

# Archive of AGR-5/6/7 Particle Radiographs for Identification of Particles with Defective IPyC



Grant W. Helmreich

**November 2024**



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Nuclear Energy and Fuel Cycle Division

**ARCHIVE OF AGR-5/6/7 PARTICLE RADIOGRAPHS  
FOR IDENTIFICATION OF PARTICLES WITH DEFECTIVE IPYC**

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August 2024

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## ABSTRACT

As a part of fuel quality control characterization, 2D radiographs of large numbers of particles produced by the Advanced Gas Reactor Fuel Development and Qualification (AGR) Program's AGR-5/6/7 irradiation were acquired. These radiographs were used for the identification of particles with excessive uranium dispersion from the kernel into the surrounding buffer layer caused by chlorine infiltration through a defective inner pyrolytic carbon (IPyC) layer during silicon carbide (SiC) deposition. Additional features of interest associated with fabrication anomalies were also catalogued. Raw radiography images, along with the noted defective IPyC defects found by analysis at Oak Ridge National Laboratory are reported herein.

## 1. INTRODUCTION

During deposition of the silicon carbide (SiC) layer of tri-structural-isotropic (TRISO) particles, chlorine gas is produced as a byproduct. If the inner pyrolytic carbon (IPyC) layer on which the SiC is being deposited is too permeable, then some of this chlorine gas may infiltrate the IPyC and be sealed within the particle by the fully deposited SiC layer. During subsequent heating, the sequestered chlorine may react with the uranium-based kernel, resulting in uranium dispersion into the low-density buffer layer. Excessive uranium dispersion is considered undesirable in TRISO particles because of its the potential for direct damage from fission product recoils to the structural coating layers and the increased probability of fission products reacting with the structural coating layers.

The occurrence of excessive uranium dispersion in TRISO particles caused by defective IPyC is determined by heat-treating coated particles in a manner sufficient to trigger uranium dispersion if chlorine is present in the vicinity of the kernel and then imaging the heat-treated particles using x-ray radiography. At Oak Ridge National Laboratory (ORNL), particles were mixed in a bed of graphite powder, placed under an argon atmosphere, and then heat treated at 1,800°C for one hour with a 20°C/min ramp rate to simulate compacting. Heat-treated particles were then placed into "tape mounts" by pouring a monolayer of particles onto a piece of Kapton tape, shaking off excess back into the sample tray, and then sealing the particles in place with a second piece of Kapton tape. Each tape mount was then radiographed, and particles with excessive uranium dispersion were identified based on the irregular cloud of high-Z material visible within the SiC layer. Full details of this process as applied to AGR-5/6/7 are available in the literature [1, 2].

## 2. RESULTS FROM J52O-16-93168 SAMPLE NP-C1369

Sample NP-C1369 consisted of 120,819 particles from J52O-16-93168, which was a coated particle fuel batch produced by Babcock and Wilcox Technologies (BWXT) for possible selection for the Advanced Gas Reactor (AGR) Fuel Development and Qualification Program's AGR-5/6/7 irradiation. This batch was ultimately not selected for use in the AGR-5/6/7 irradiation because of the high population of particles with excessive uranium dispersion resulting from defective IPyC [3]. Additional anomalies present in the fuel which were identified by radiography during examination for excessive uranium dispersion were also catalogued [2]. Follow-on x-ray computed tomography (XCT) imaging of some particles of interest was also performed to gain a better understanding of the nature of these defects and anomalies [2].

A summary of the observed number of defects and anomalies in J52O-16-93168 Sample NP-C1369 is presented in Table 1. The raw radiographs of each tape mount in this sample are given in Appendix A, whereas examples of the various defects and anomalies observed are given in the remaining appendices.



