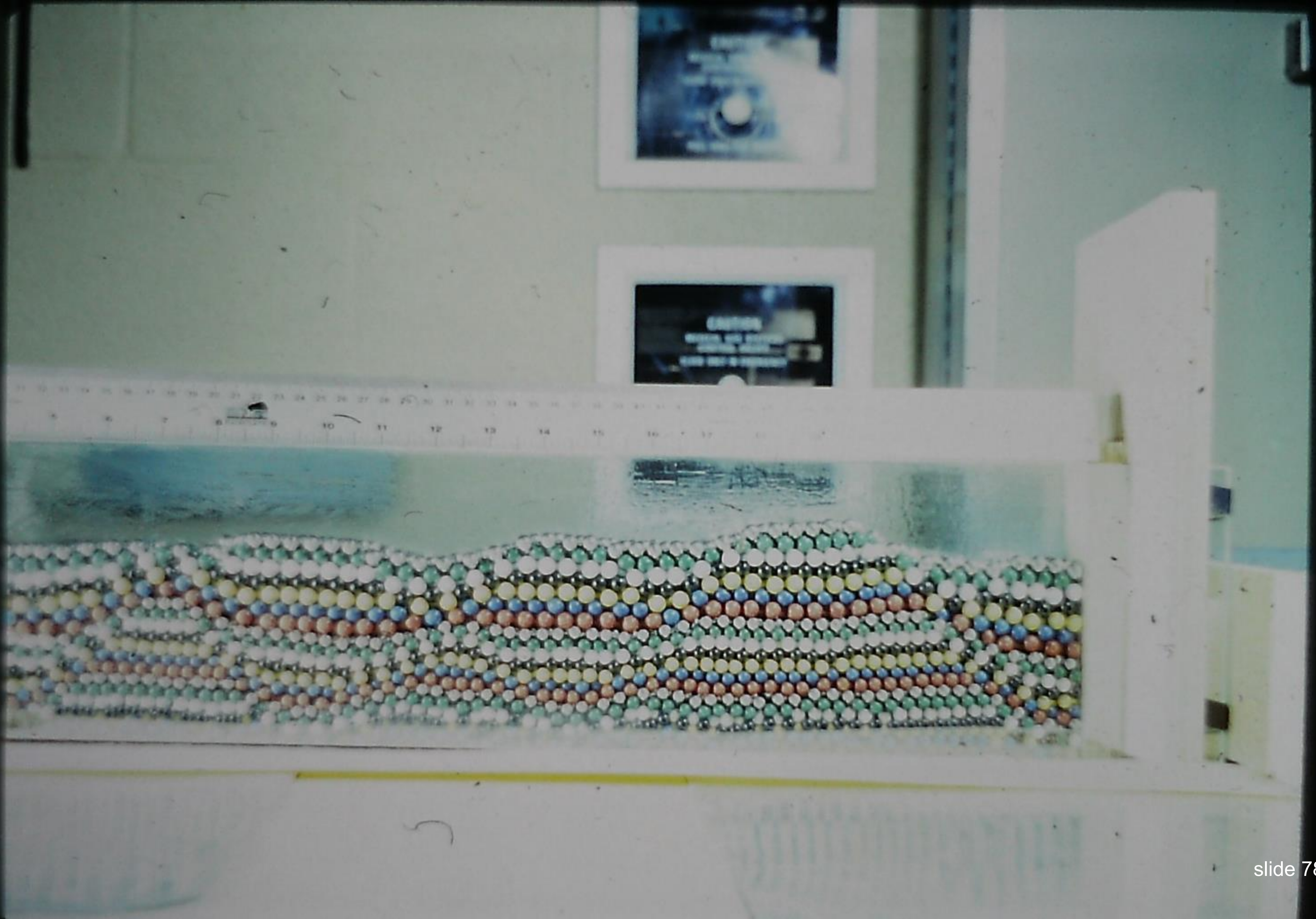


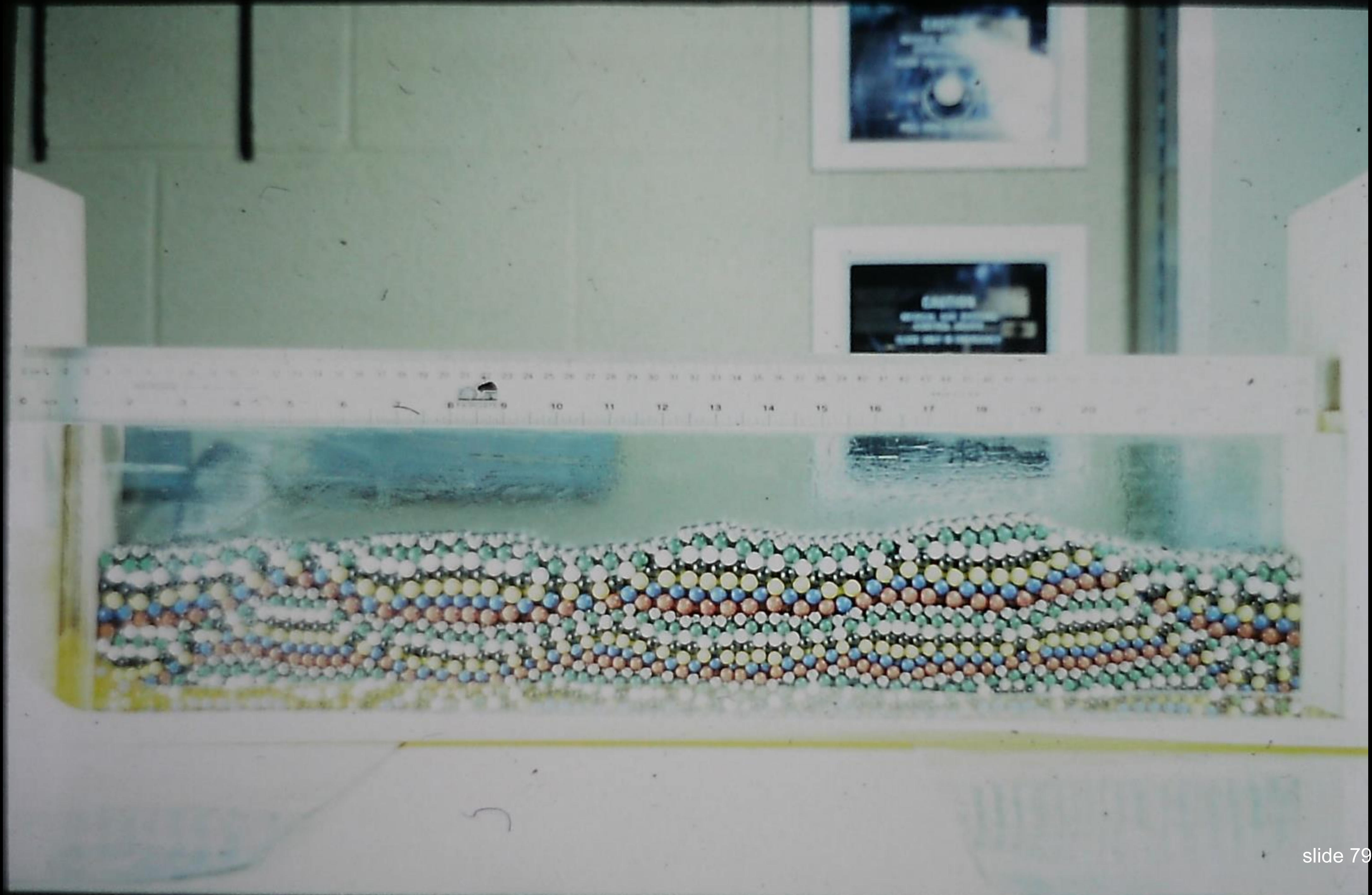
slide 74





slide 76





slide 79

TWO DIFFERENT SIZES, TOP LOCK BOTTOM IN PLAC

Run #31

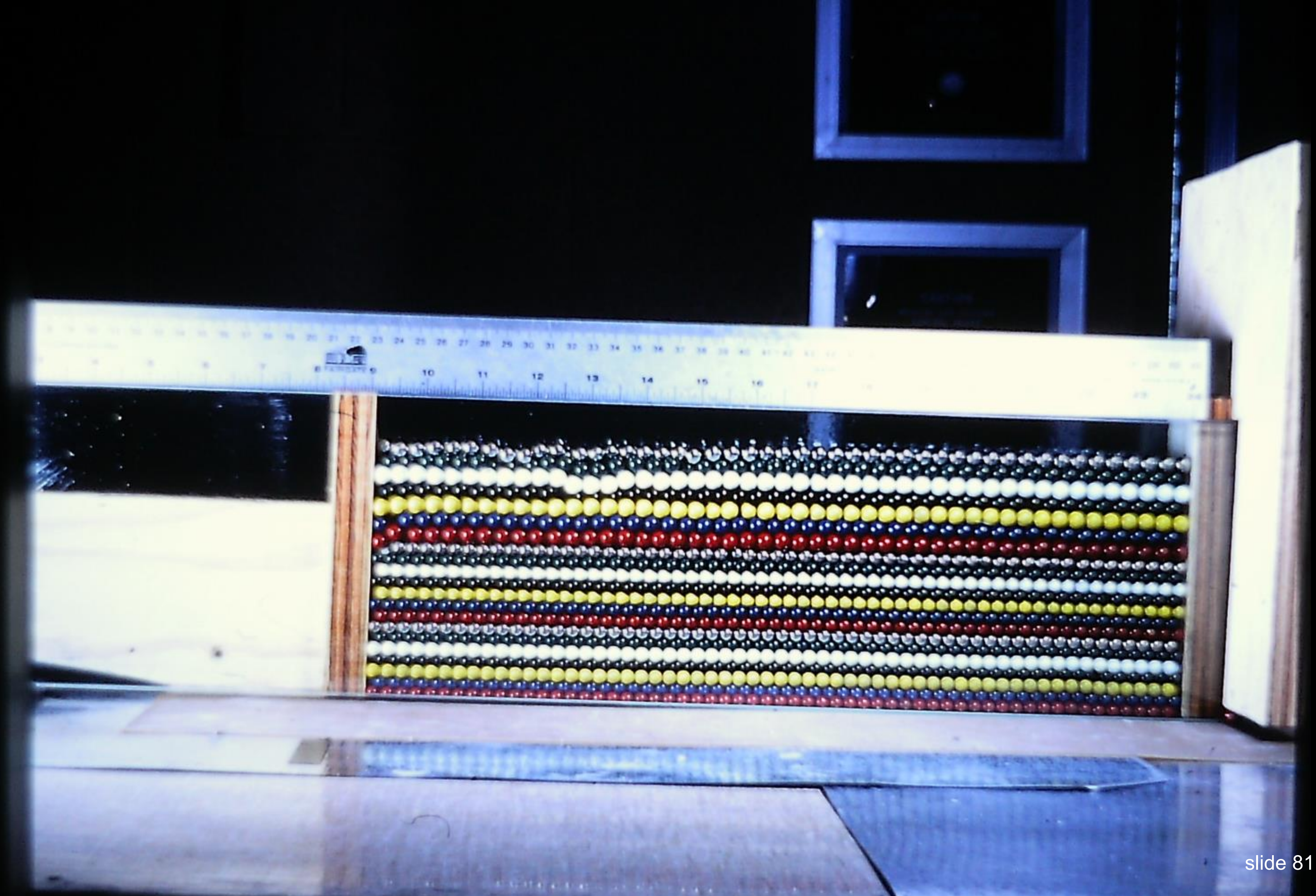
14 Layers Of 1/4" Balls Topped By

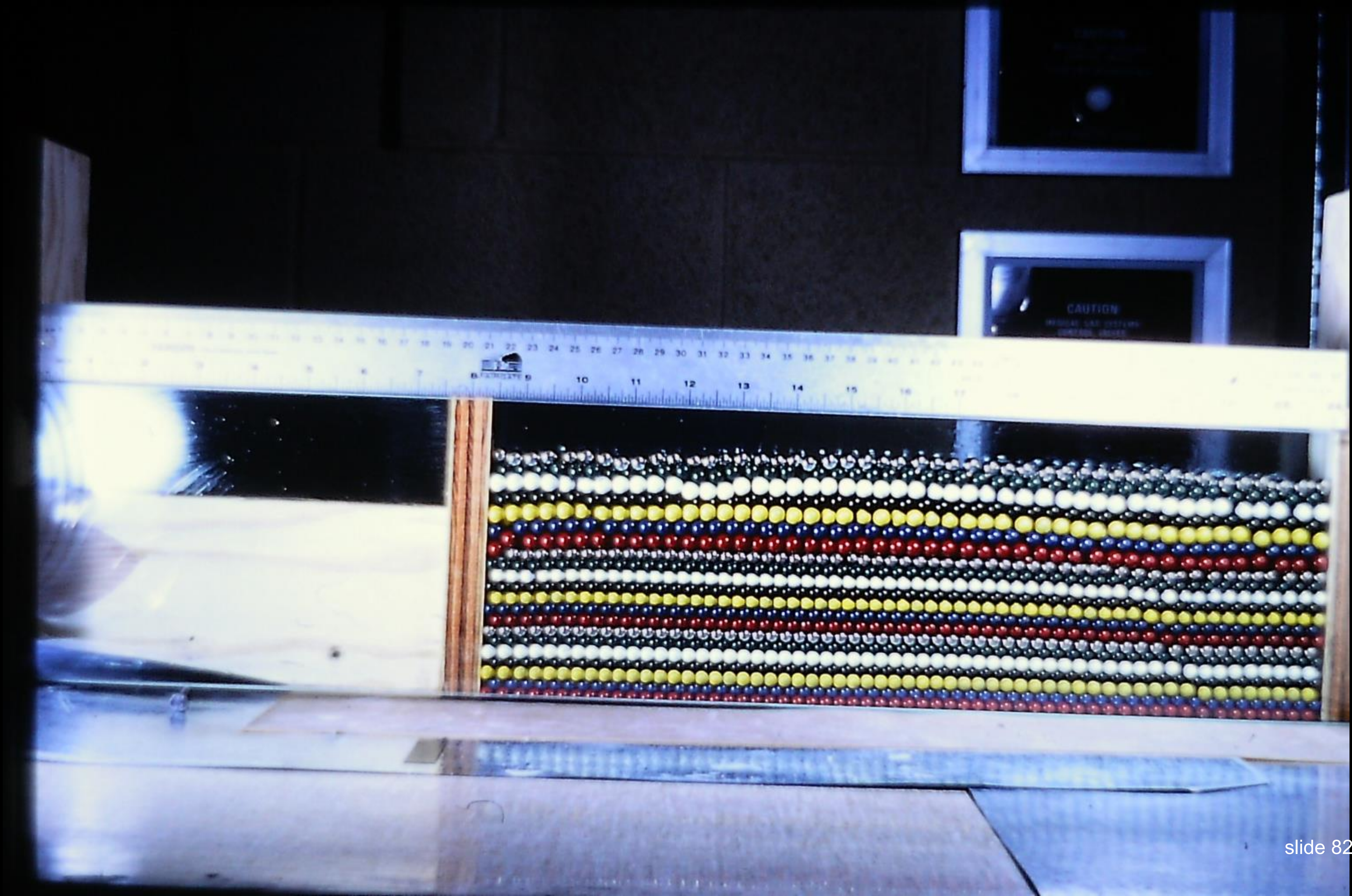
7 Layers 5/16" Balls,

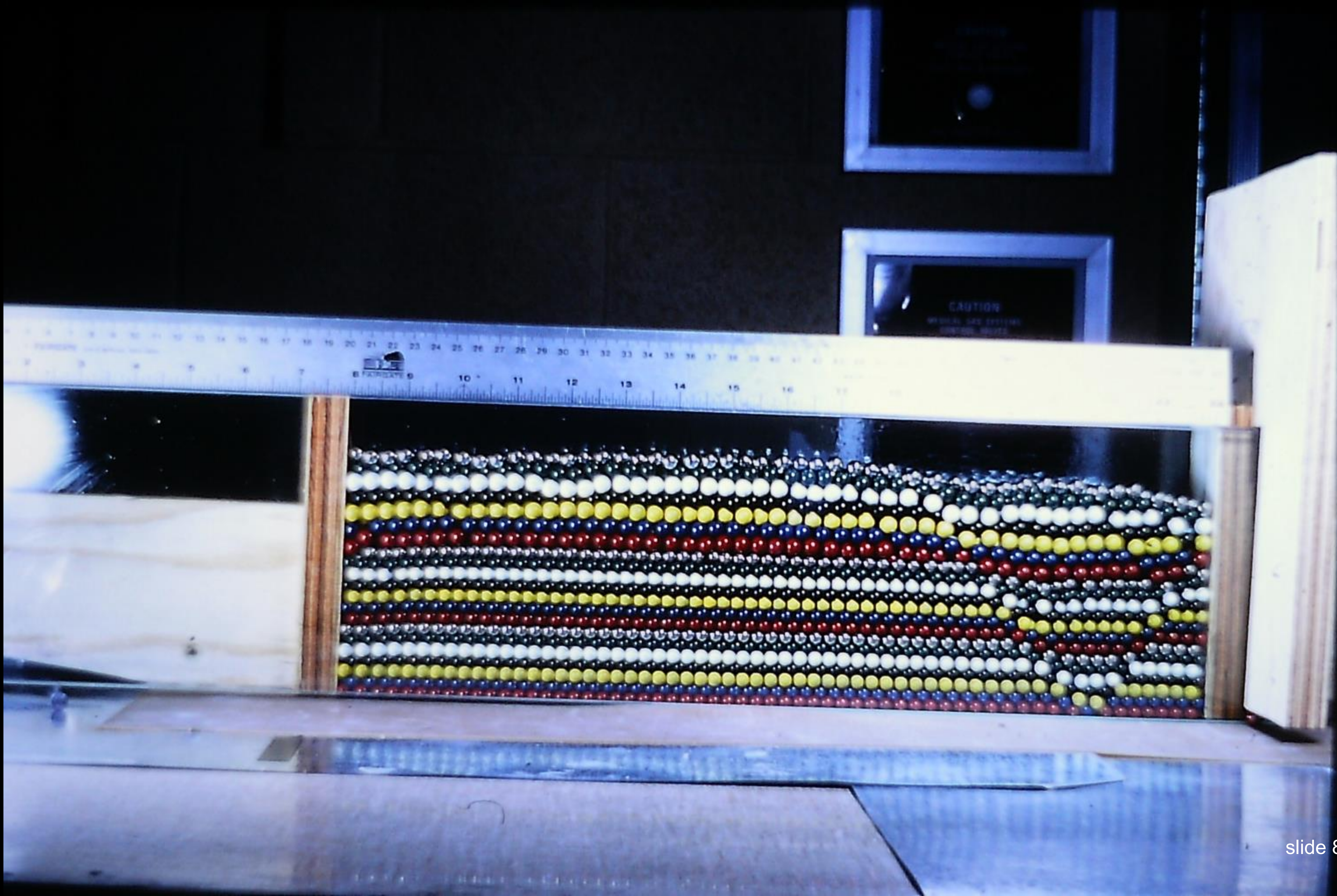
Attempted 3D Close-Packed Hexagonal

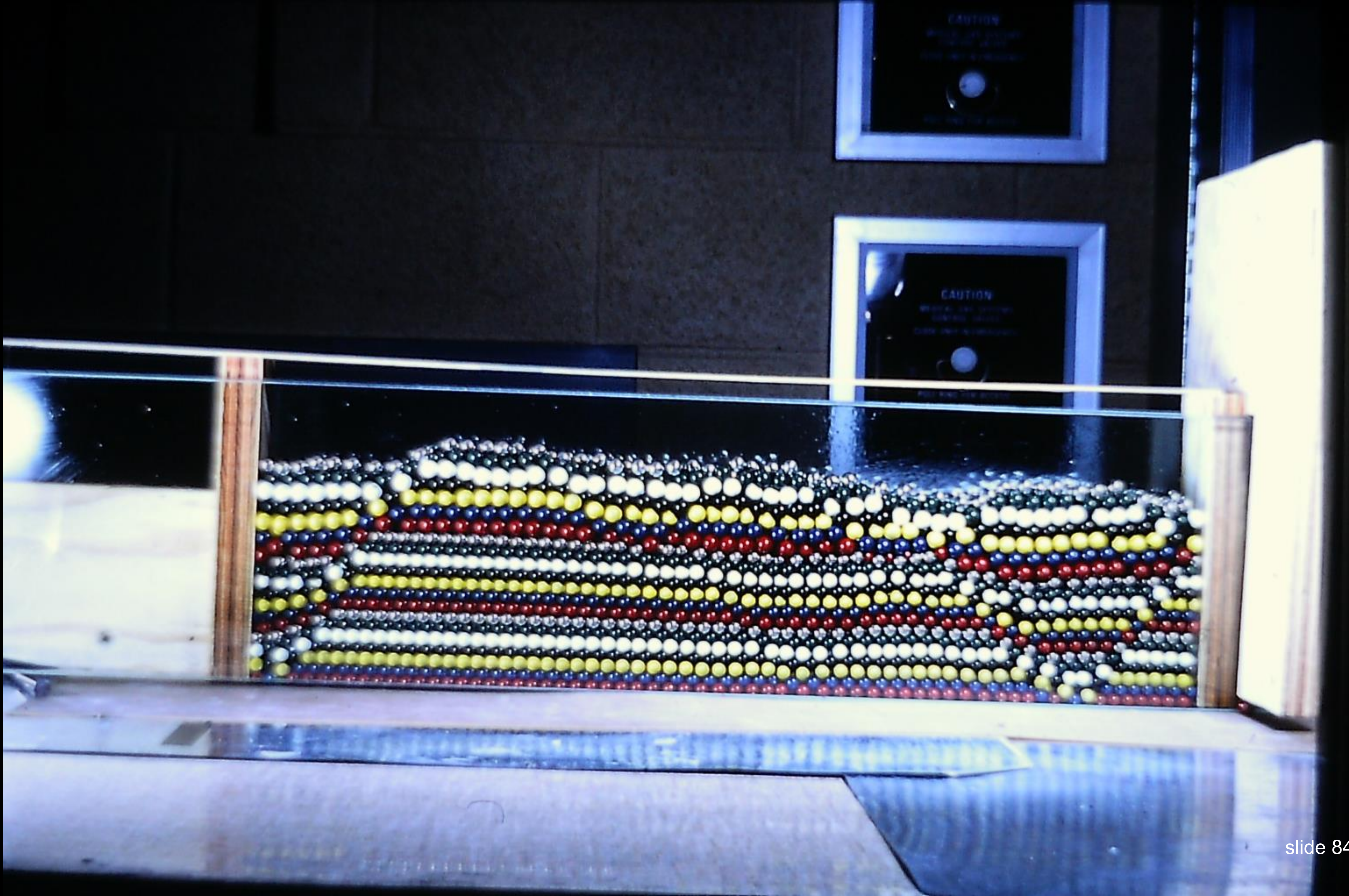
6.7 cm/hr

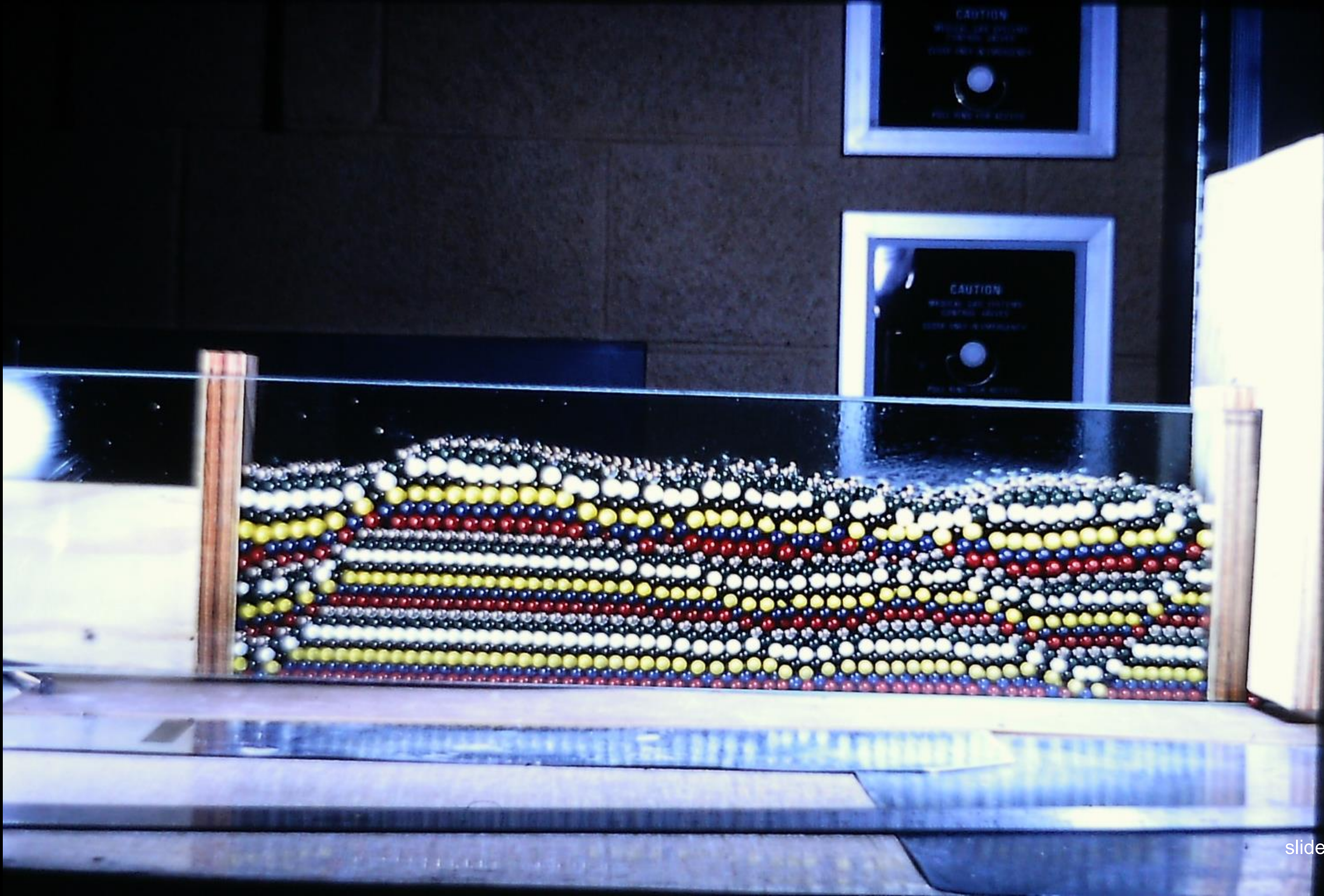
β = 1.00, 1.05, 1.08, 1.17, 1.21, 1.27, 1.45