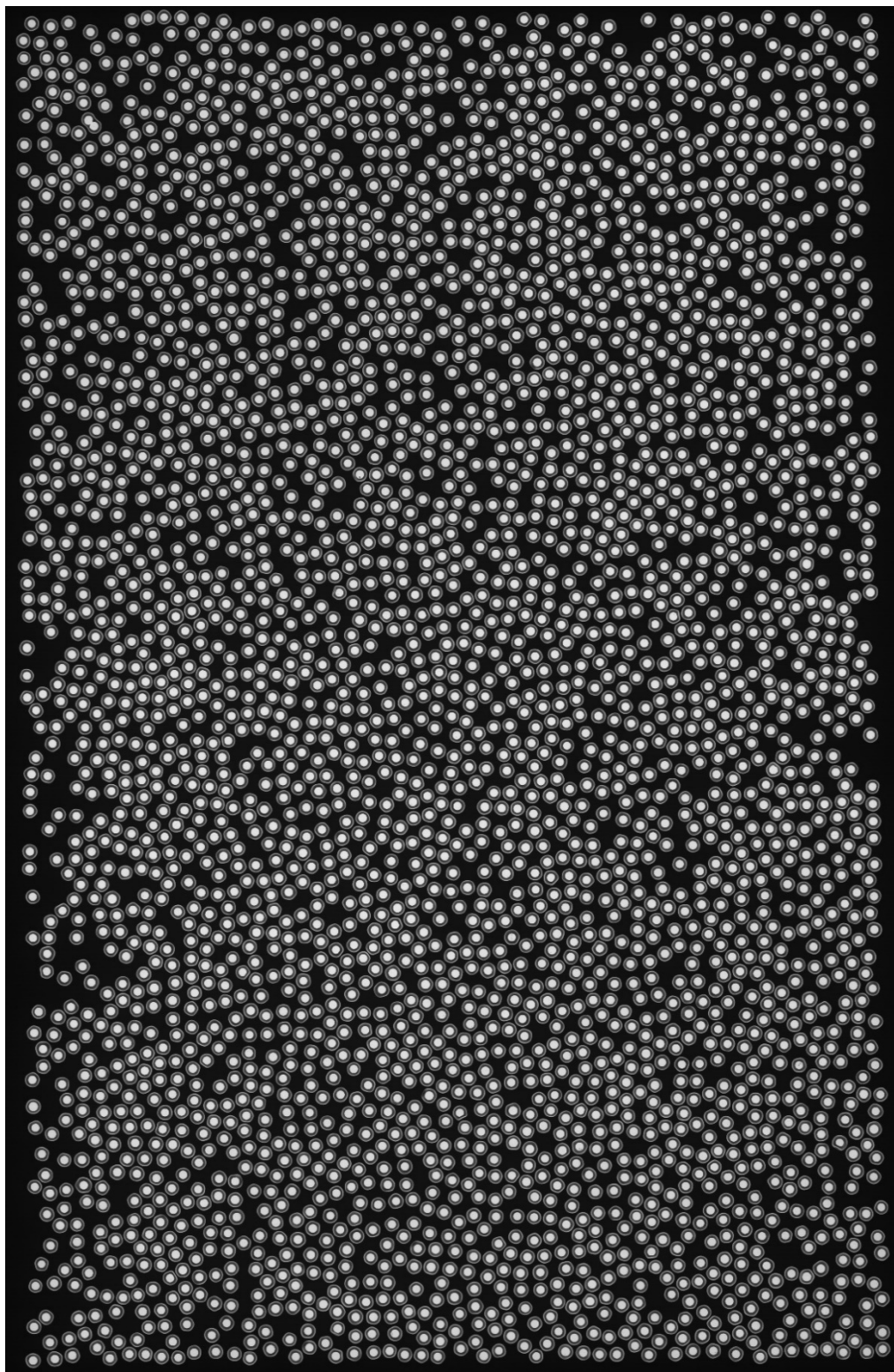
**Table 1. Observed number of given defects and anomalies in 120,819 particles from J52O-16-93168 sample NP-C1369**

| <b>Defect or anomaly</b>     | <b>Number observed</b> |
|------------------------------|------------------------|
| Excessive uranium dispersion | 18                     |
| Thin or missing buffer       | 3                      |
| Thin or missing SiC          | 10                     |
| Dimple or facet              | 2,895                  |
| Severe dimple or facet       | 168                    |
| Notched kernel               | 122                    |
| Irregular kernel             | 245                    |
| Multi-kernel                 | 23                     |

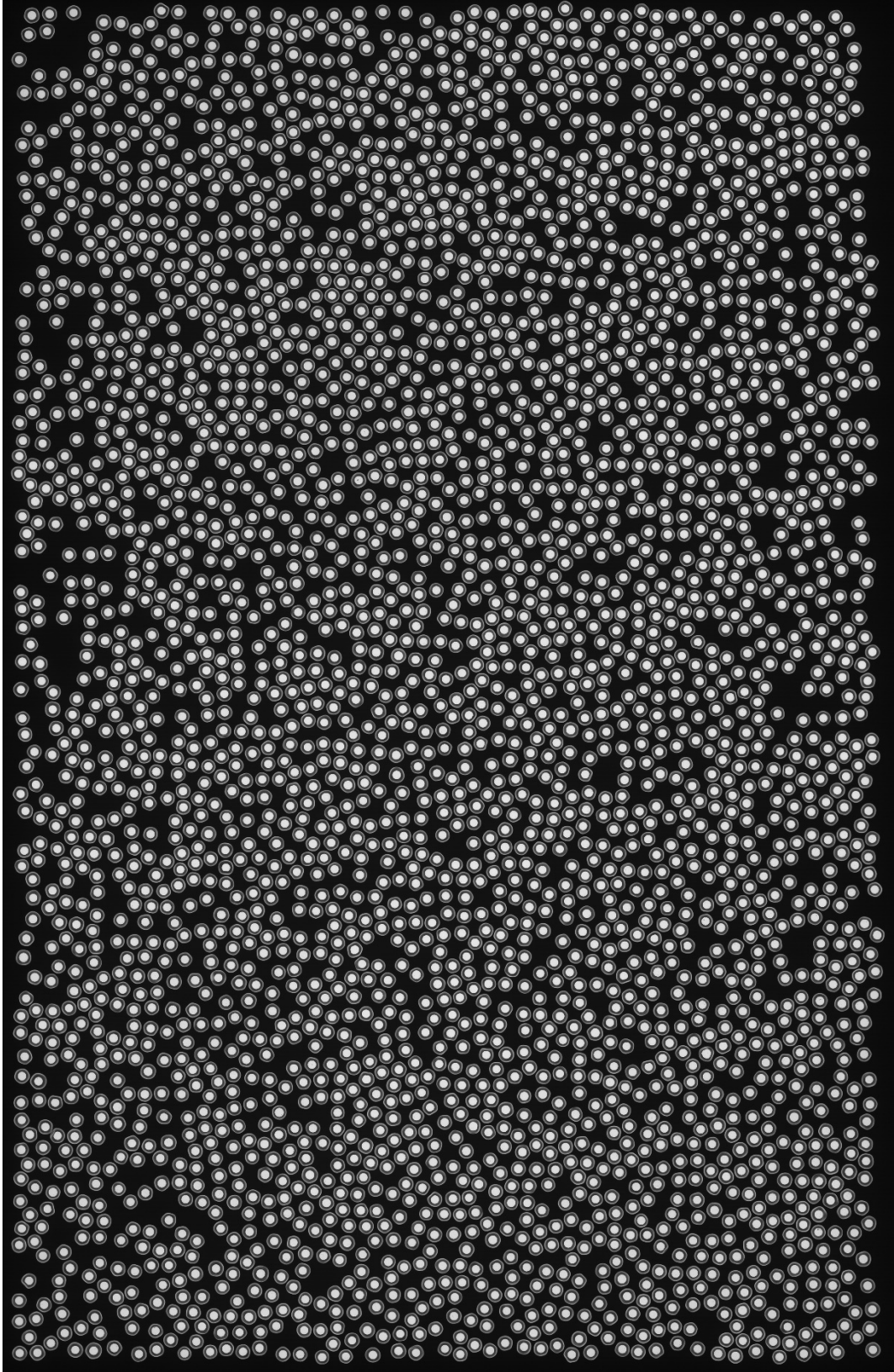
### 3. REFERENCES

- [1] G. Helmreich, J. Hunn, D. Skitt, J. Dyer and A. Schumacher, *Acceptance Test Data for the AGR-5/6/7 Irradiation Test Fuel TRISO Composite*, ORNL/TM-2017/037, Oak Ridge National Laboratory, Oak Ridge, 2017.
- [2] G. Helmreich, J. Hunn, D. Skitt, J. Dyer and A. Schumacher, *X-ray Analysis of Defects and Anomalies in AGR-5/6/7 TRISO Particles*, ORNL\TM-2017-038, Oak Ridge National Laboratory, Oak Ridge, 2017.
- [3] J. Hunn, G. Helmreich, D. Skitt, A. Schumacher and J. Dyer, *Acceptance Test Data for Candidate AGR-5/6/7 TRISO Particle Batches*, ORNL/TM-2017-036, Oak Ridge National Laboratory, Oak Ridge, 2017.