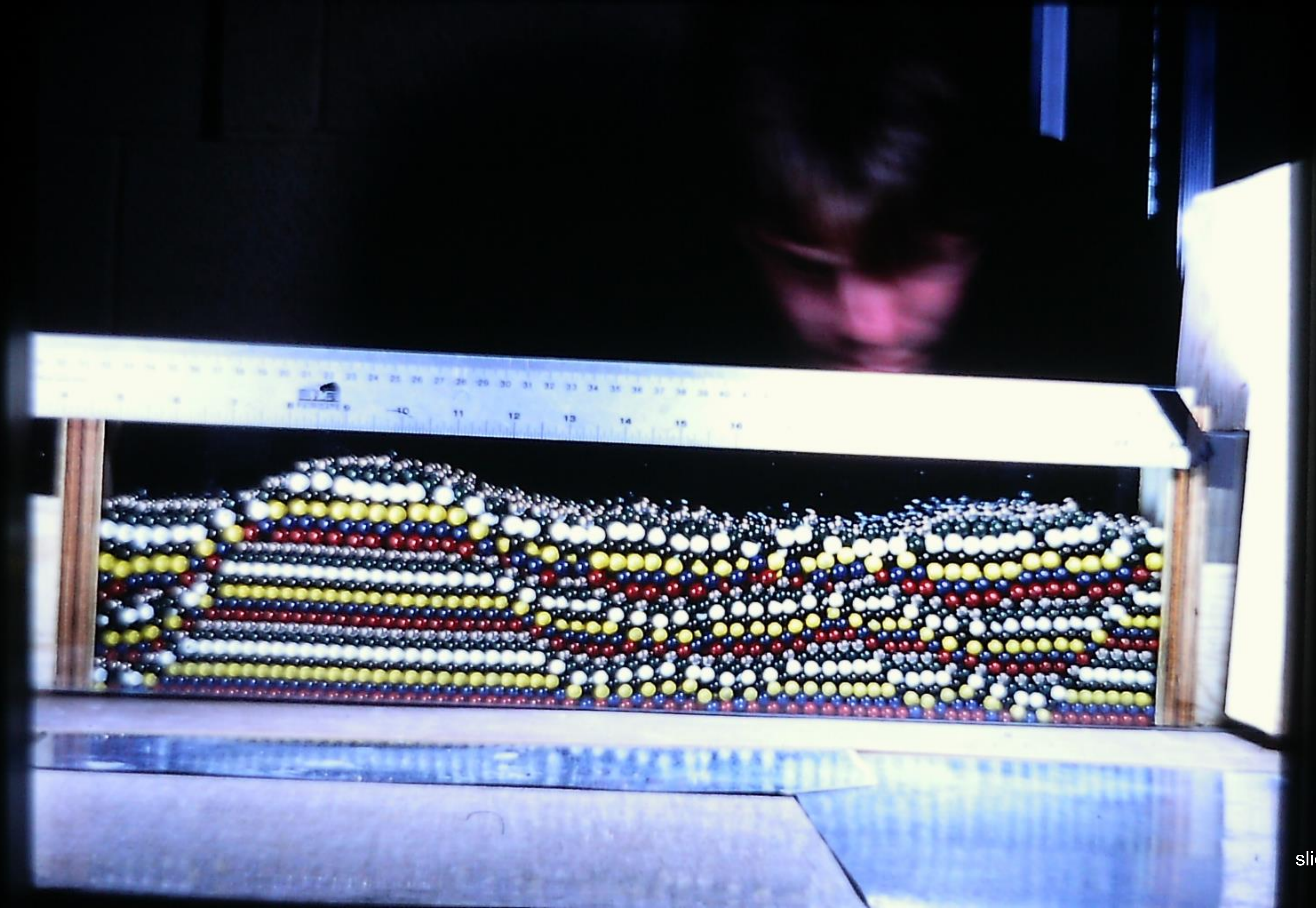



CAUTION

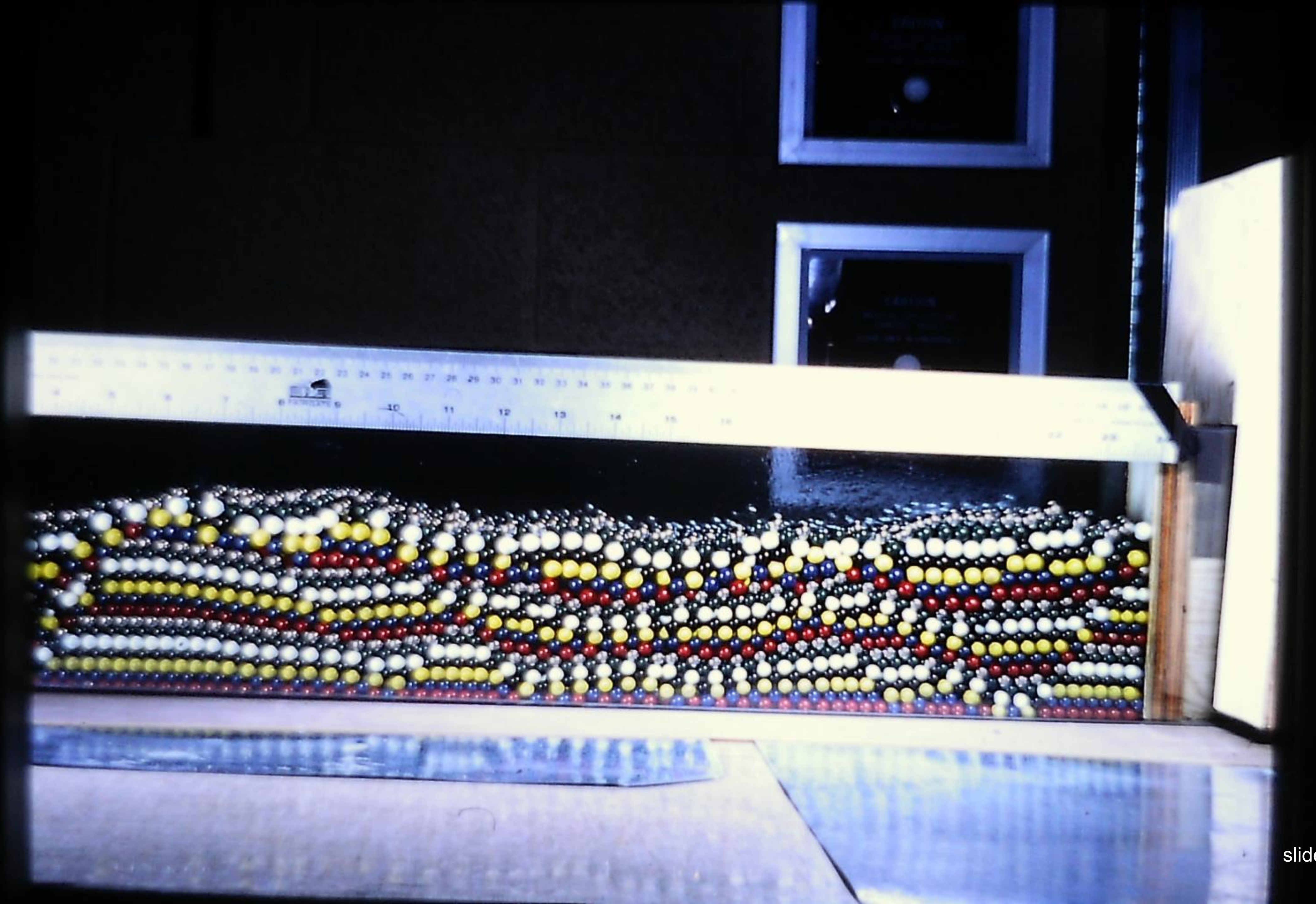



CAUTION


CAUTION
CAUTION



slide 86



PLAN VIEW, SIDEWAYS MOTION
DROPPING FAULTS, CURVED FAULTS

Run #30

7 Layers 1/4" Balls

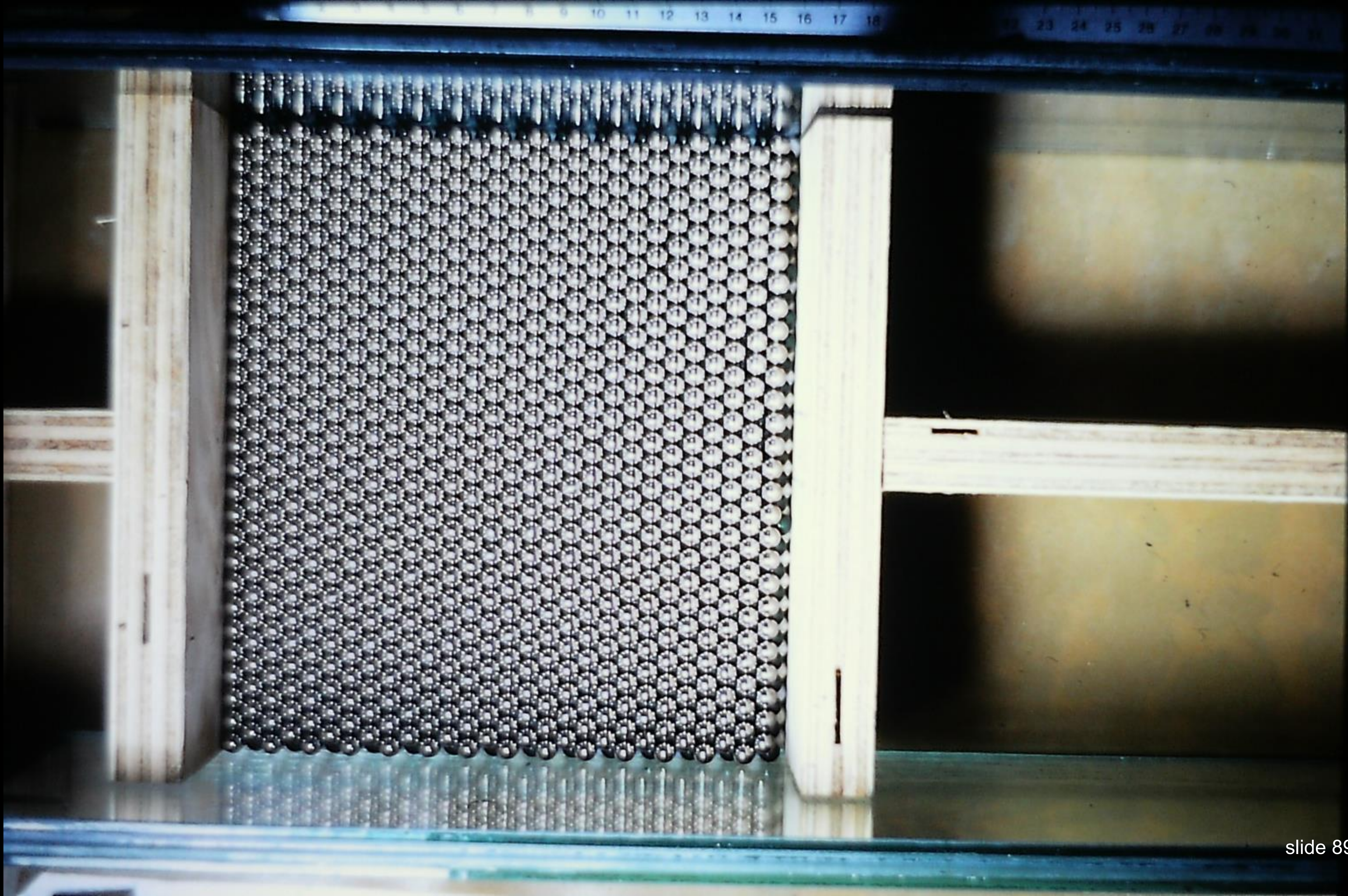
3D Close-Packed Hexagonal

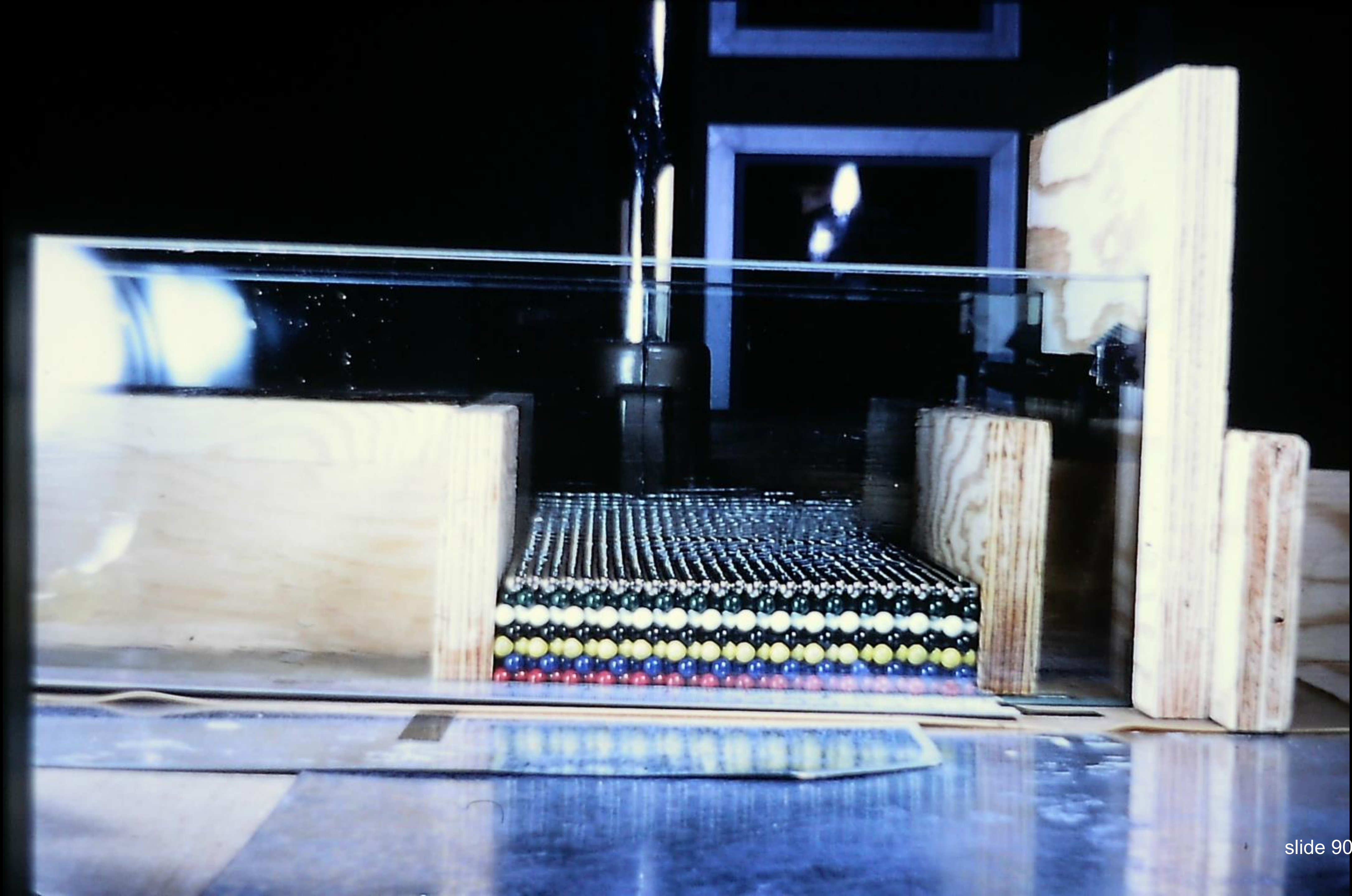
With Rows Perpendicular

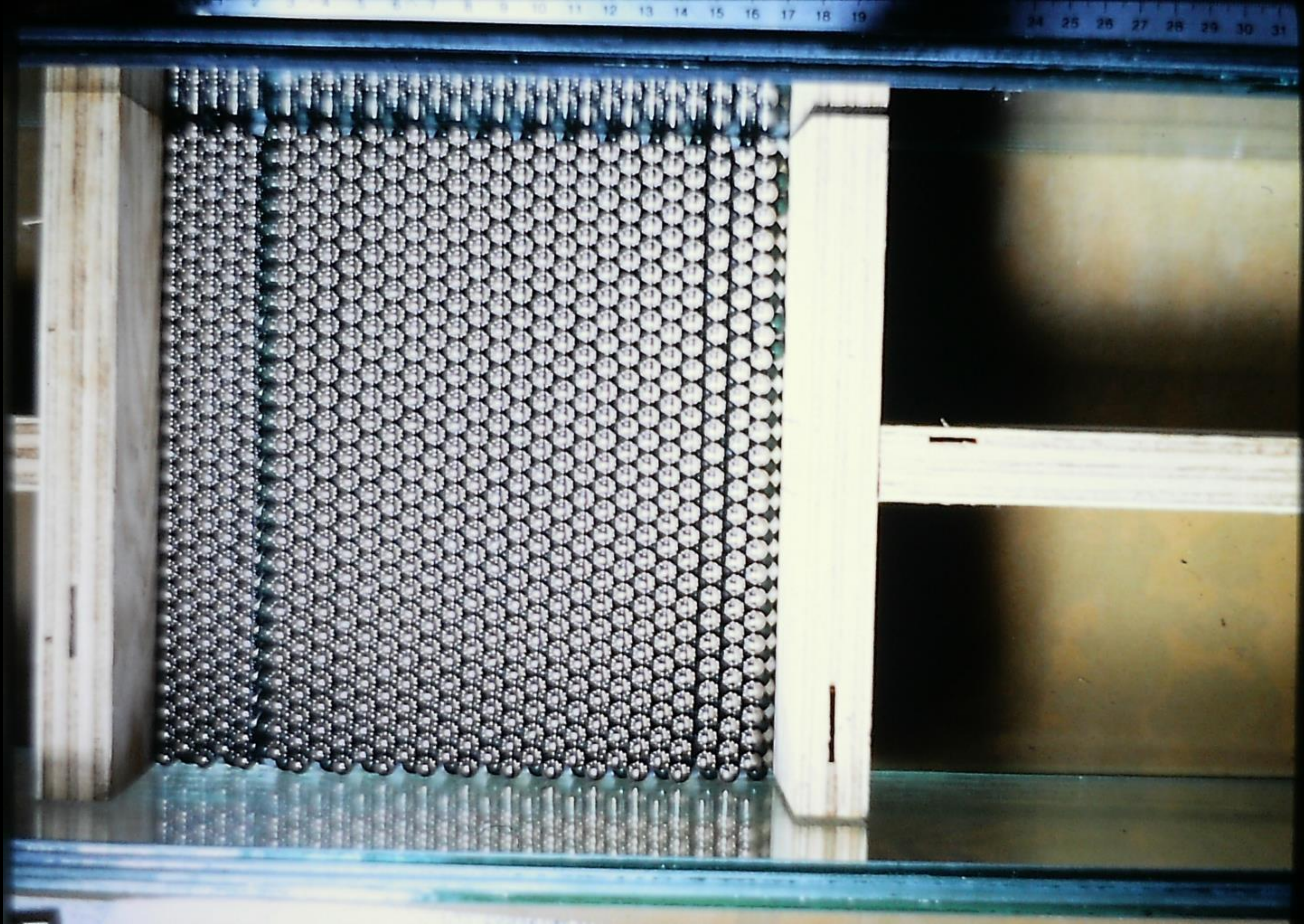
To Direction Of Extension

6.7 cm/hr

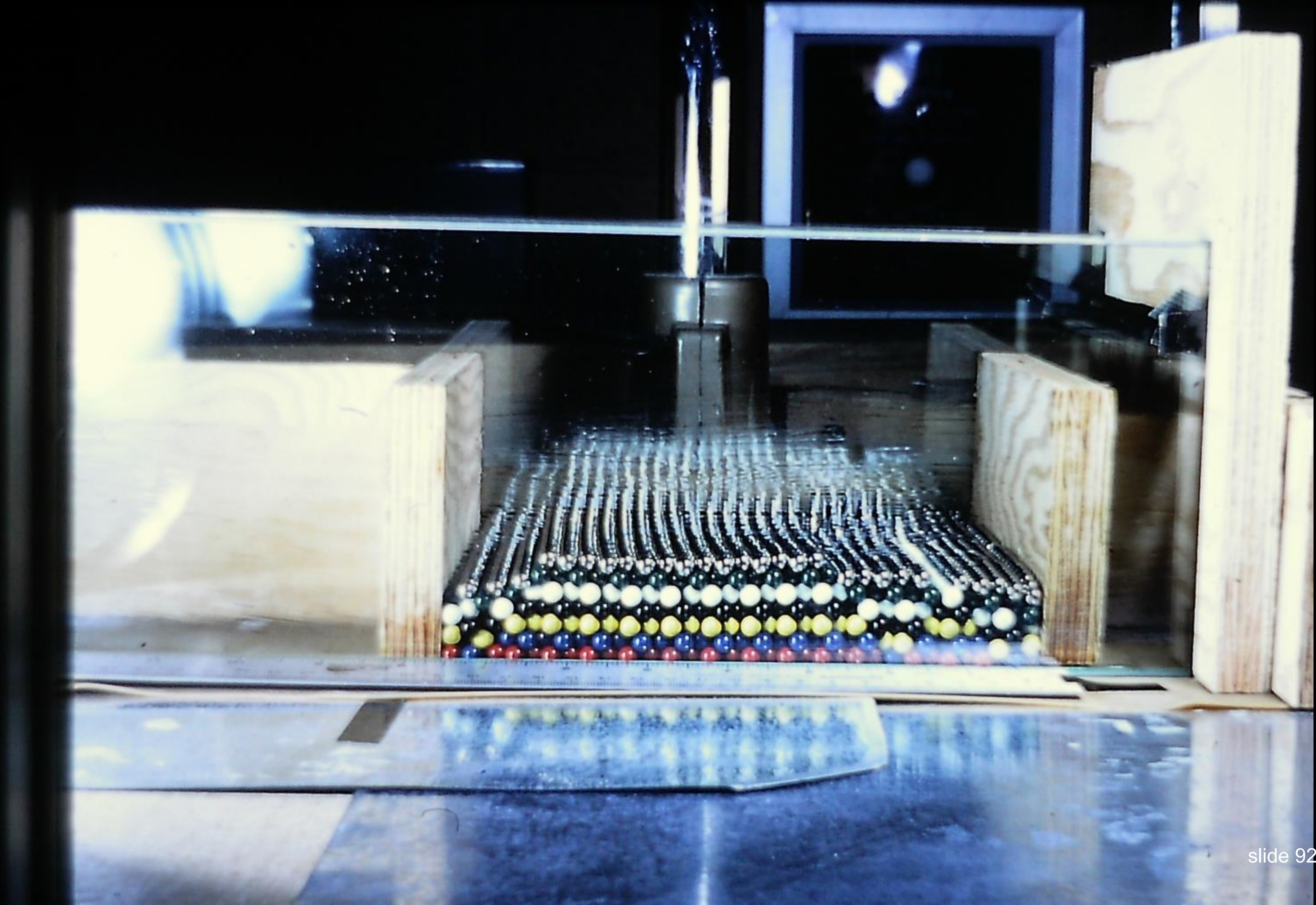
β = 1.00, 1.08, 1.19, 1.23, 1.38


9 10 11 12 13 14 15 16 17 18
23 24 25 26 27

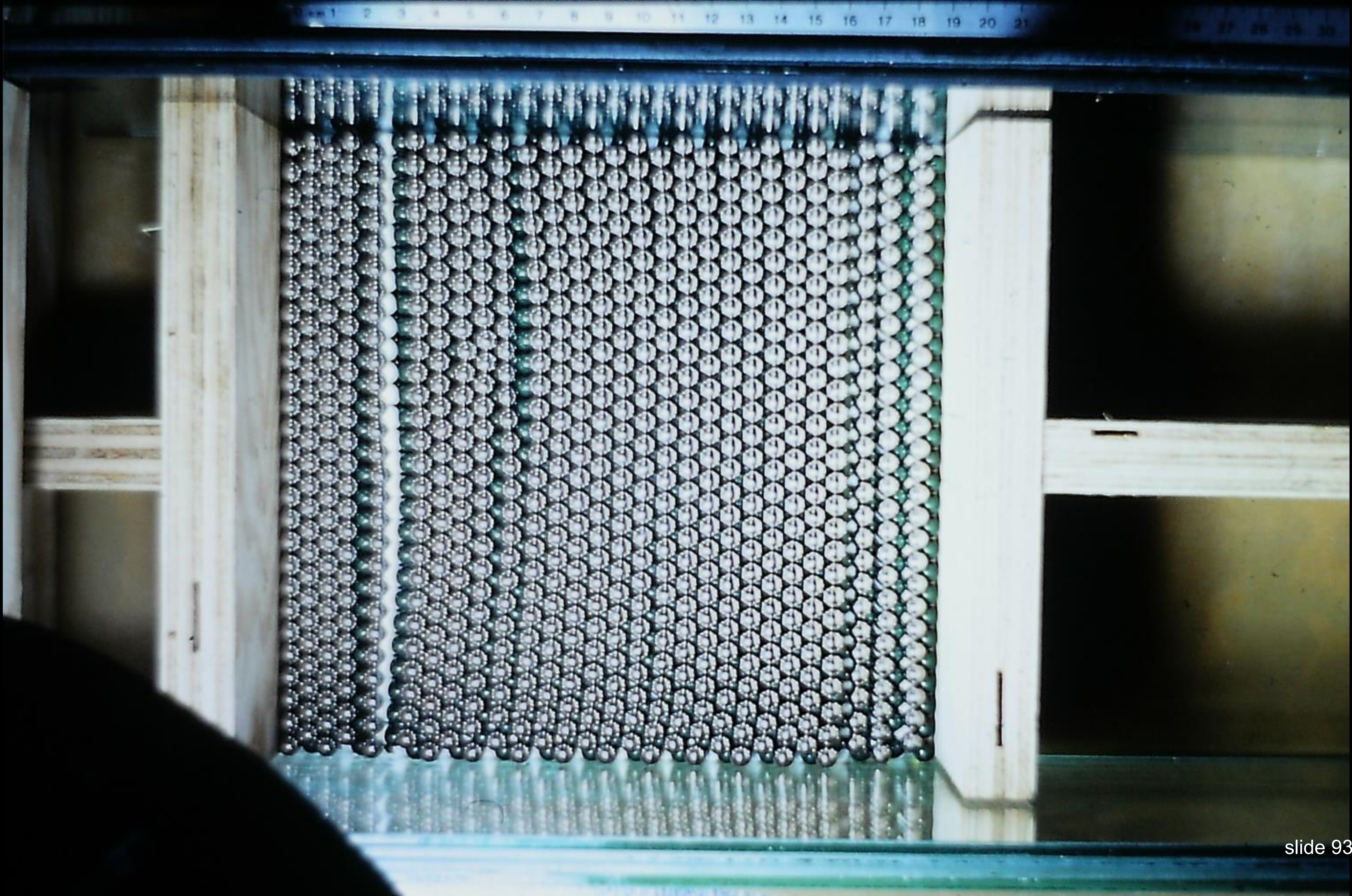