**APPENDIX A. RADIOGRAPHS OF TAPE MOUNTS FROM SAMPLE  
NP-C1369**

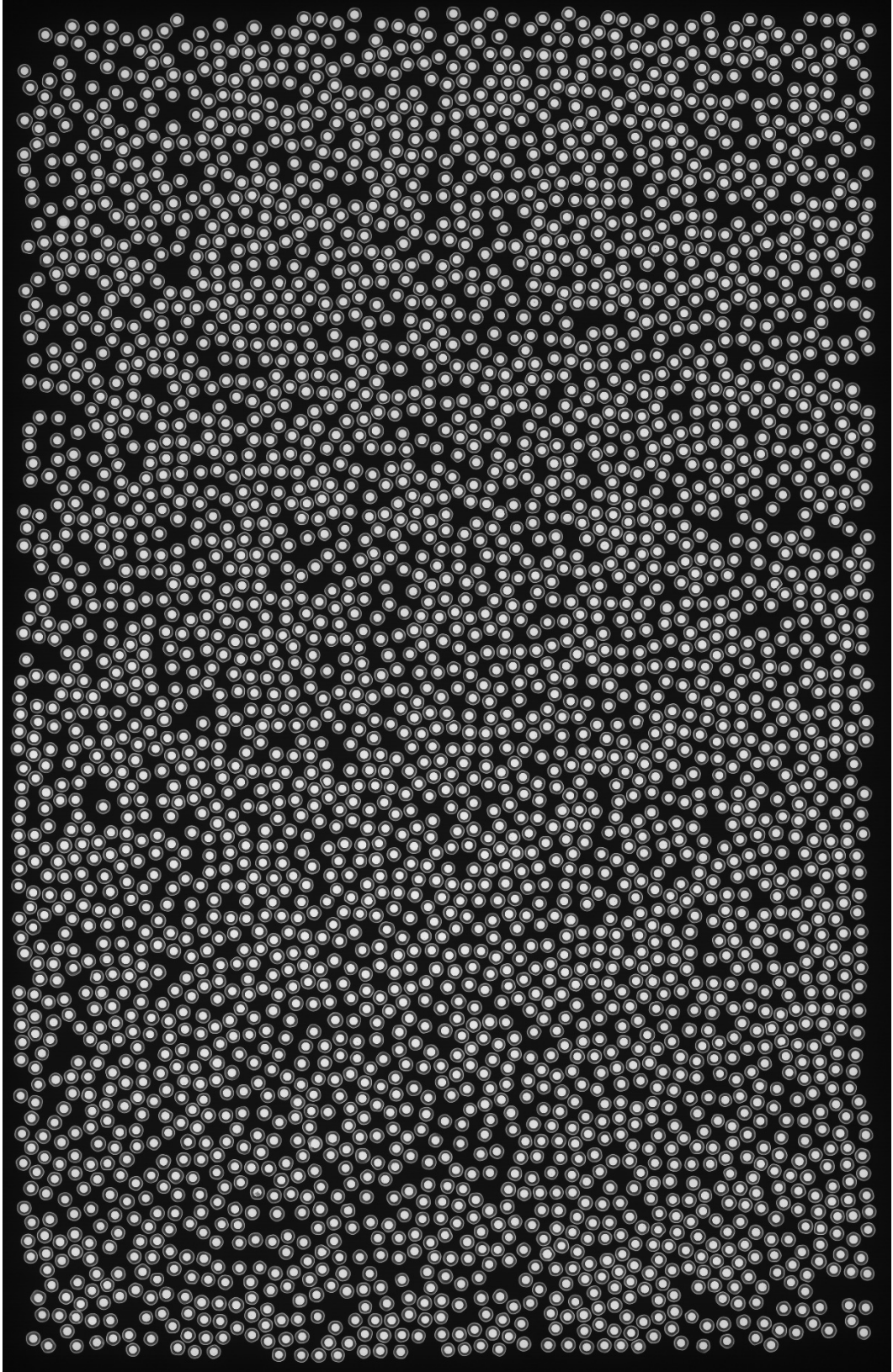


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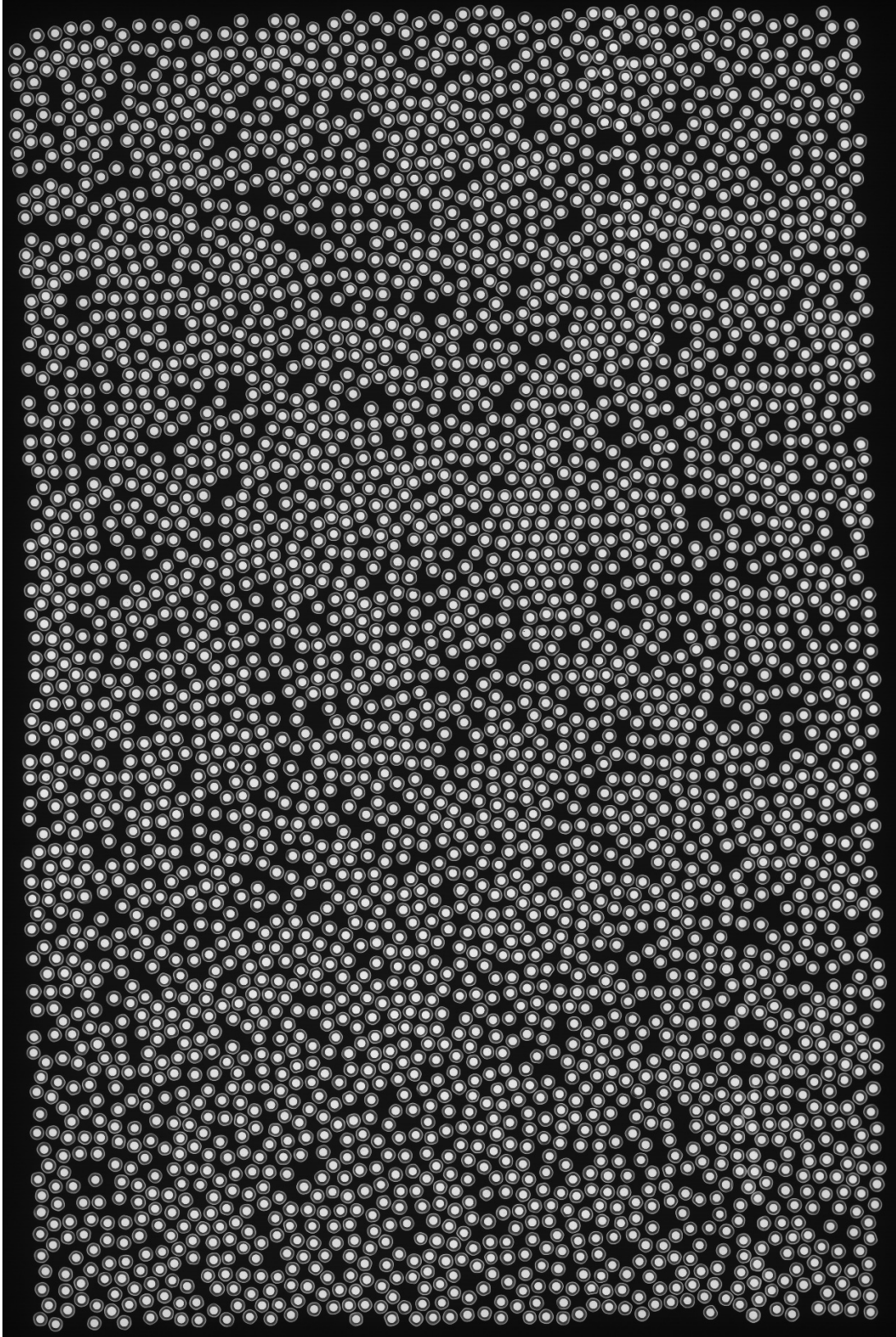