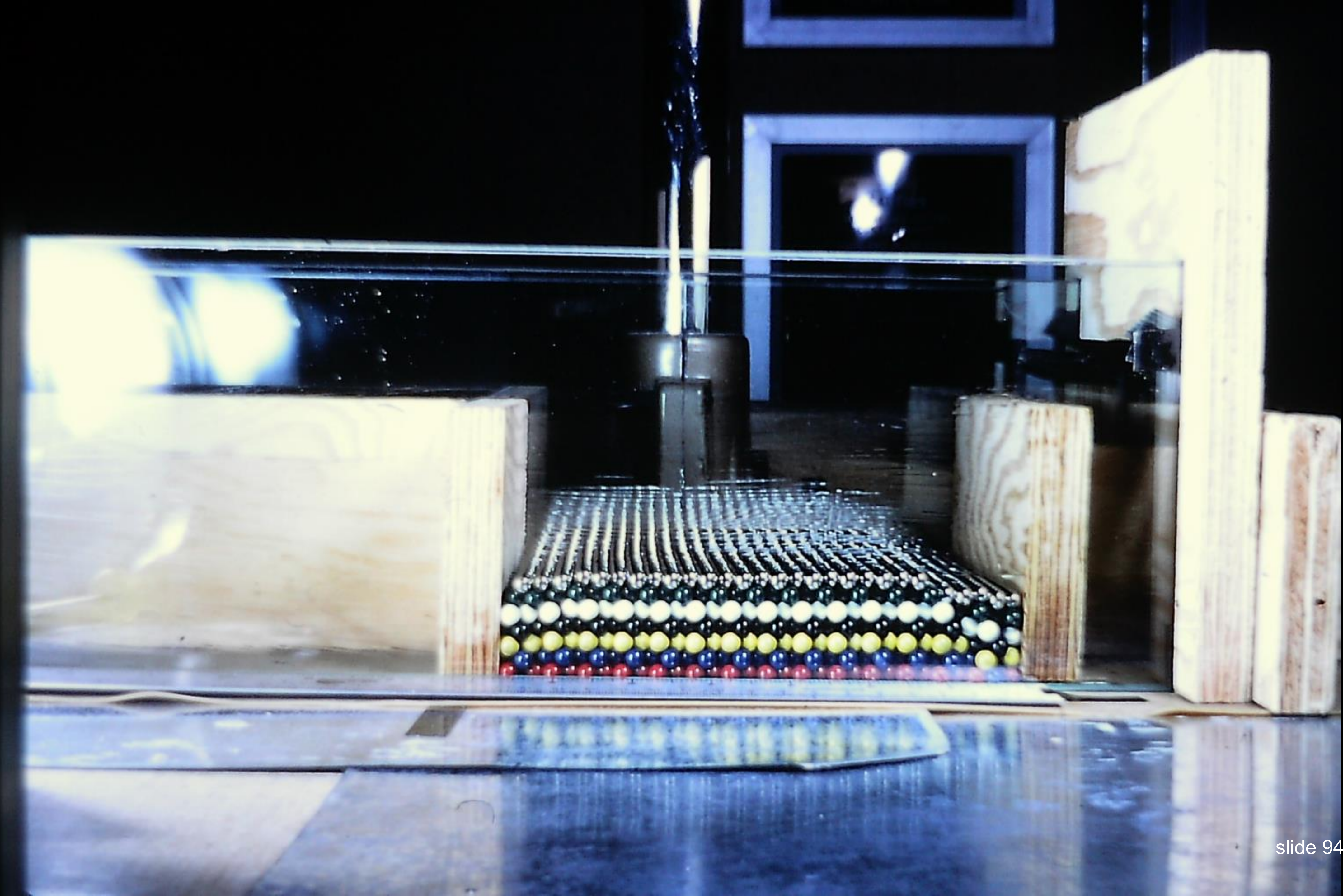


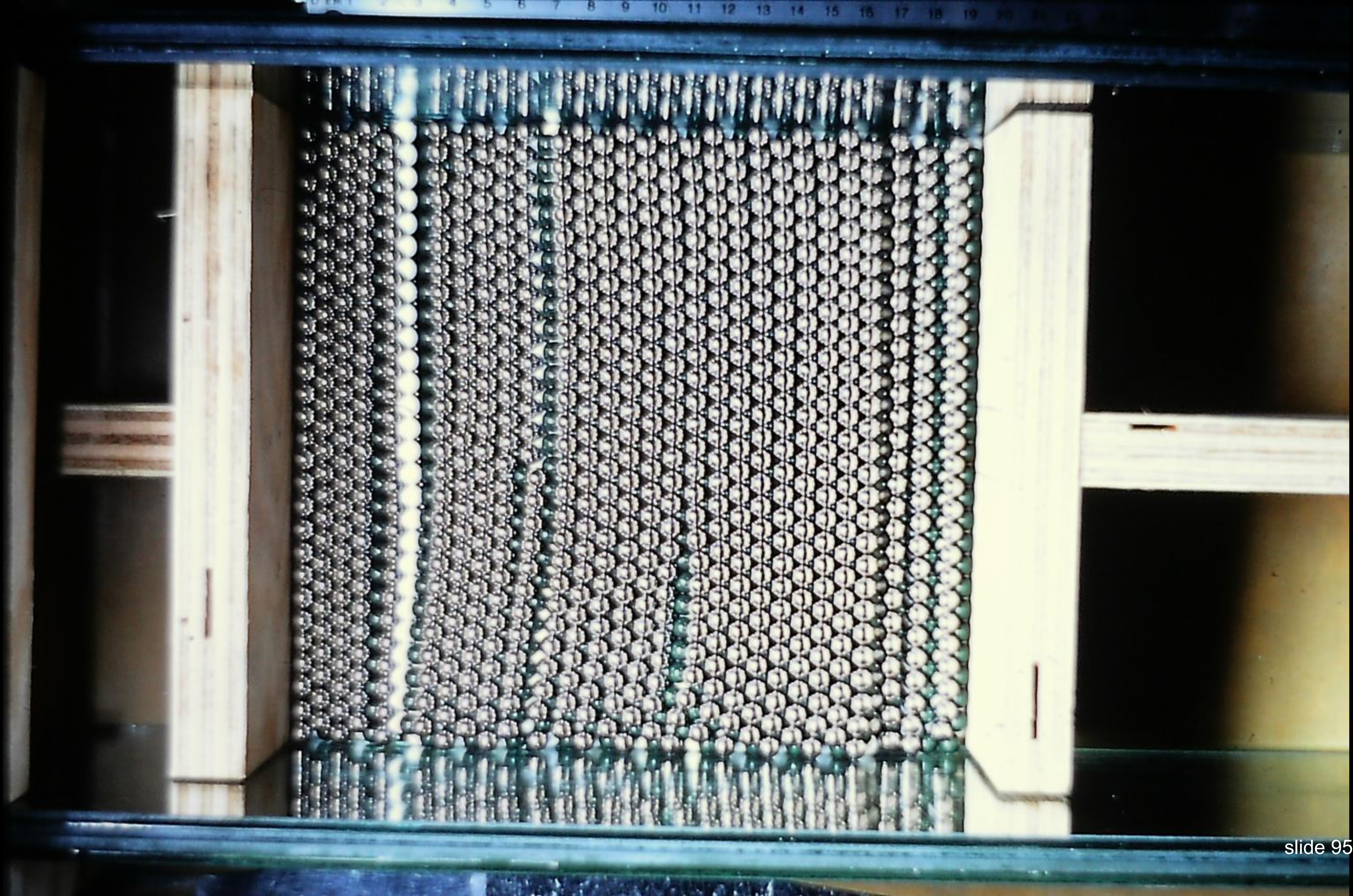
slide 91



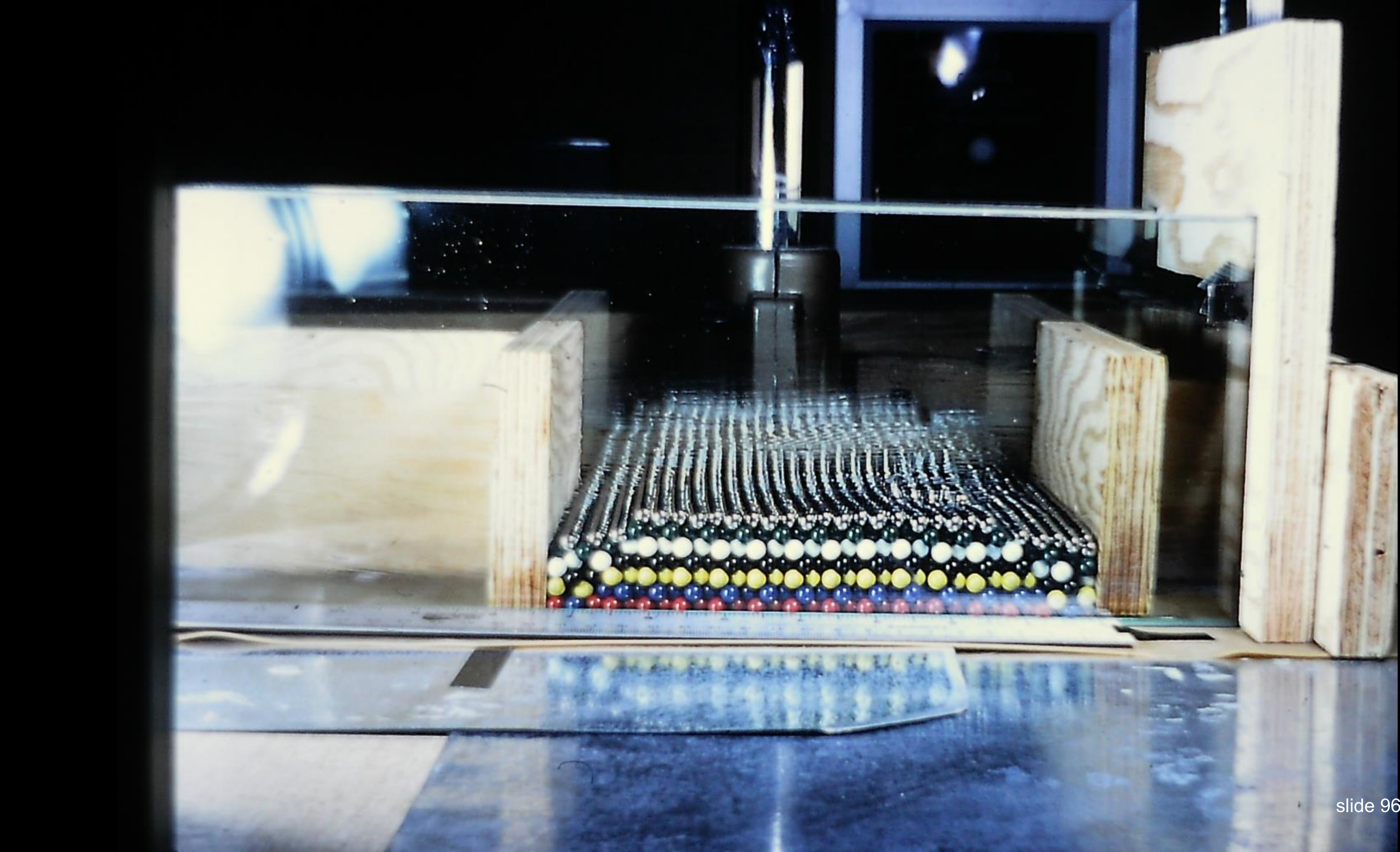
slide 92

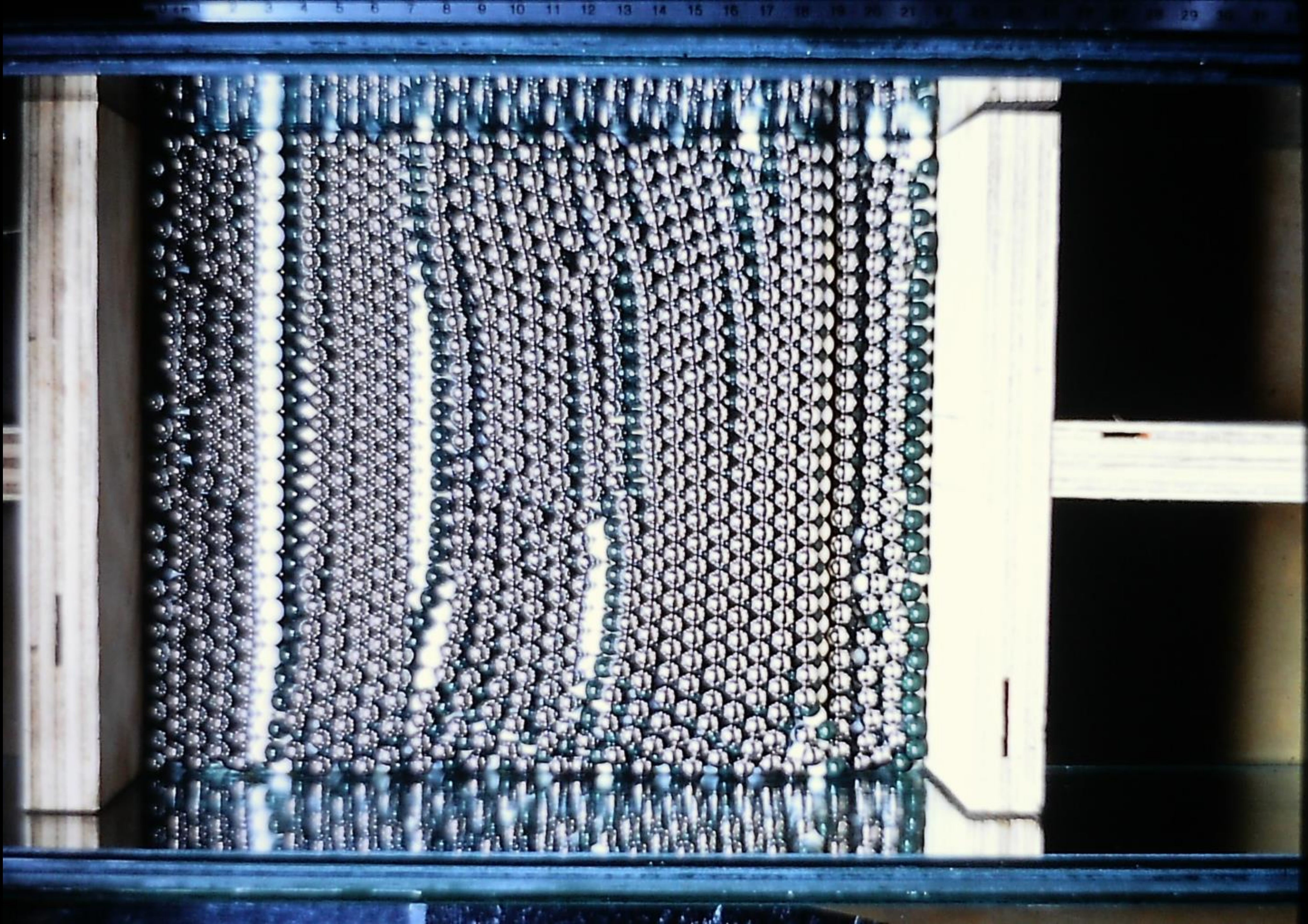


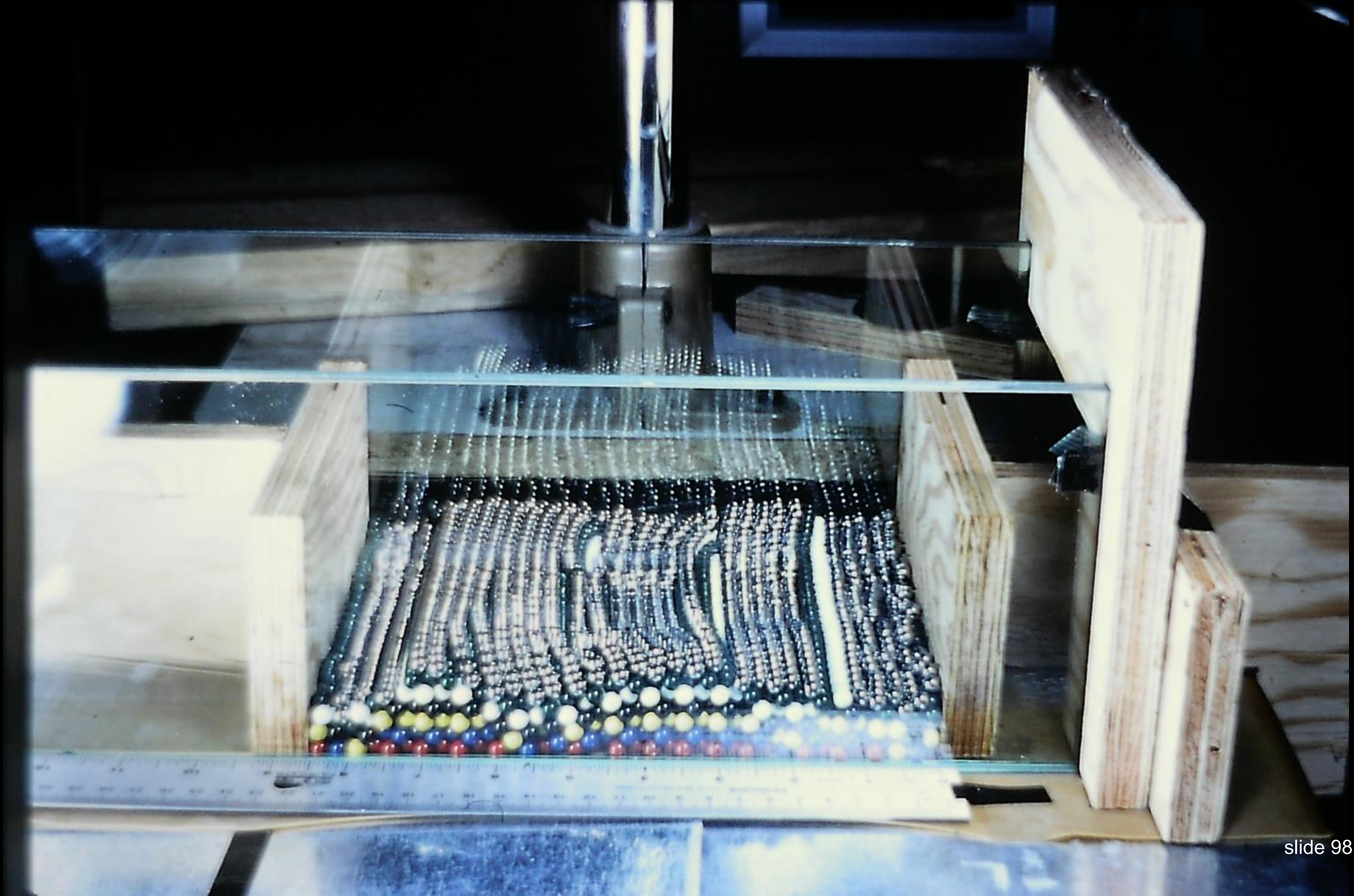




slide 95







PLAN VIEW, CROSS PACKING

Run #28

7 Layers

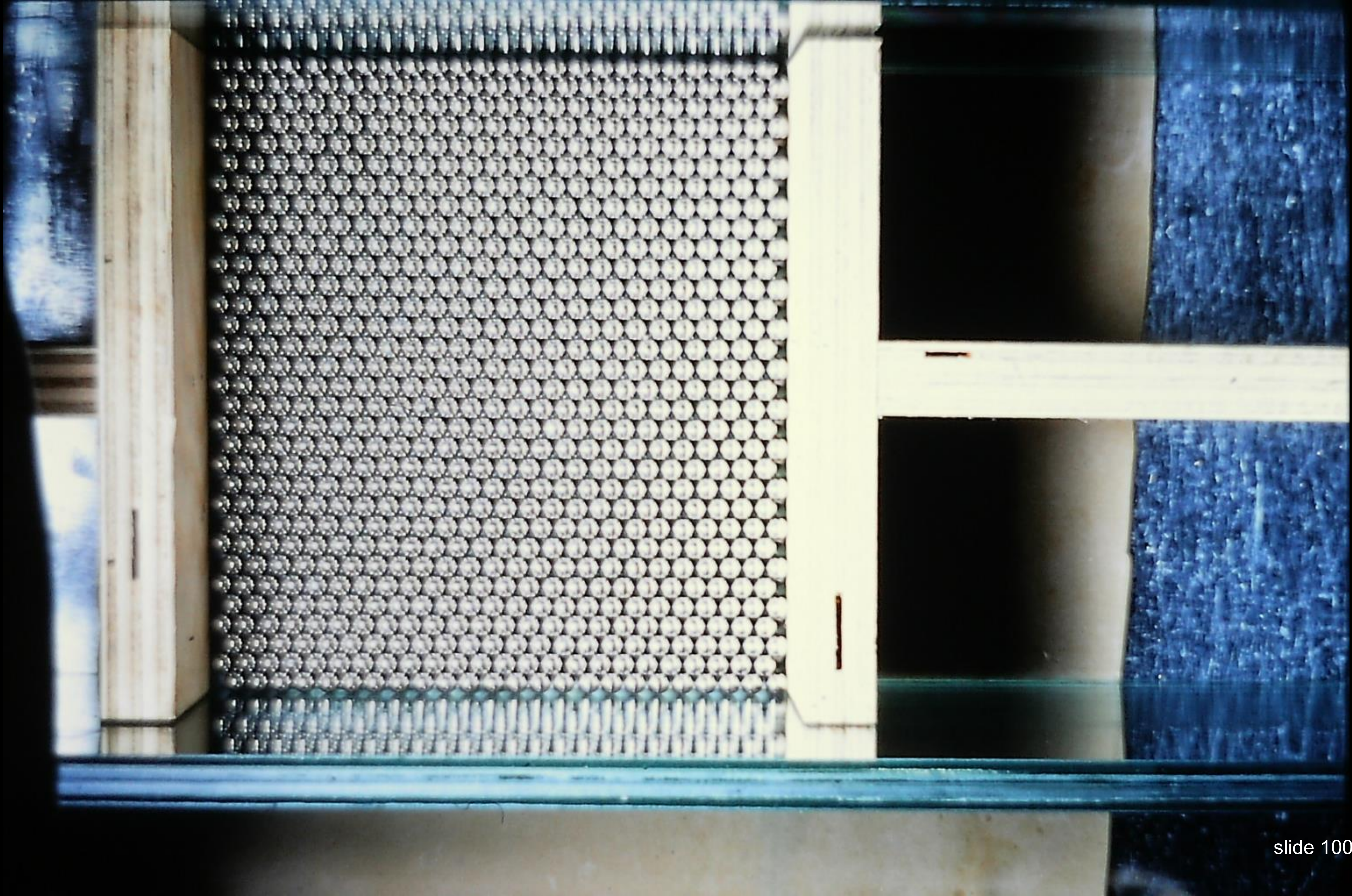
1/4" Balls

3D Close-Packed Hexagonal

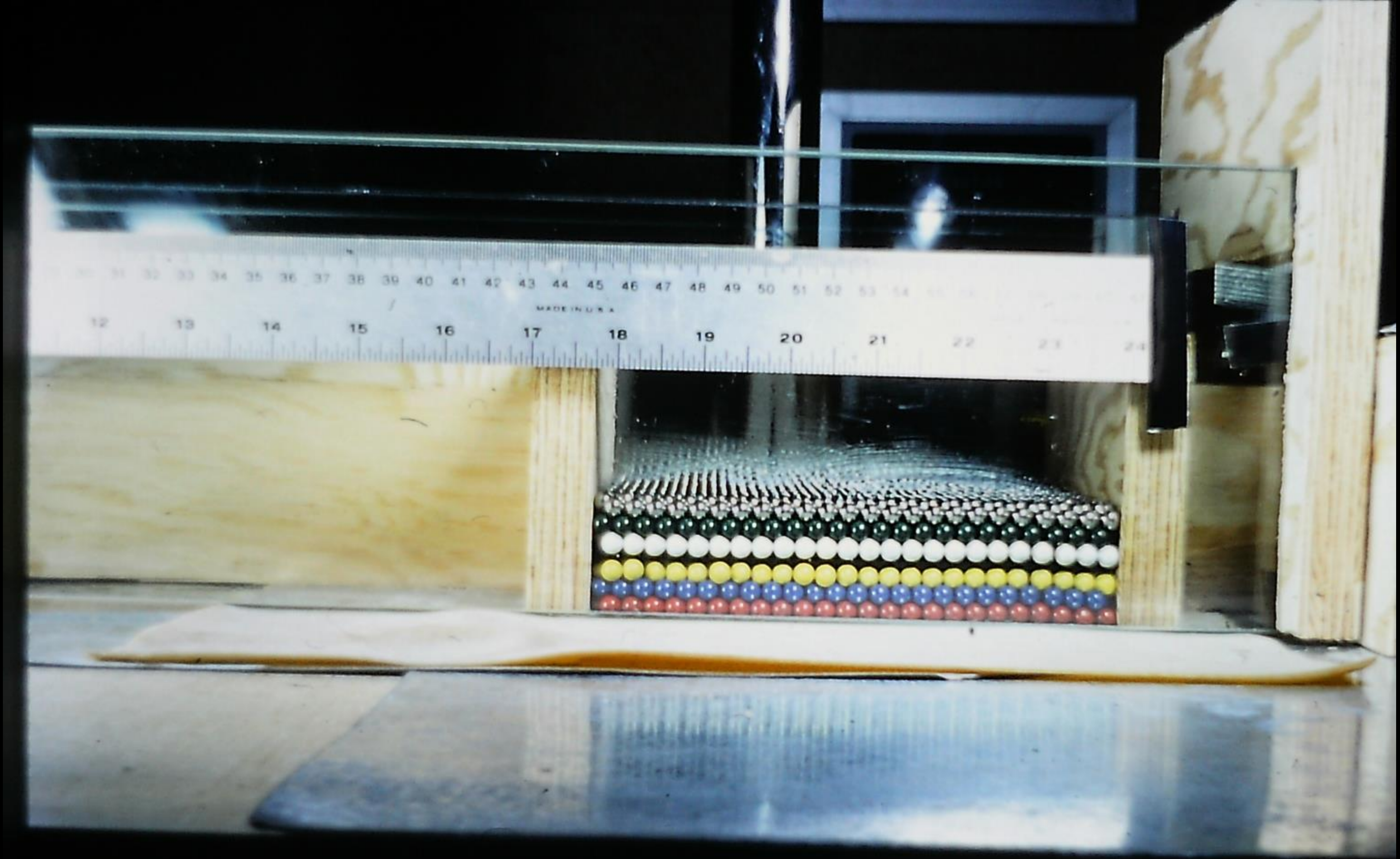
Rows Parallel To Direction Of Extension

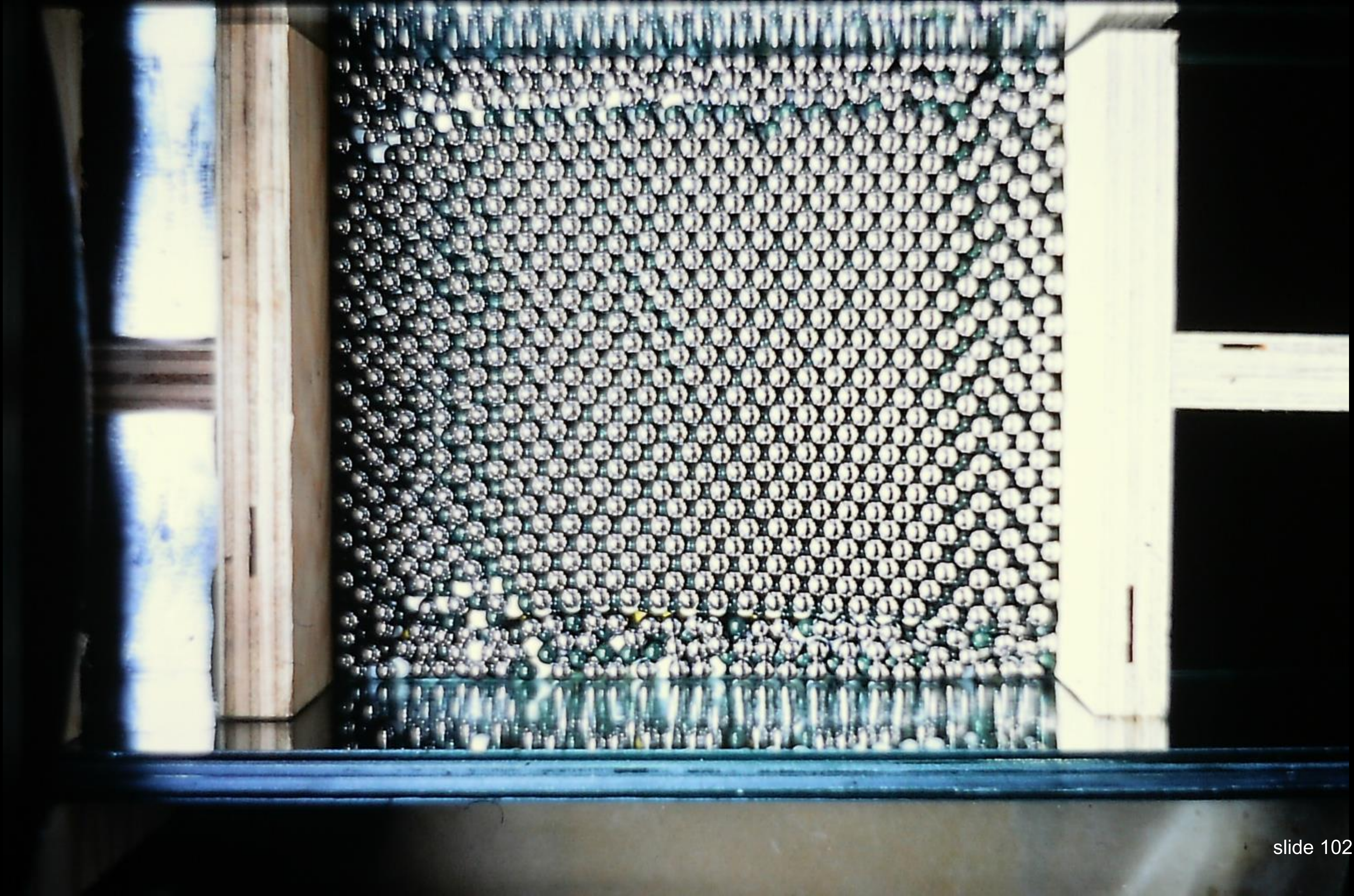
6.1 cm/hr

β = 1.00, 1.27



slide 100





REE SIZES, ± 25% RANGE, RANDOM PACKING

Run #19

~21 Layers

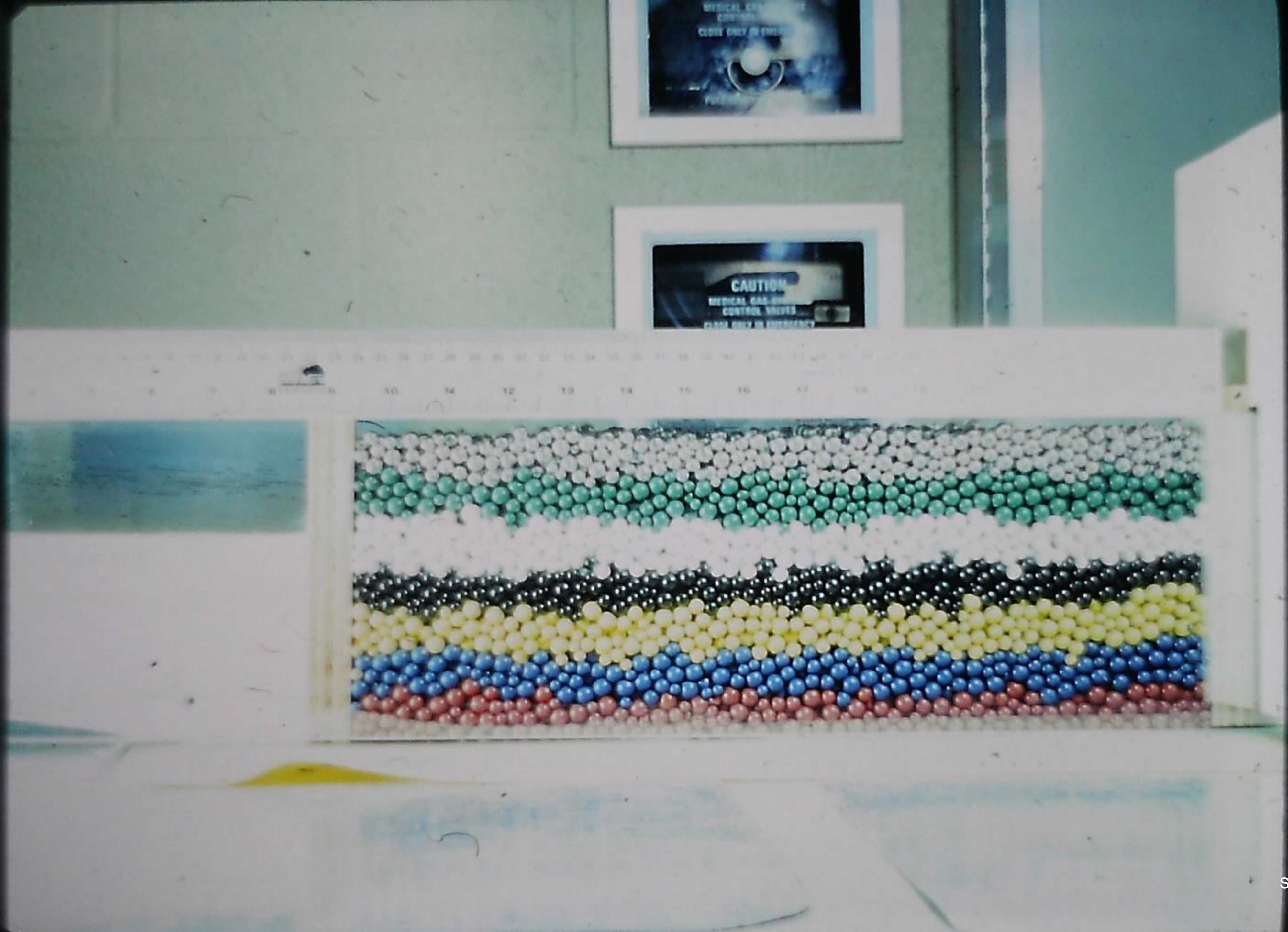