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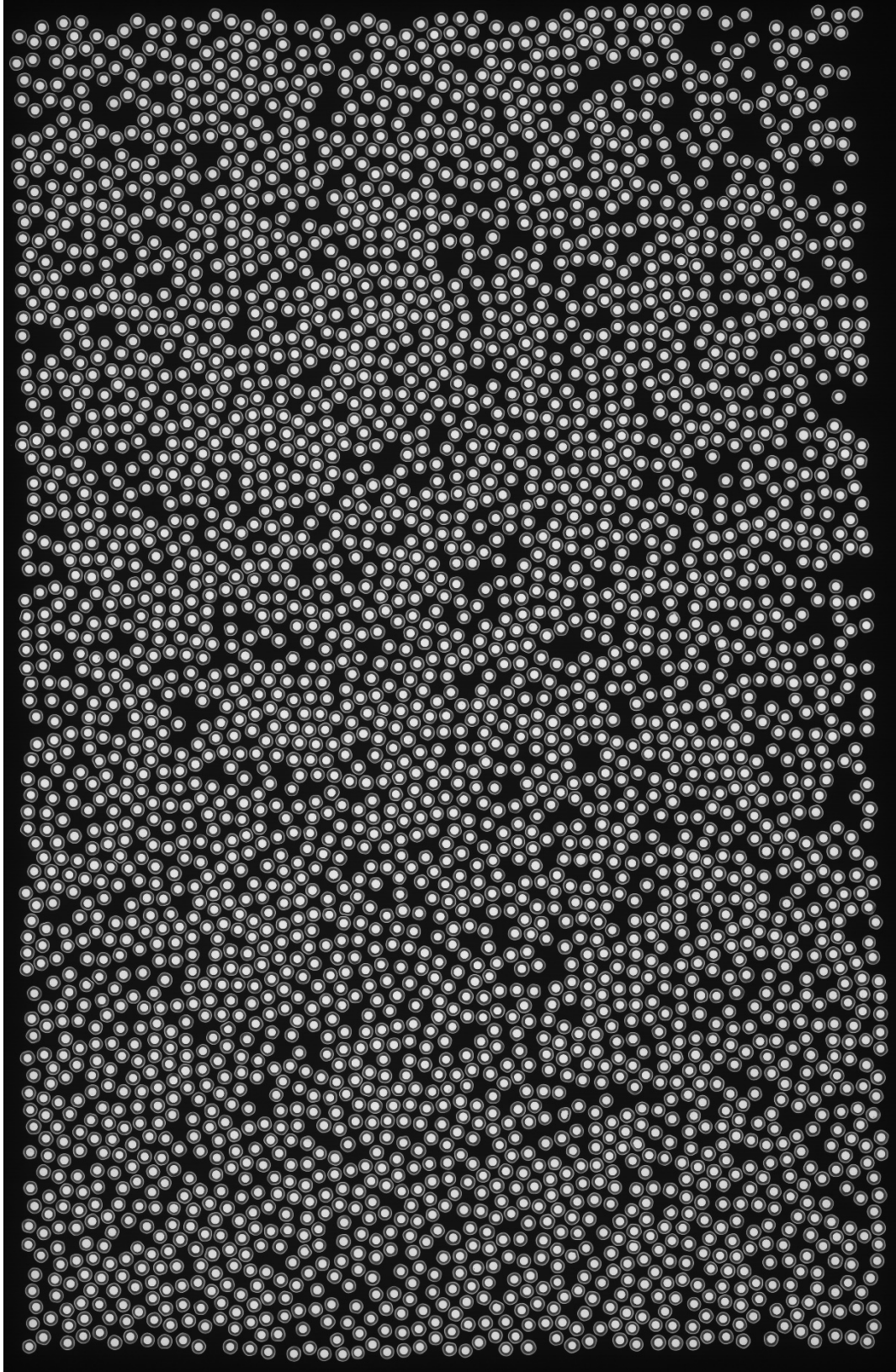