3/16", 1/4", 5/16" Balls

Equally Distributed,

Random Packing

7.2 cm/hr

β = 1.00, 1.18


CAUTION


CAUTION
CONTROL VALVES
CLOSE ONLY IN EMERGENCY

THREE SIZES, ± 25% RANGE, RANDOM PACKING

Run #22

7 Major Layers

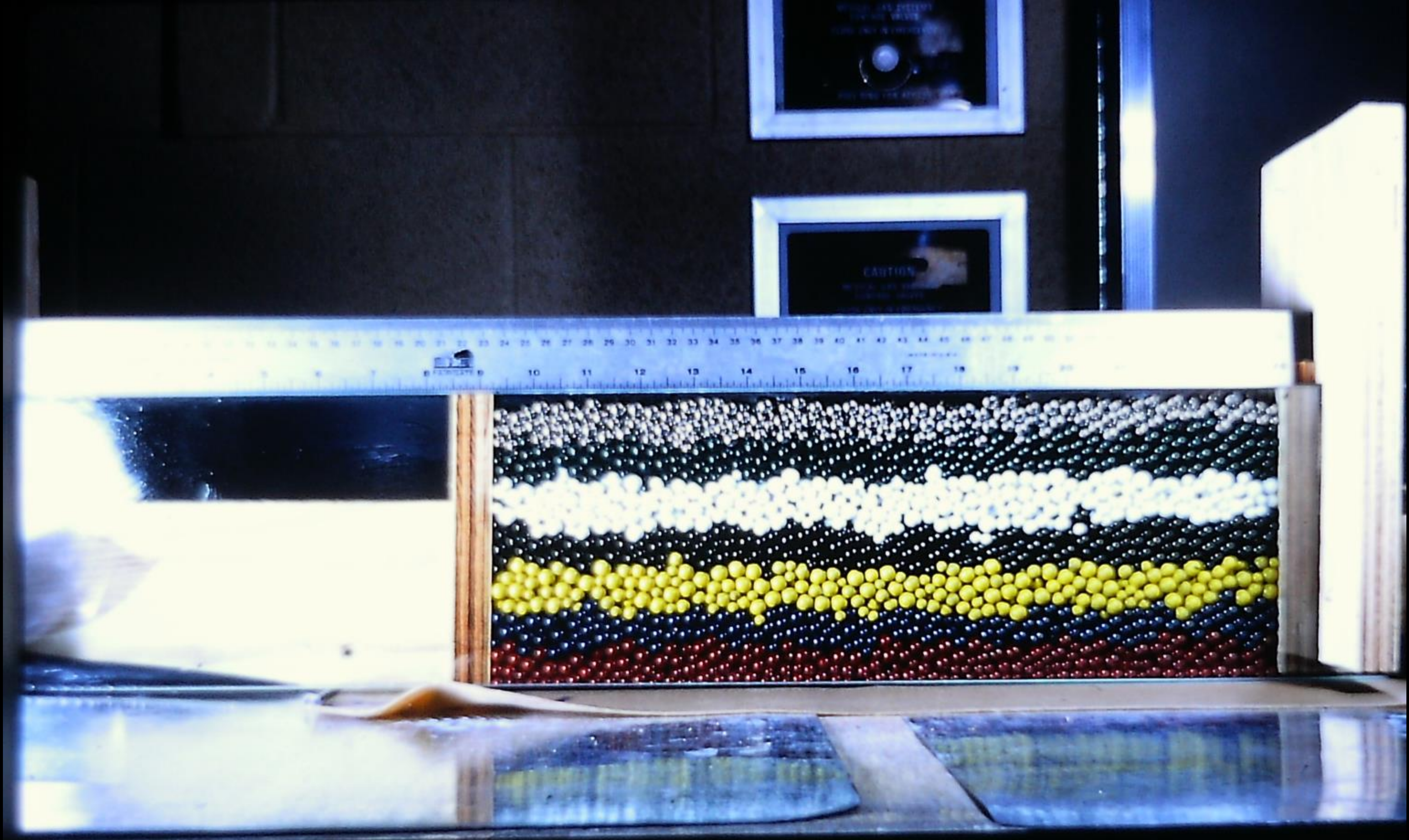
3/16", 1/4", 5/16" Balls

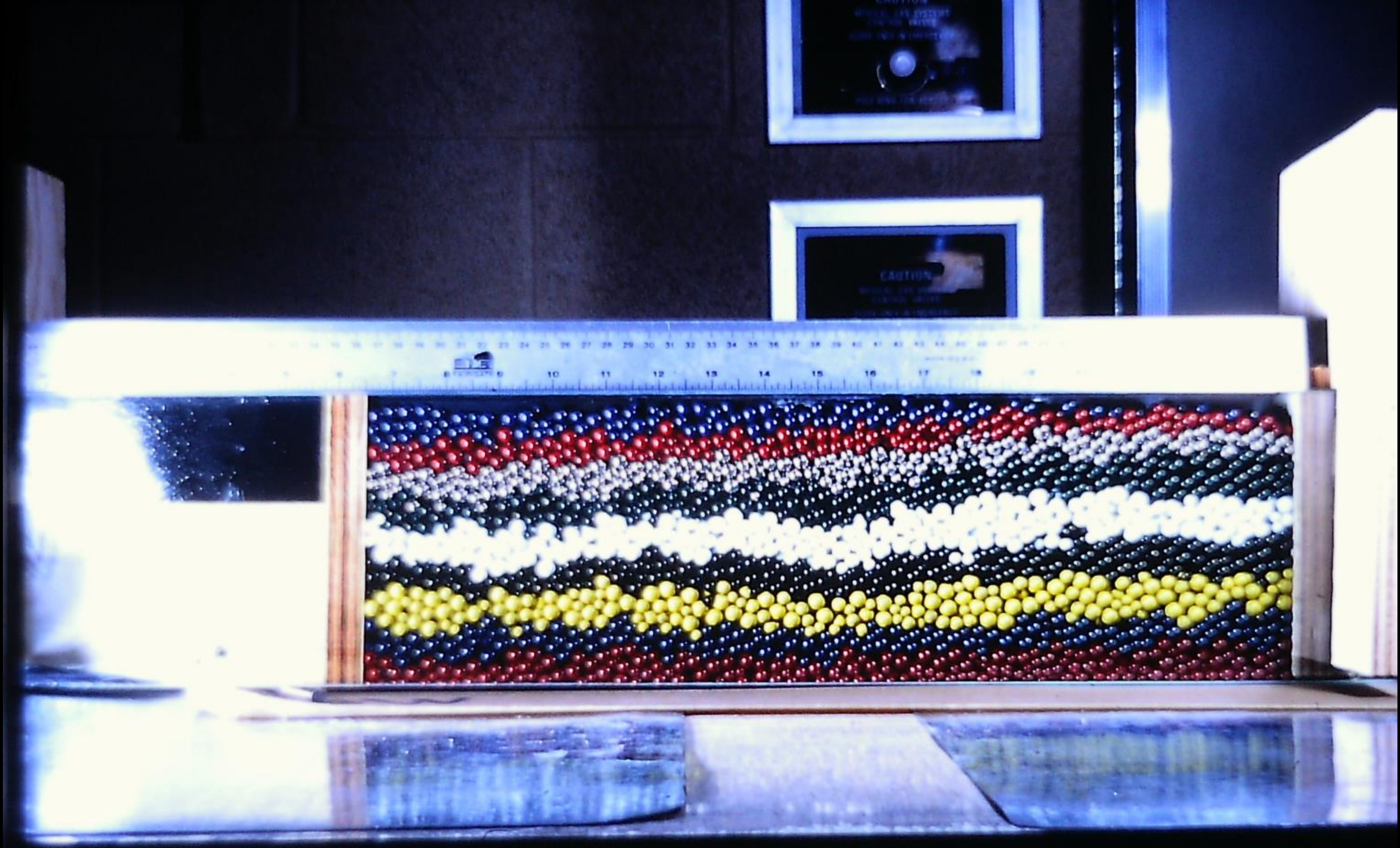
Equally Distributed, Each Major Layer

~3/4" Thick, Random Packing

7.3 cm/hr

β = 1.00, 1.19


CAUTION


CAUTION

THREE SIZES, ± 25% RANGE,
NORMALLY DISTRIBUTED, RANDOM PACKING

Run #25

14 Layers

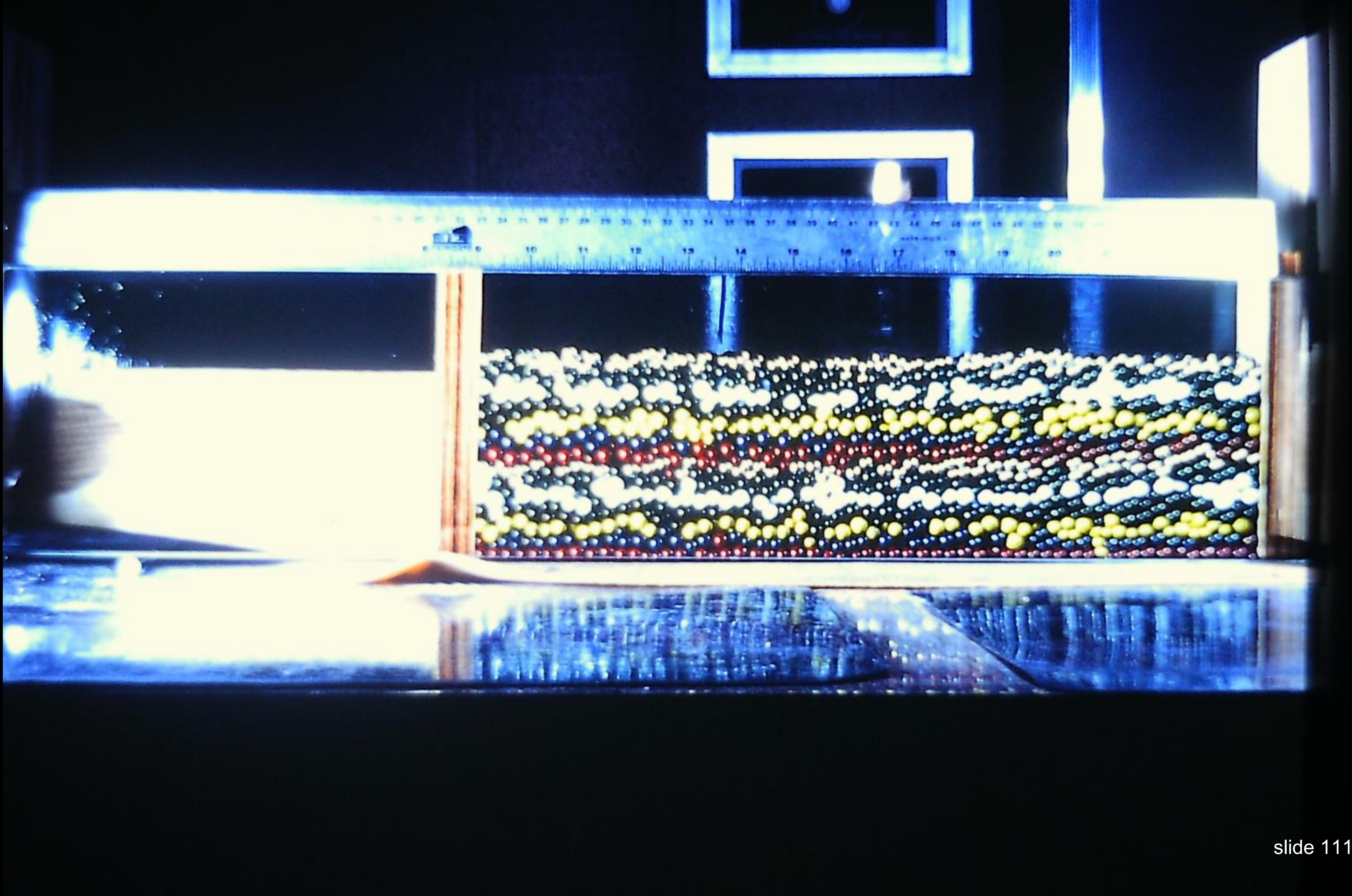
3/16", 1/4", 5/16" Balls

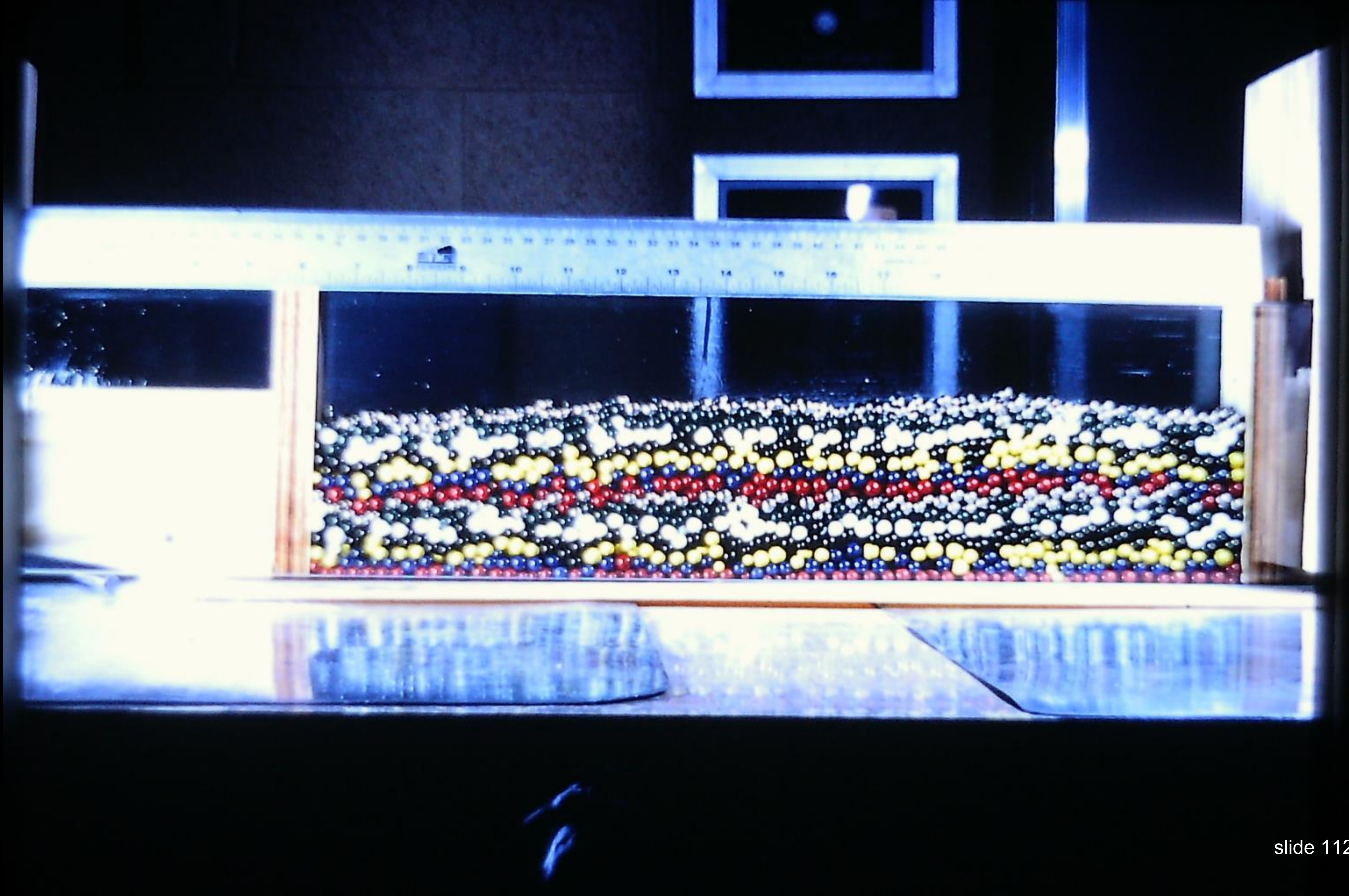
Distributed (1/4 : 1/2 : 1/4)

Random Packing

7.2 cm/hr

β = 1.00, 1.19





slide 112

THREE SIZES, $\pm$ 6% RANGE,
NORMALLY DISTRIBUTED, CLOSELY PACKED

Run #32

14 Layers

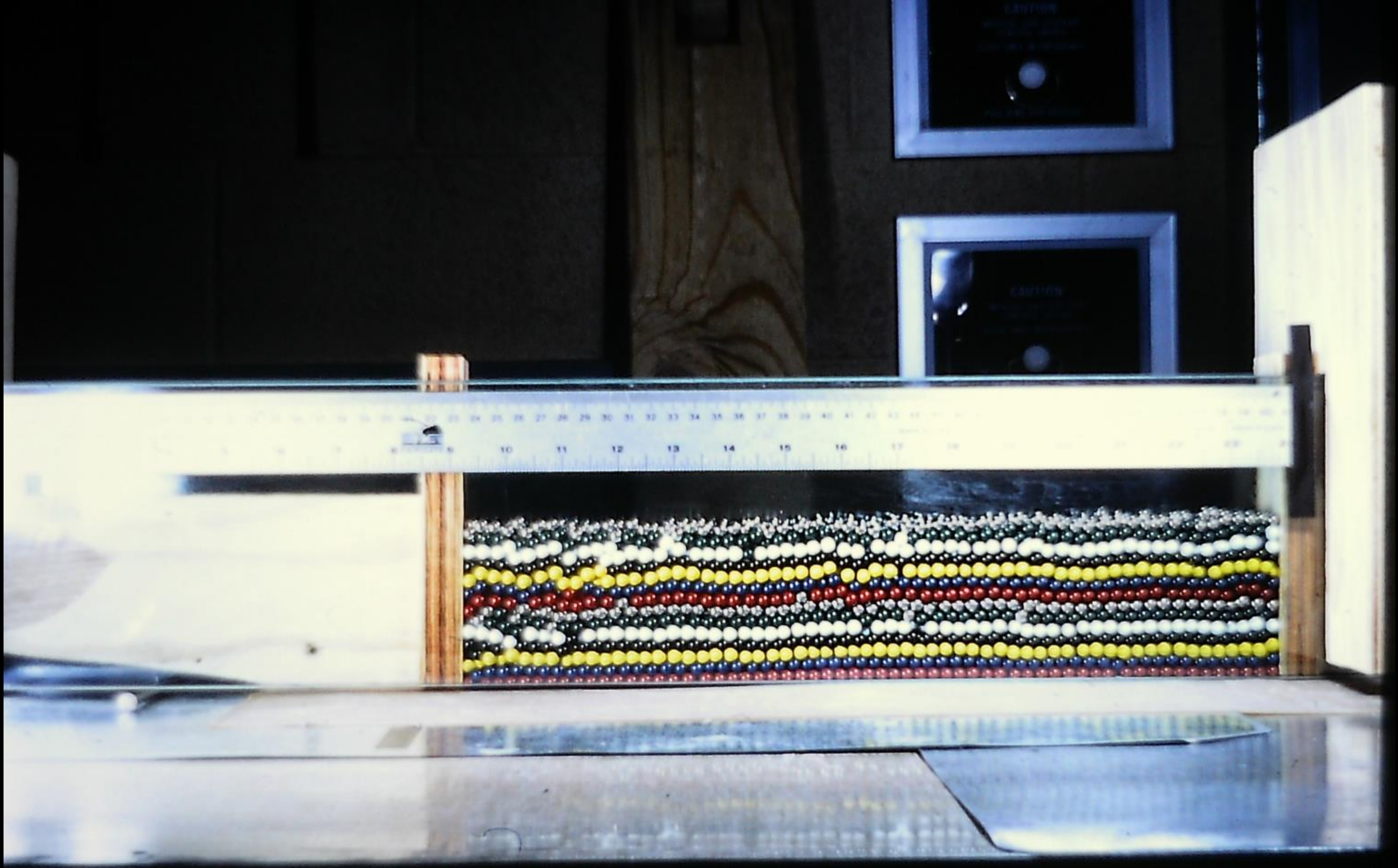
7/32", 15/64", 1/4" Balls,

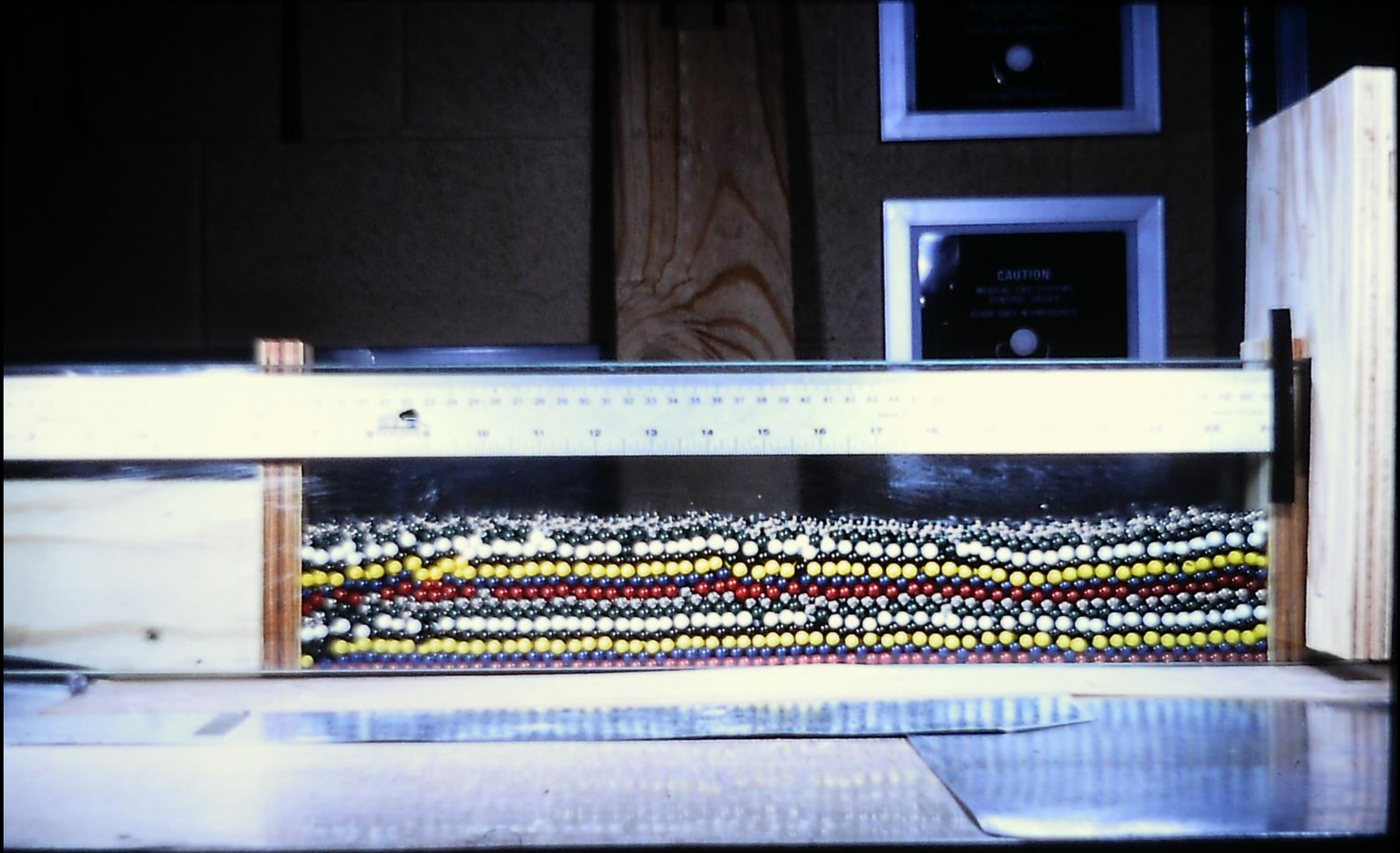
Distributed (1/4 : 1/2 : 1/4)

Attempted 3D Close-Packed Hexagonal

6.9 cm/hr

β = 1.00, 1.17




CAUTION

THREE SIZES, ± 6% RANGE, NORMALLY DISTRIBUTED, TOPPED BY UPPER LAYER

Run #33

14 Layers

7/32", 15/64", 1/4" Balls

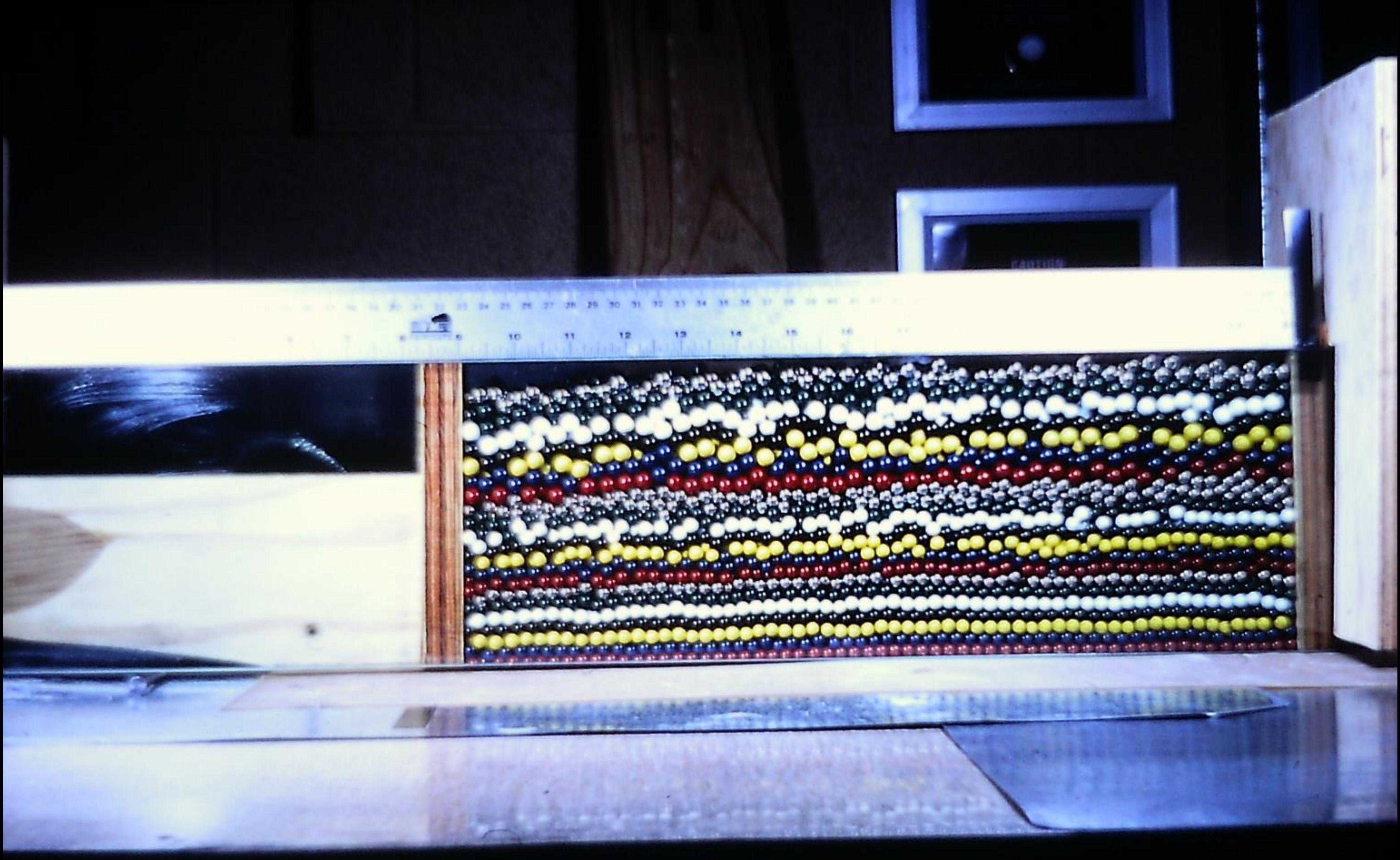
Distributed (1/4 : 1/2 : 1/4)

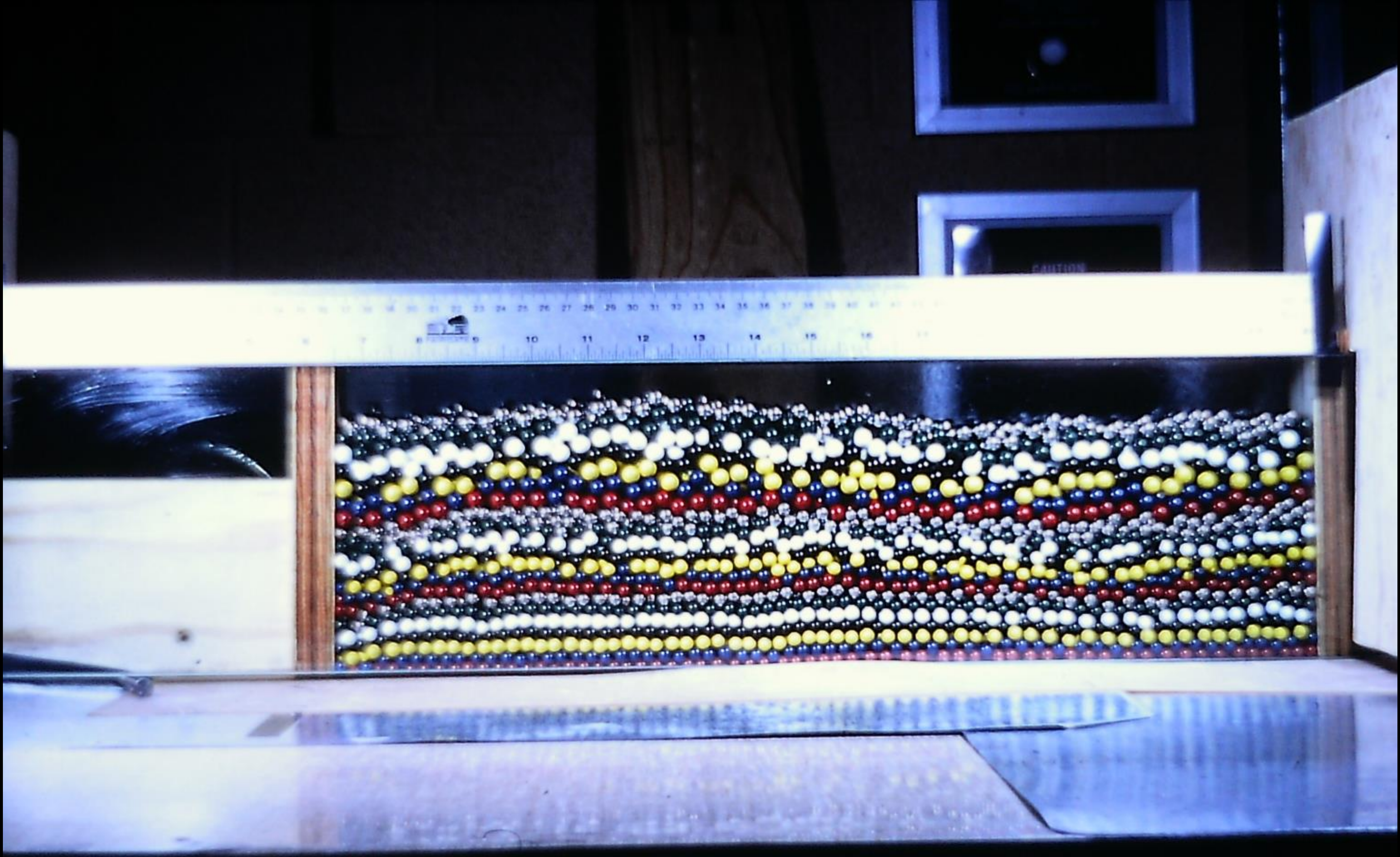
Topped by 7 Layers of 5/16" balls

Attempted 3D Close-Packed Hexagonal

6.7 cm/hr

β = 1.00 1.17





THREE SIZES, $\pm$ 6% RANGE, NORMALLY DISTRIBUTED, LOCKED IN PLACE BY UPPER LAYER

Run #34

7 Layers 7/32", 15/64", 1/4" Balls

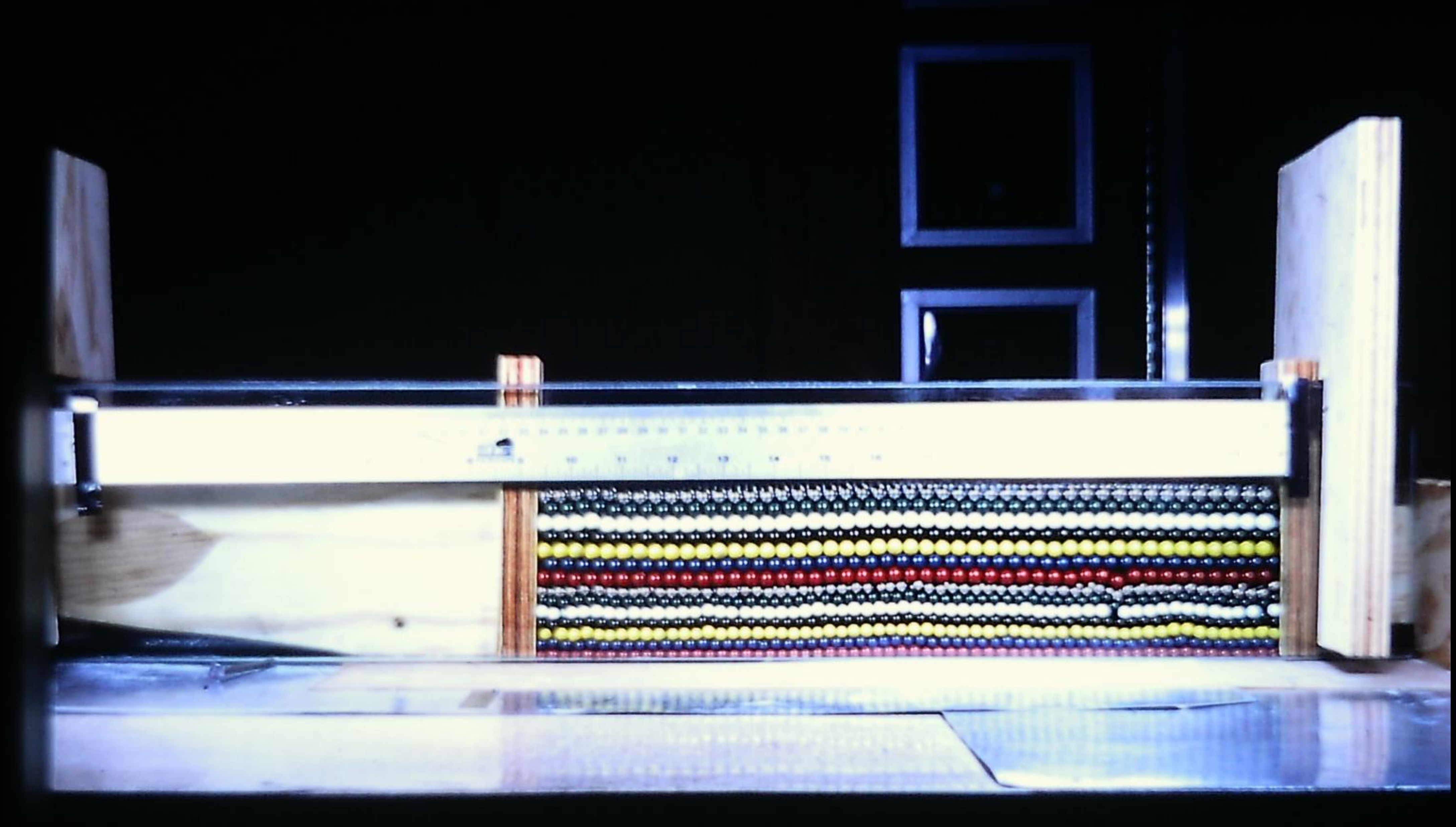
Distributed (1/4 : 1/2 : 1/4)

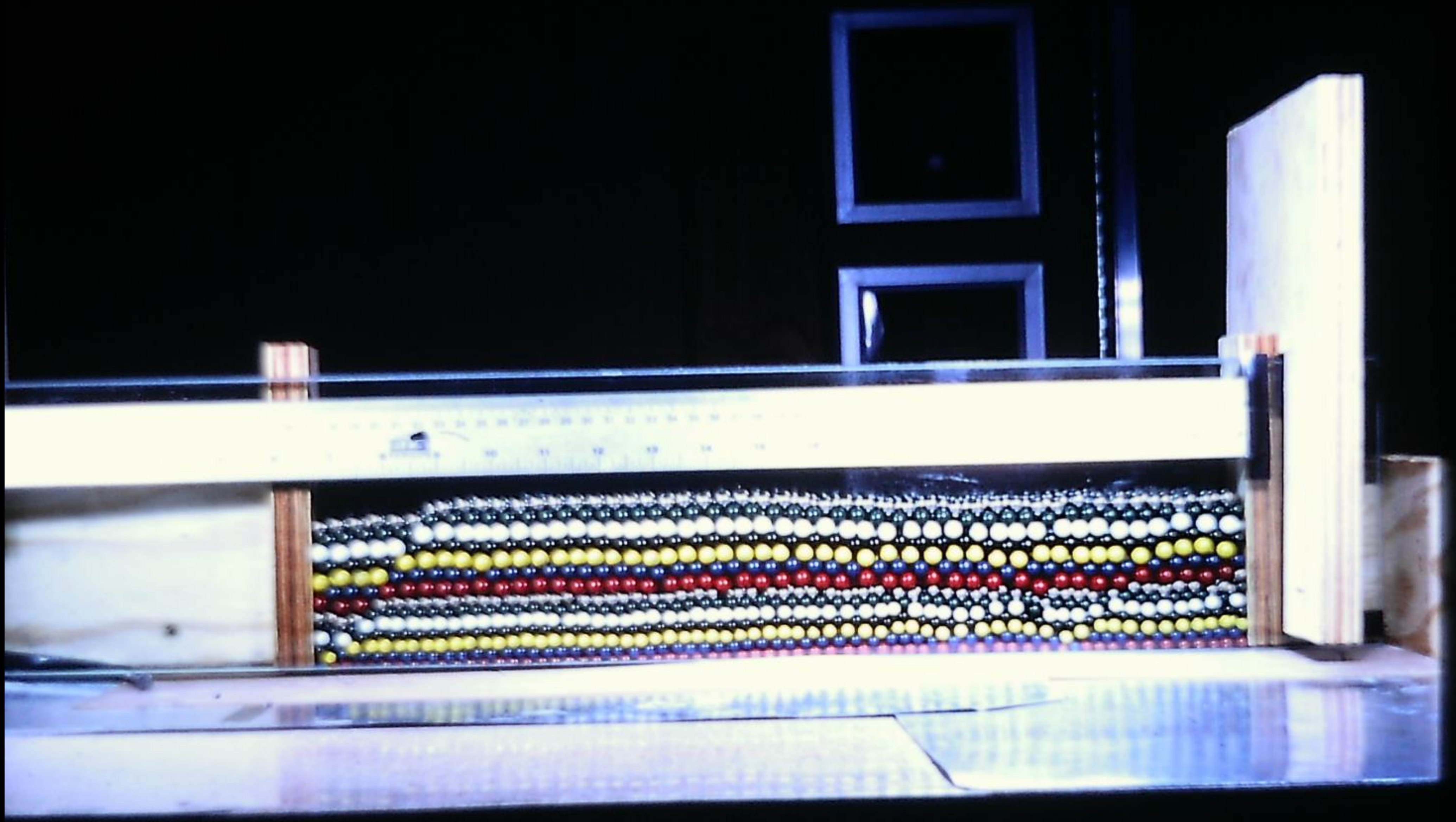
Topped By 7 Layers Of 15/64" Balls

Attempted 3D Close-Packed Hexagonal

7.1 cm/hr

β = 1.00, 1.18





slide 121

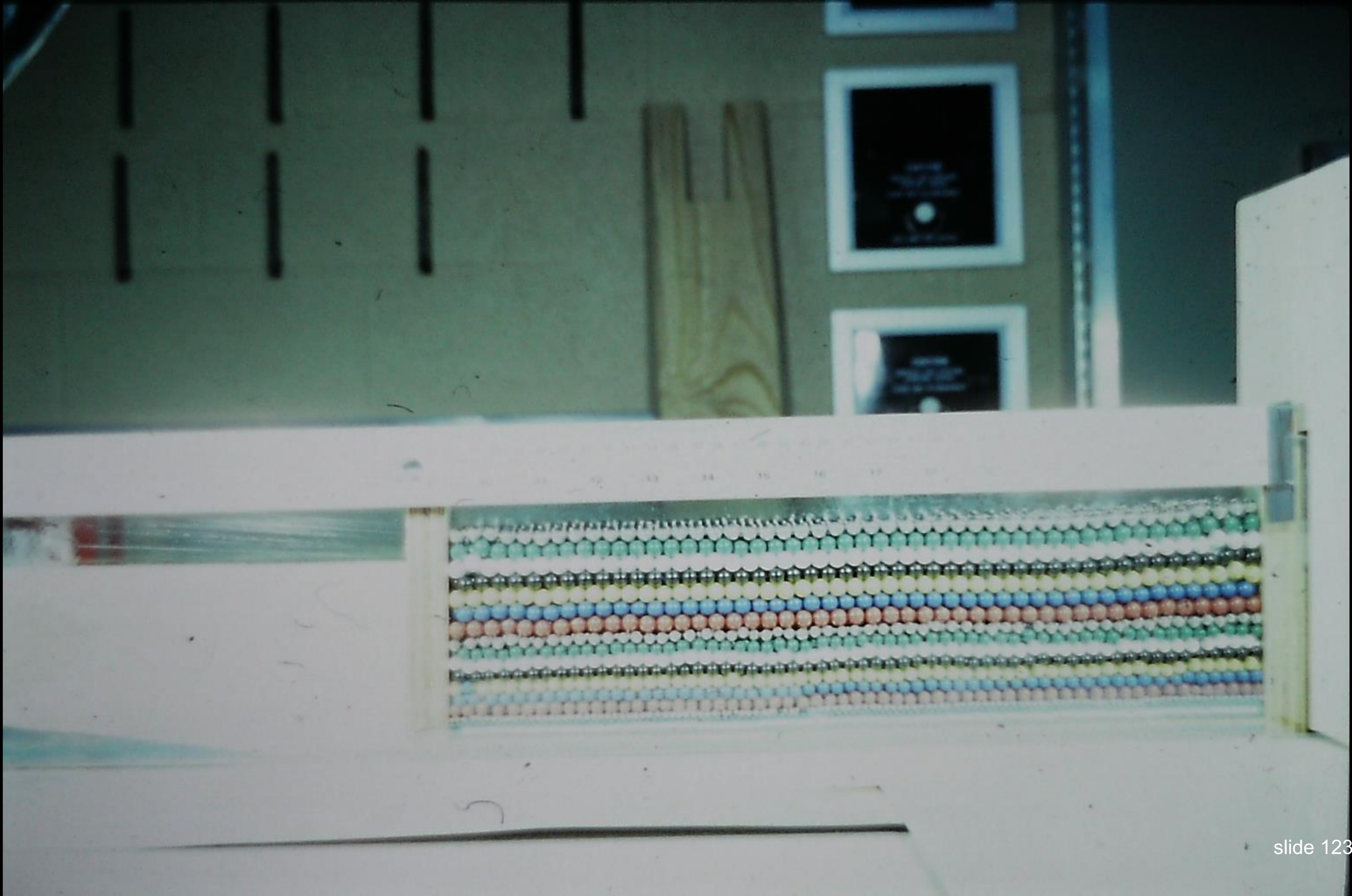
THREE SIZES, ± 6% RANGE, NORMALLY DISTRIBUTED, SMALL BALLS ON SHEET, LOCKED IN PLACE BY LARGE BALLS ON TOP

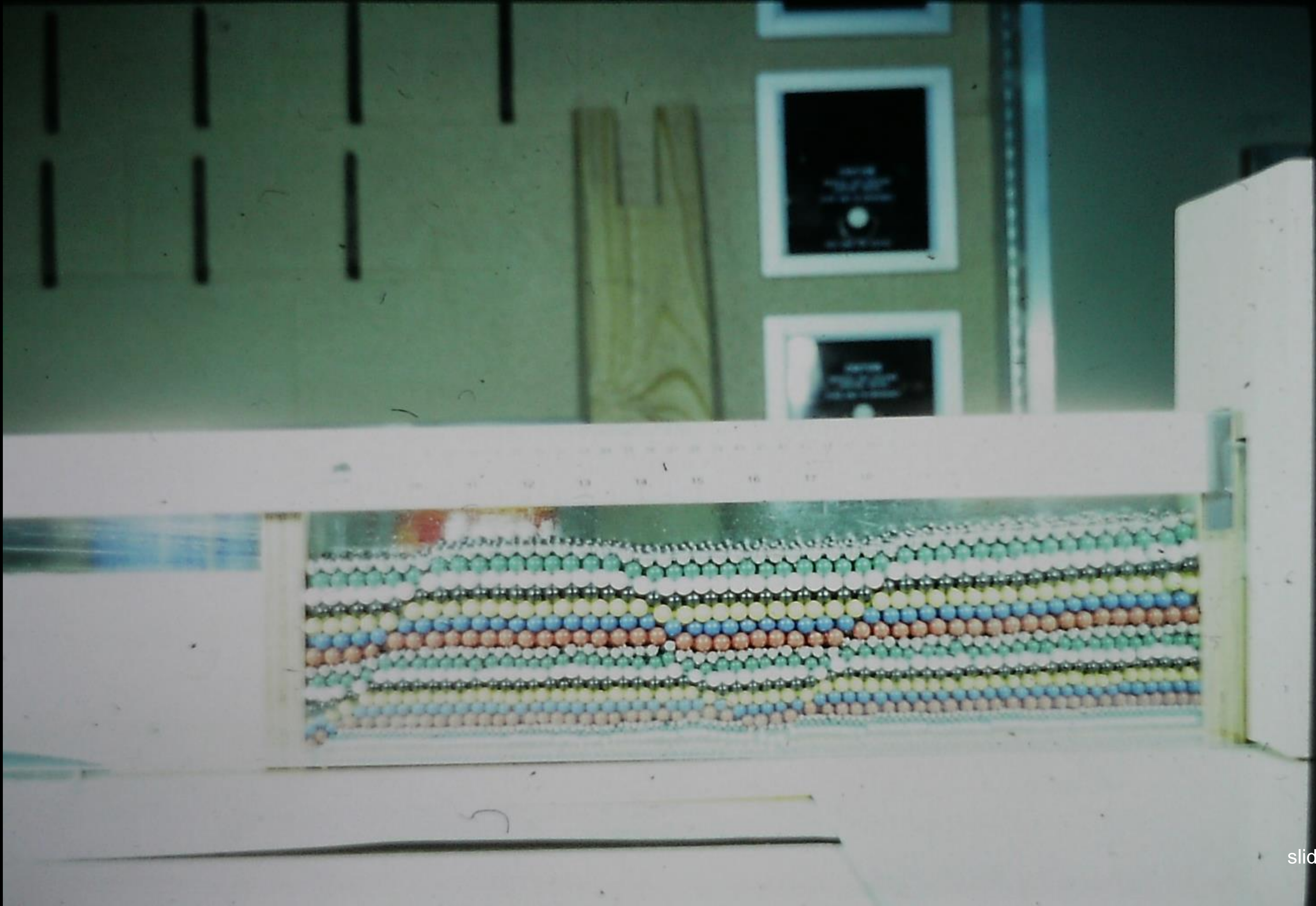
Run #36

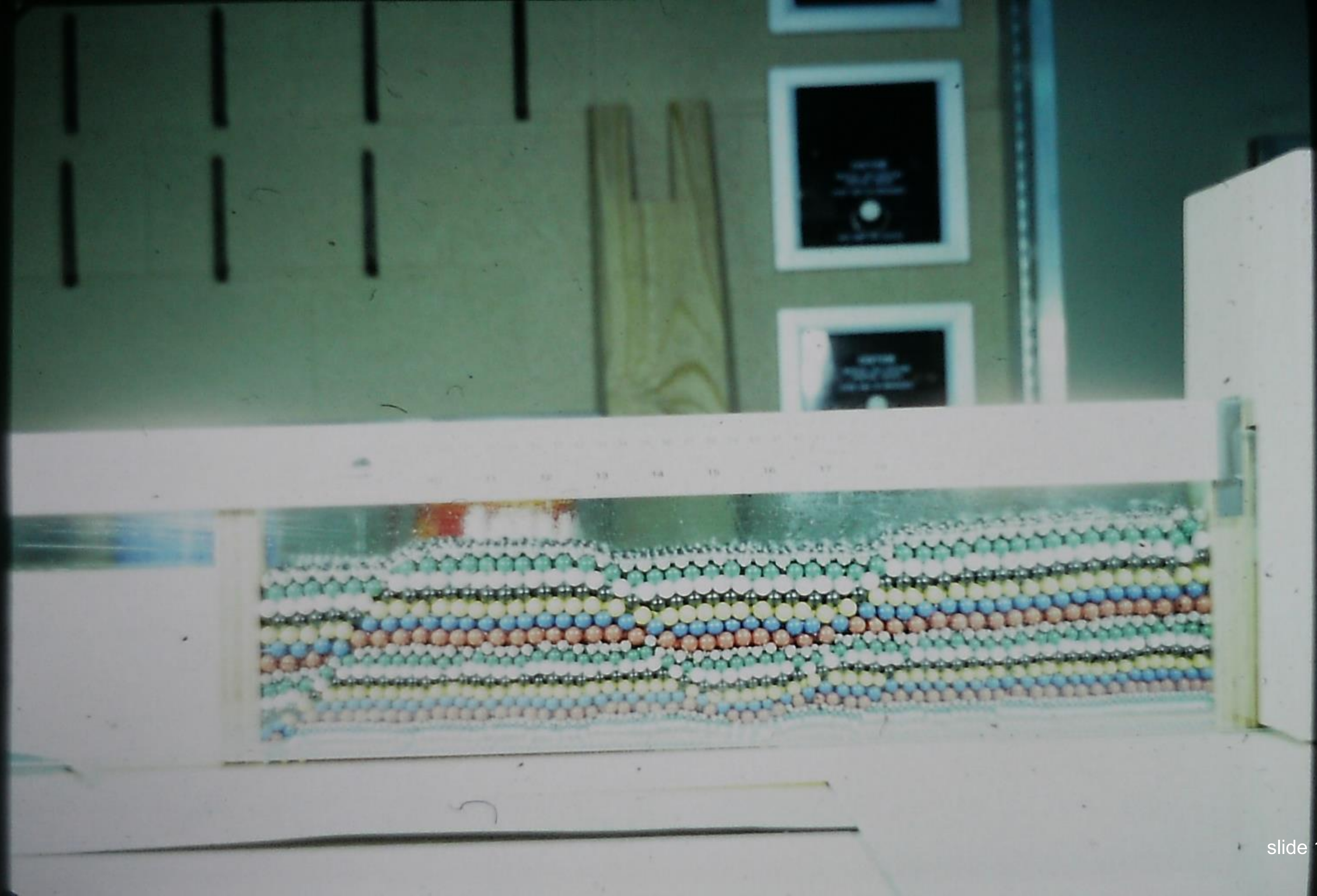
7 Layers 1/8" Balls In 3D Close-Packed Hexagonal On Bottom,
7 Layers 7/32", 15/64", 1/4" Balls Distributed (1/4 : 1/2 : 1/4) Attempted 3D Close-Packed Hexagonal Above,
Topped By 7 Layers of 5/16" Balls In An Attempted 3D Close-Packed Hexagonal,

8.0 cm/hr

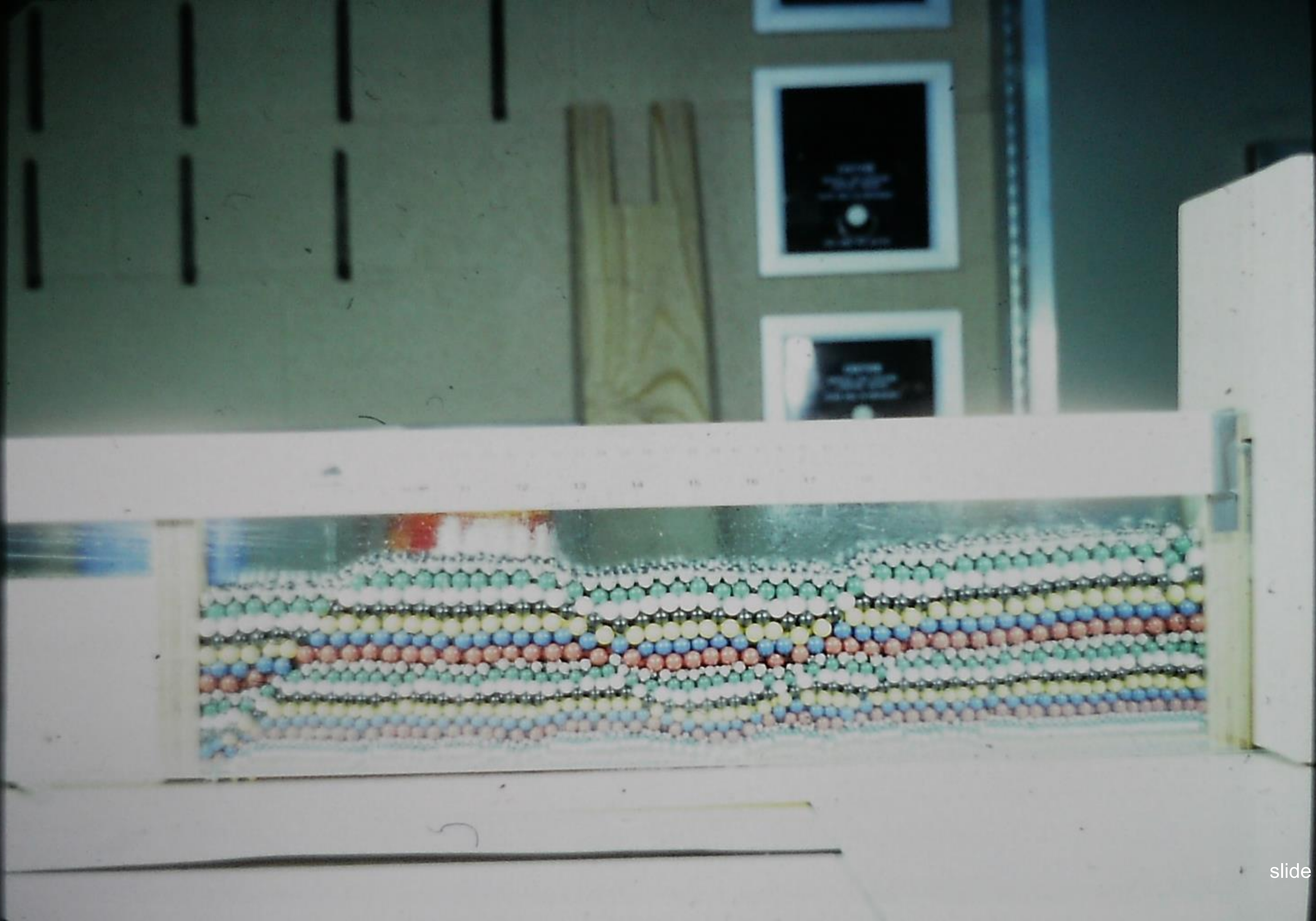
β=1.00,1.09,1.18,1.21,1.24,1.27,1.31,1.34,1.41



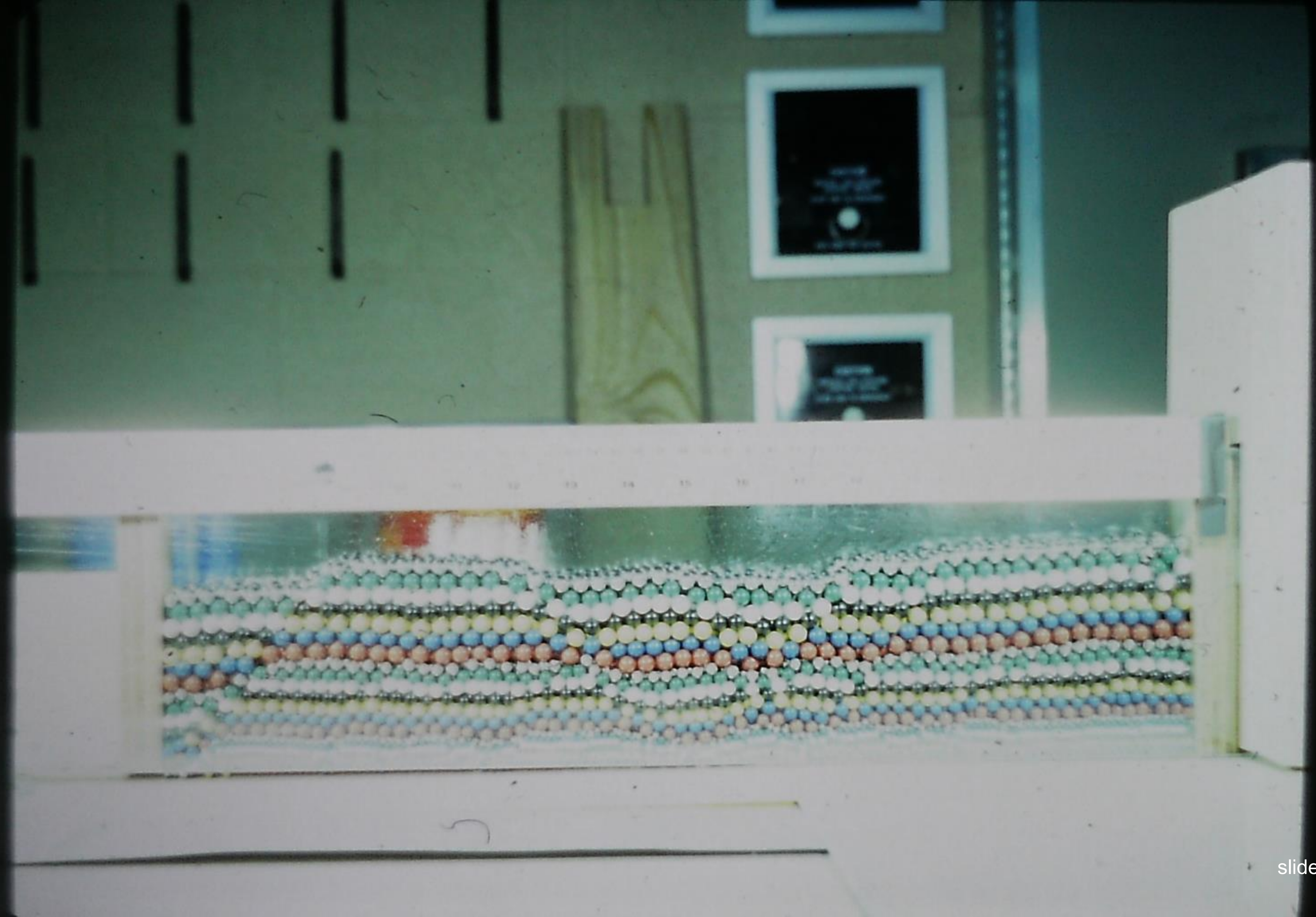




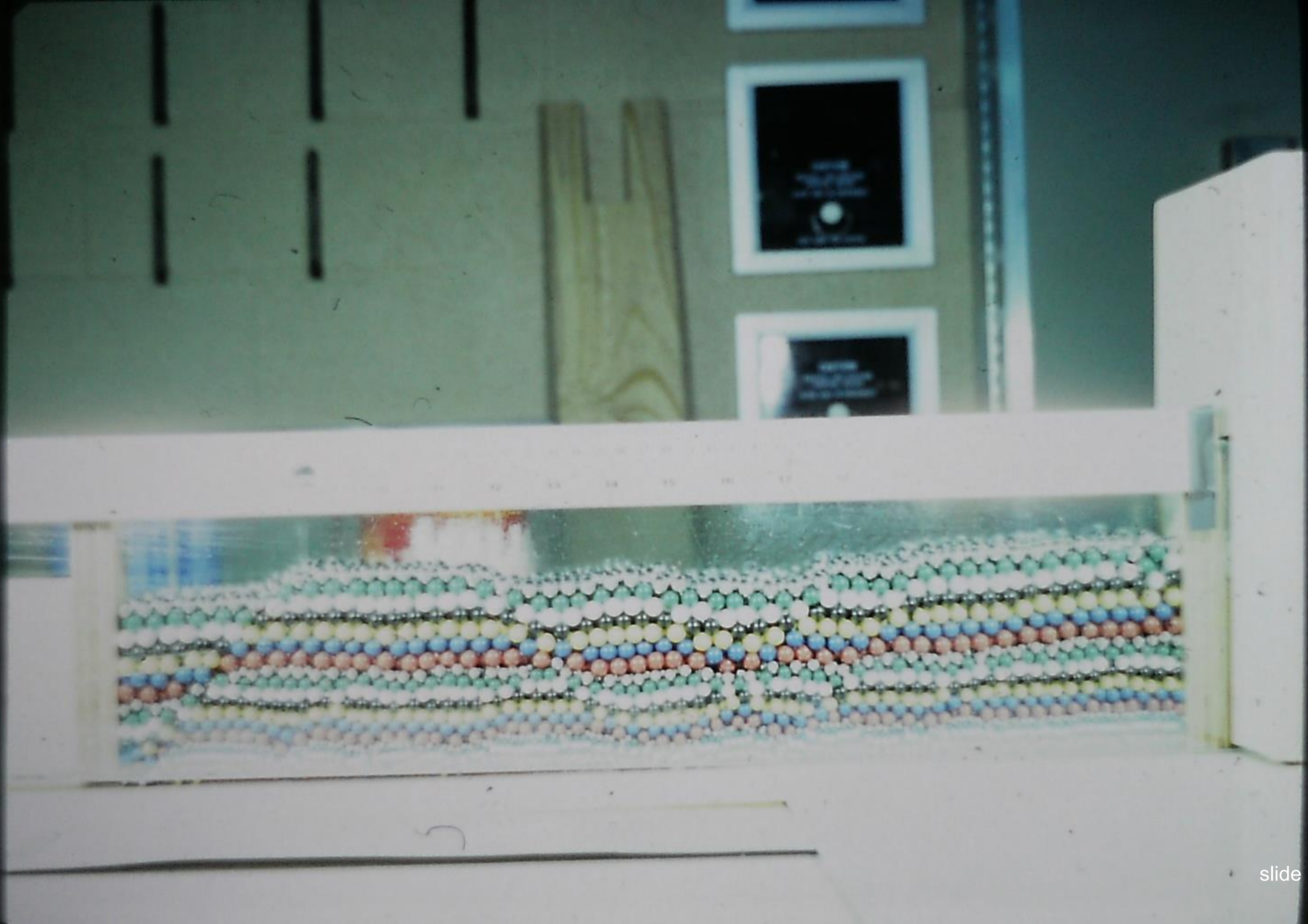
slide 125

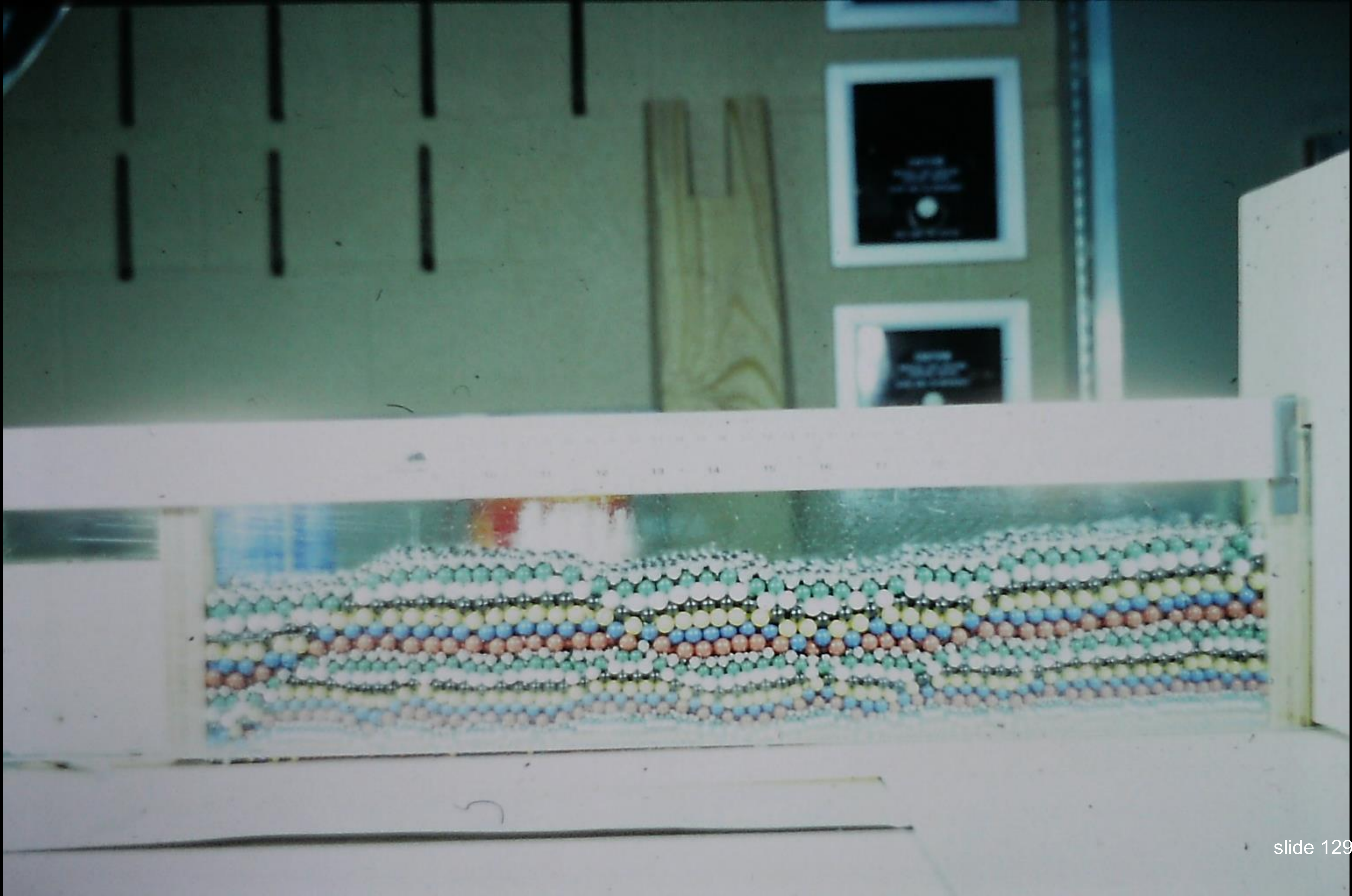


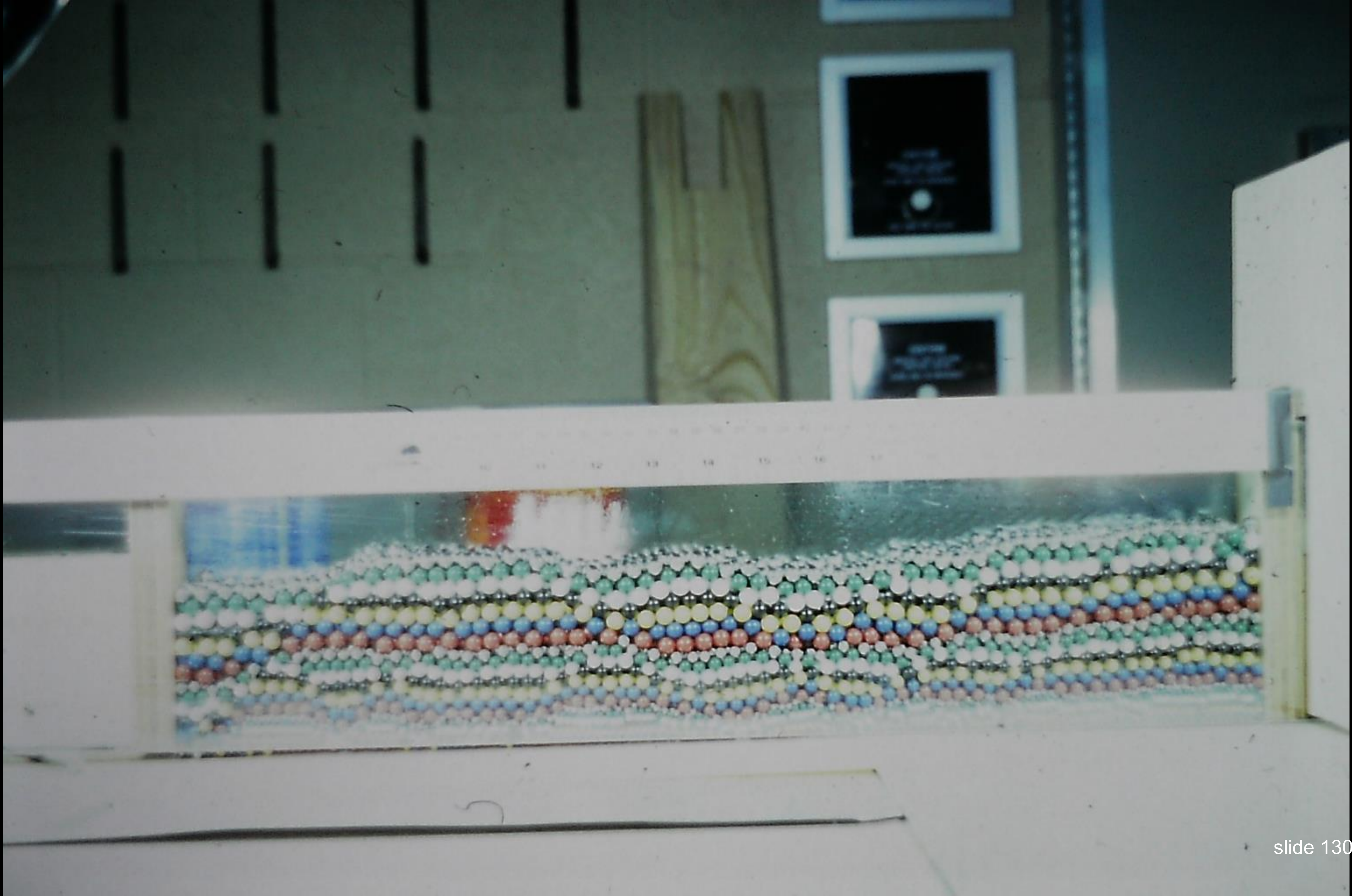
slide 126

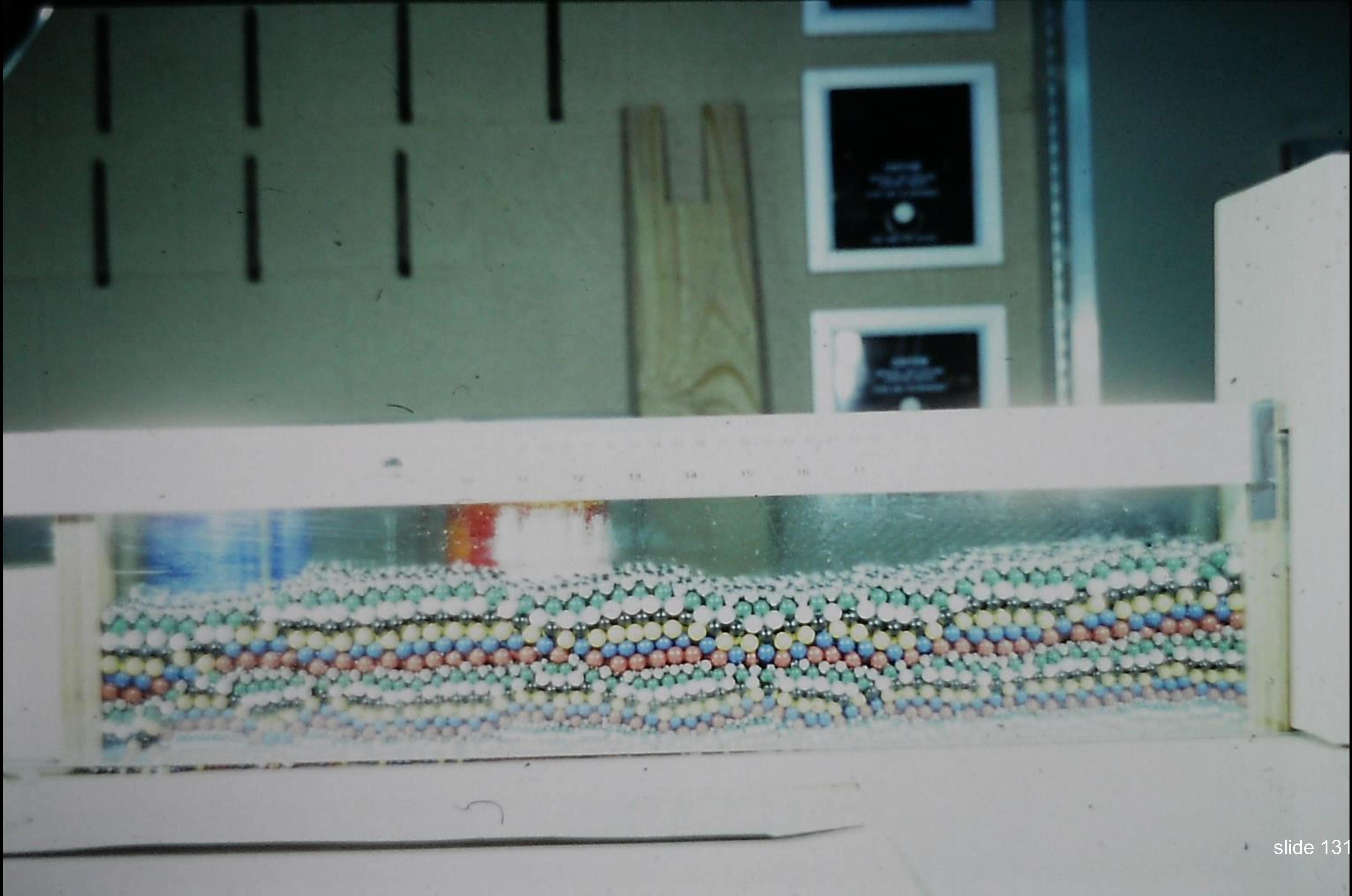


slide 127









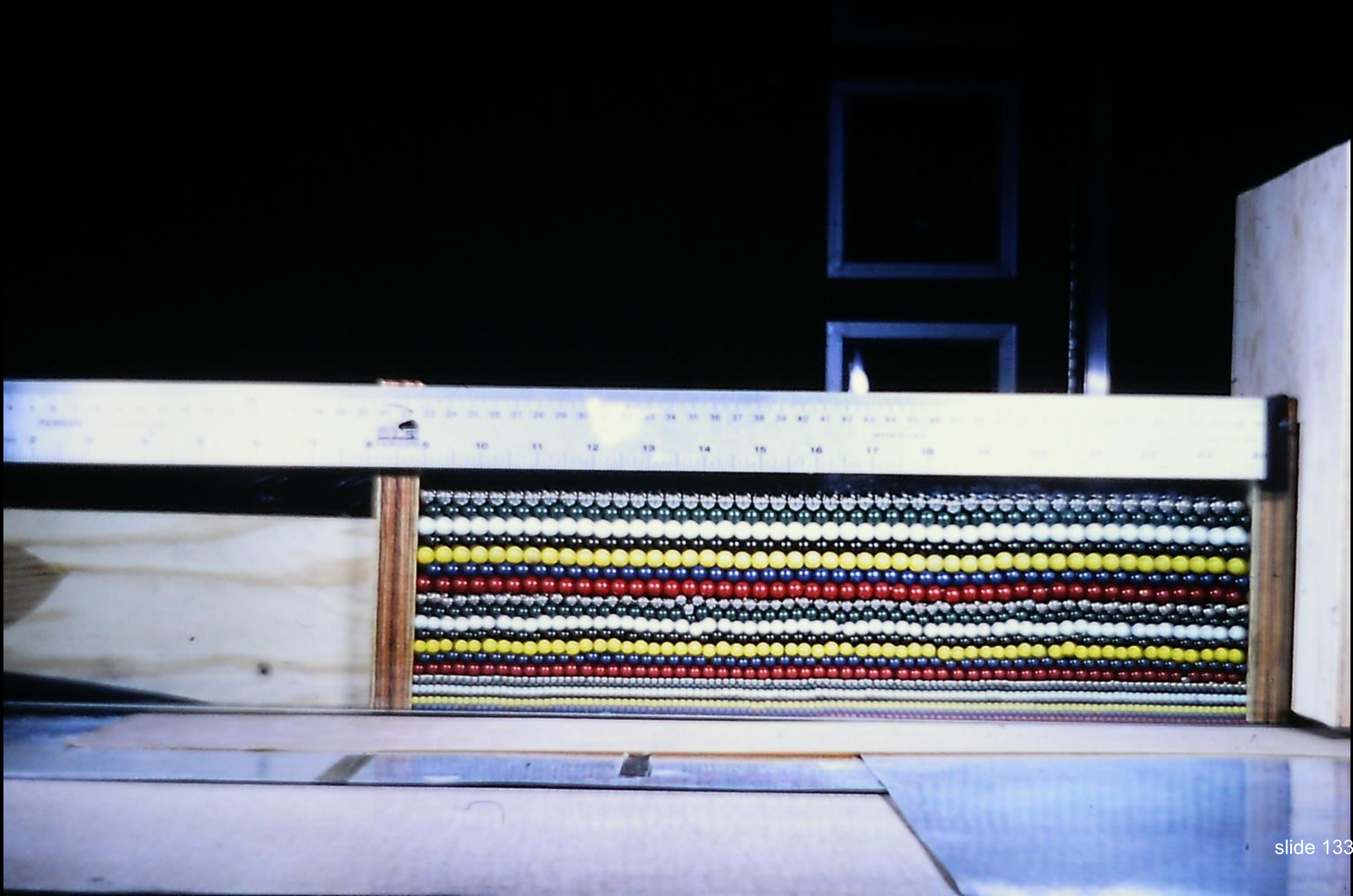
THREE SIZES, SAME AS 36, (PAINT DRIED

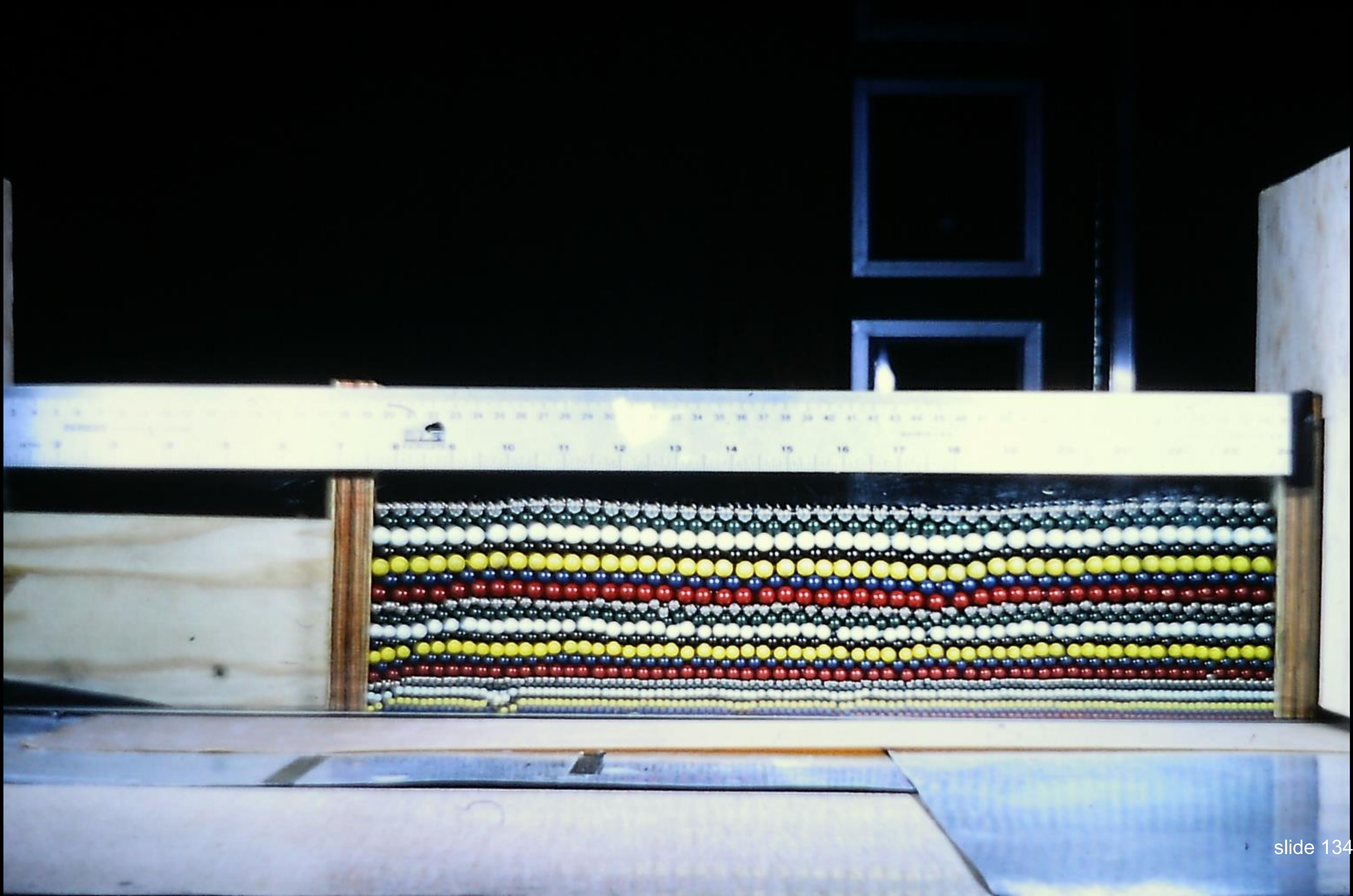
Run #38

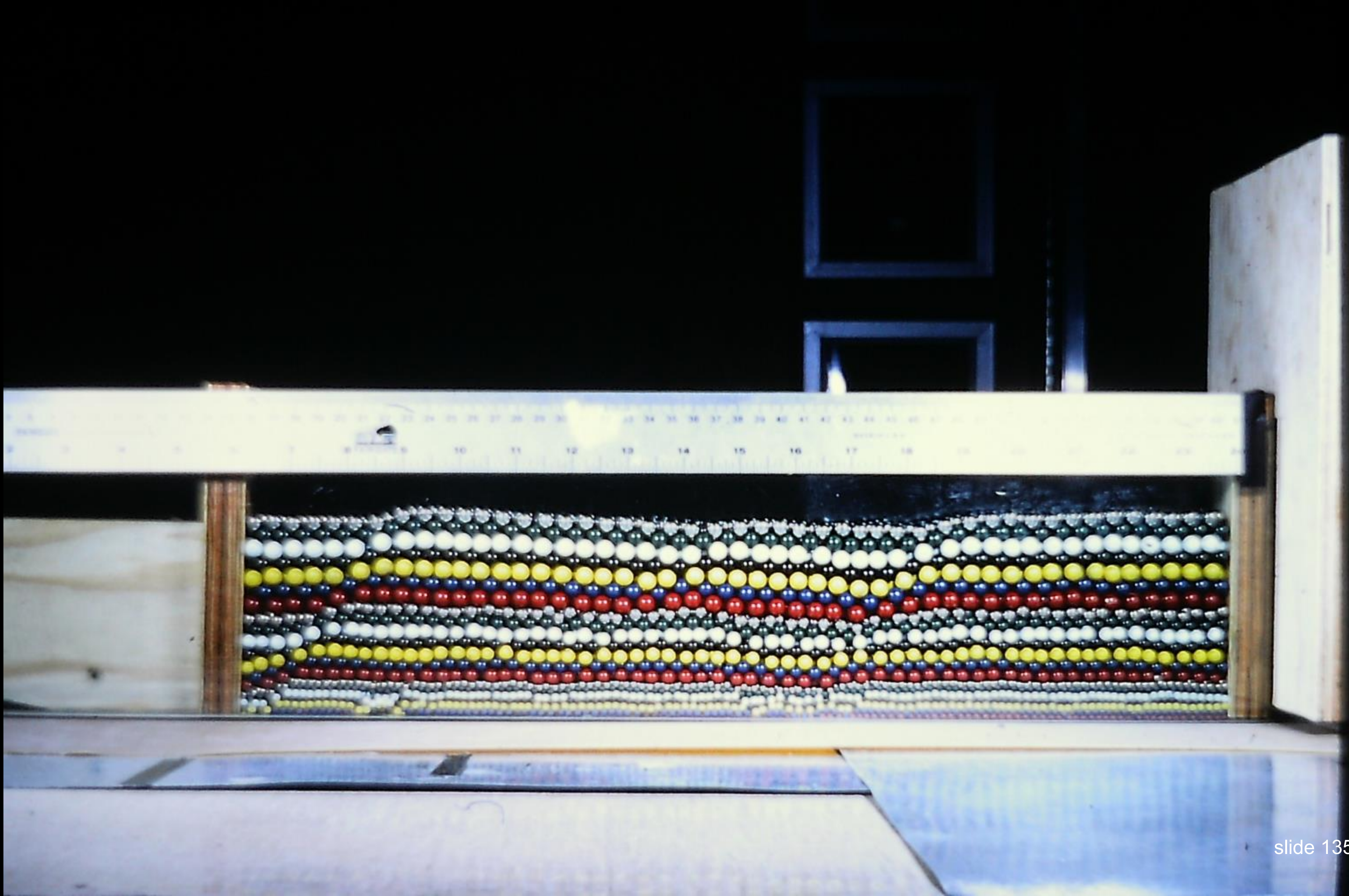
7 Layers 1/8" Balls In 3D Close-Packed Hexagonal On Bottom,
7 Layers 7/32", 15/64", 1/4" Balls Distributed (1/4 : 1/2 : 1/4) Attempted 3D Close-Packed Hexagonal Above,
Topped By 7 Layers of 5/16" Balls In An Attempted 3D Close-Packed Hexagonal,

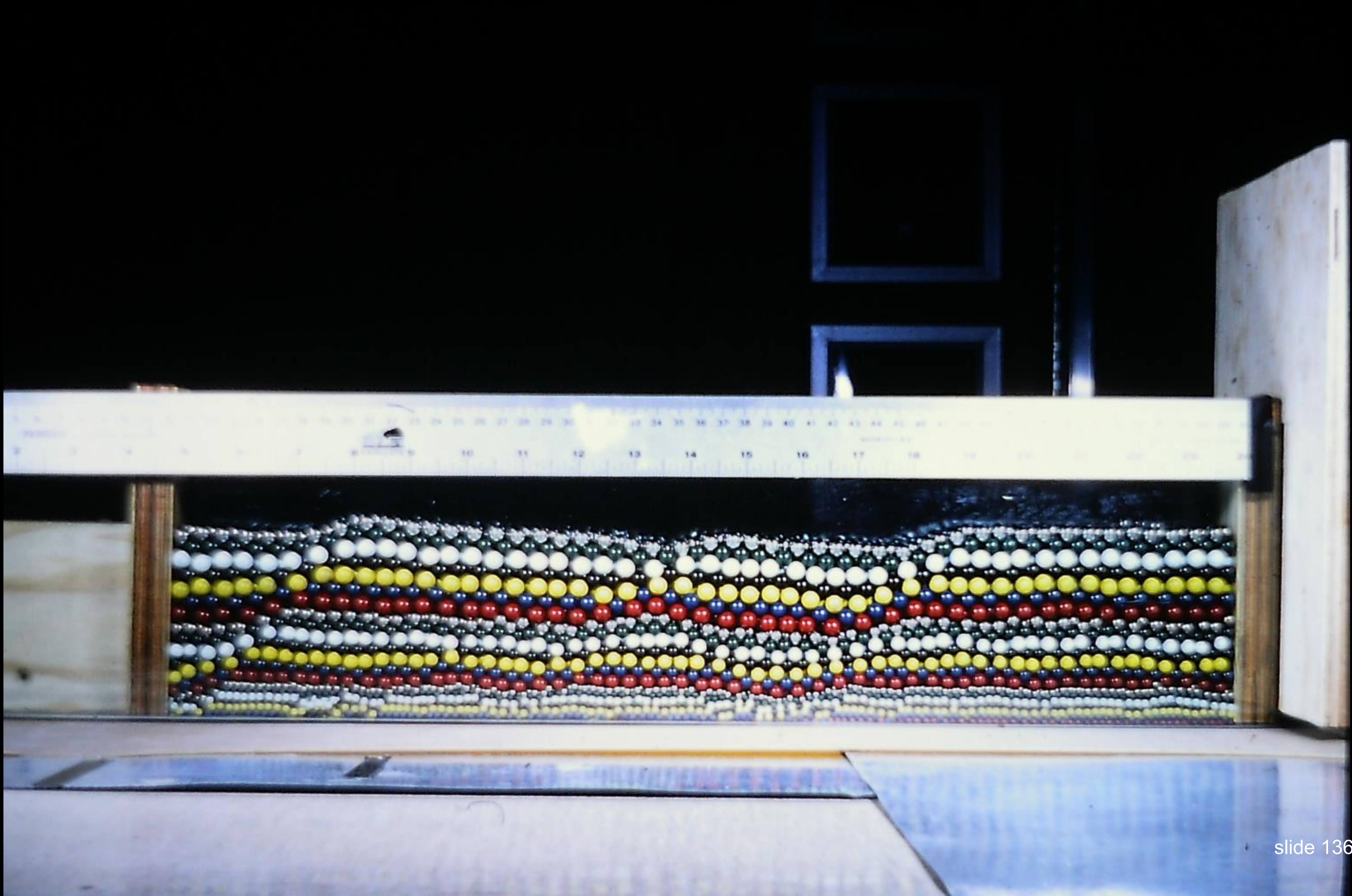
7.8 cm/hr

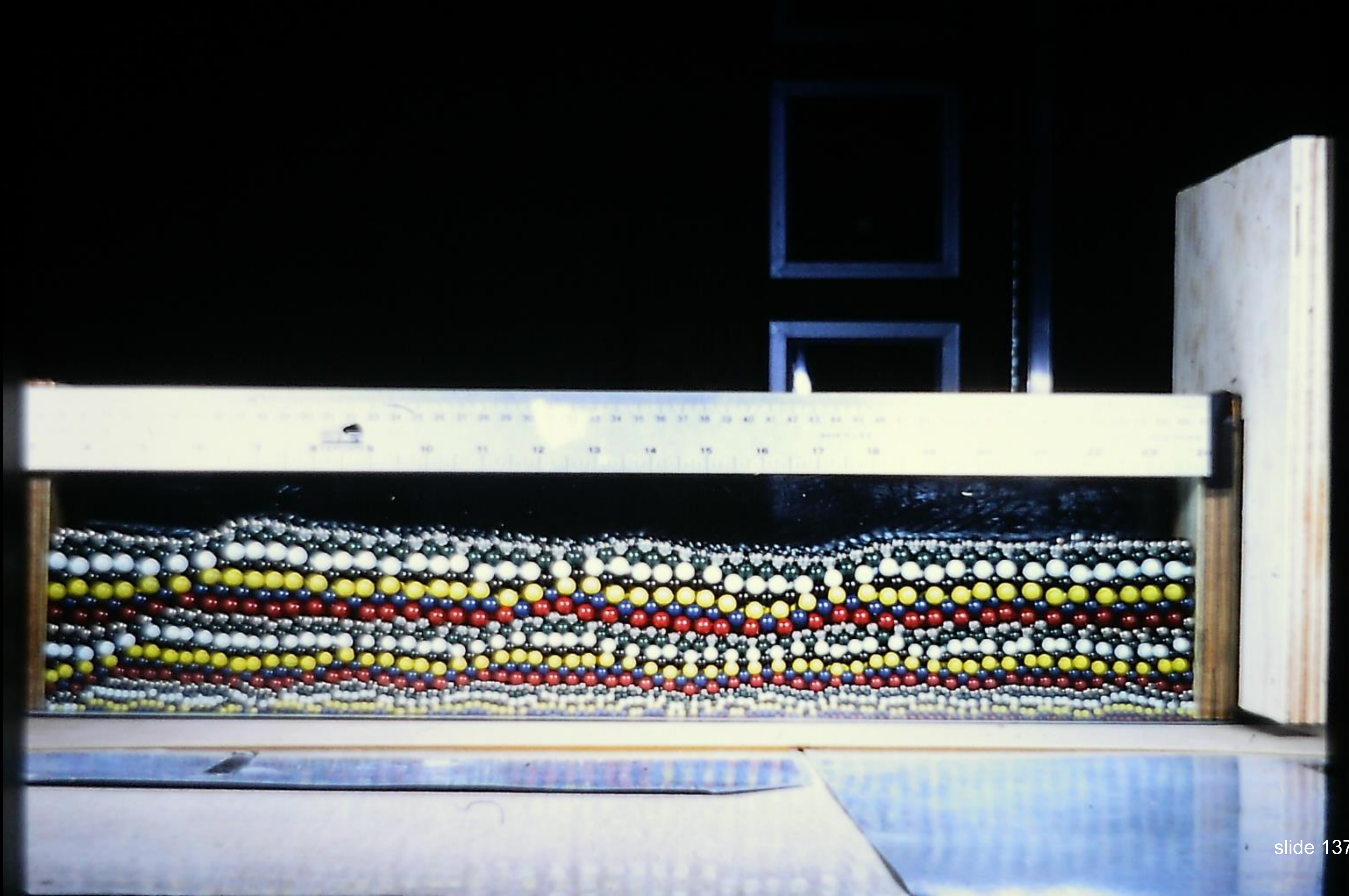
β = 1.00, 1.09, 1.18, 1.27, 1.37











PING PONG BALL MODELS OF STRUCTURES

BASIC CLOSE-PACKED HEXAGONAL ARRANGEMENT

CLOSE-PACKED HEXAGONAL ARRAY BEFORE AND AFTER SEPARATION ALONG PLANE OF FAILURE.

PLANES OF FAILURE FOR FACE-CENTERED CUBIC WHEN HEXAGONAL PLANE IS HORIZONTAL

5. ACTUAL PHOTOS OF CLOSE-PACKED HEXAGONAL ARRAY USED FOR DIAGRAM IN BOERNER AND SCLATER (IN PREPARATION).