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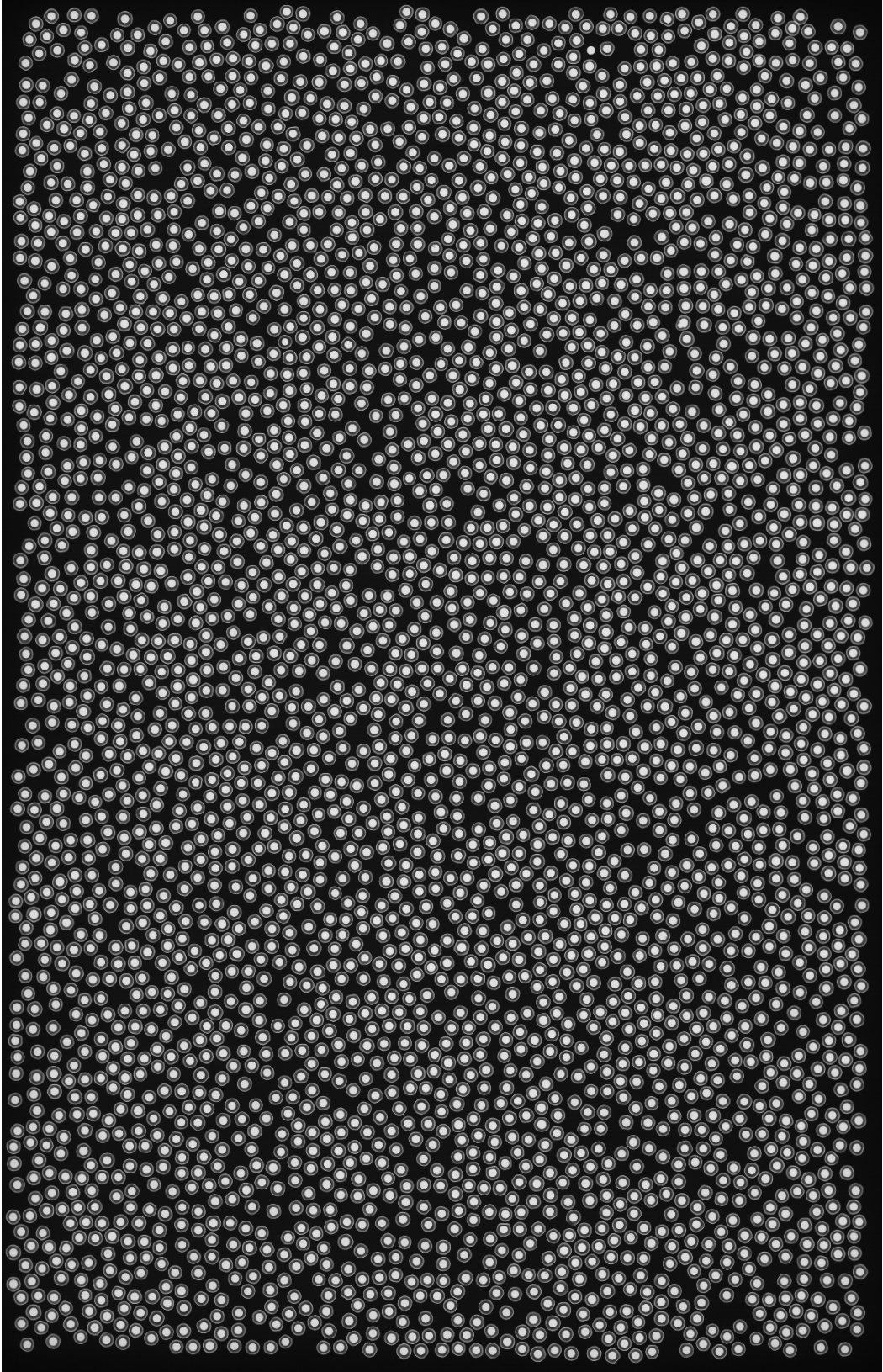


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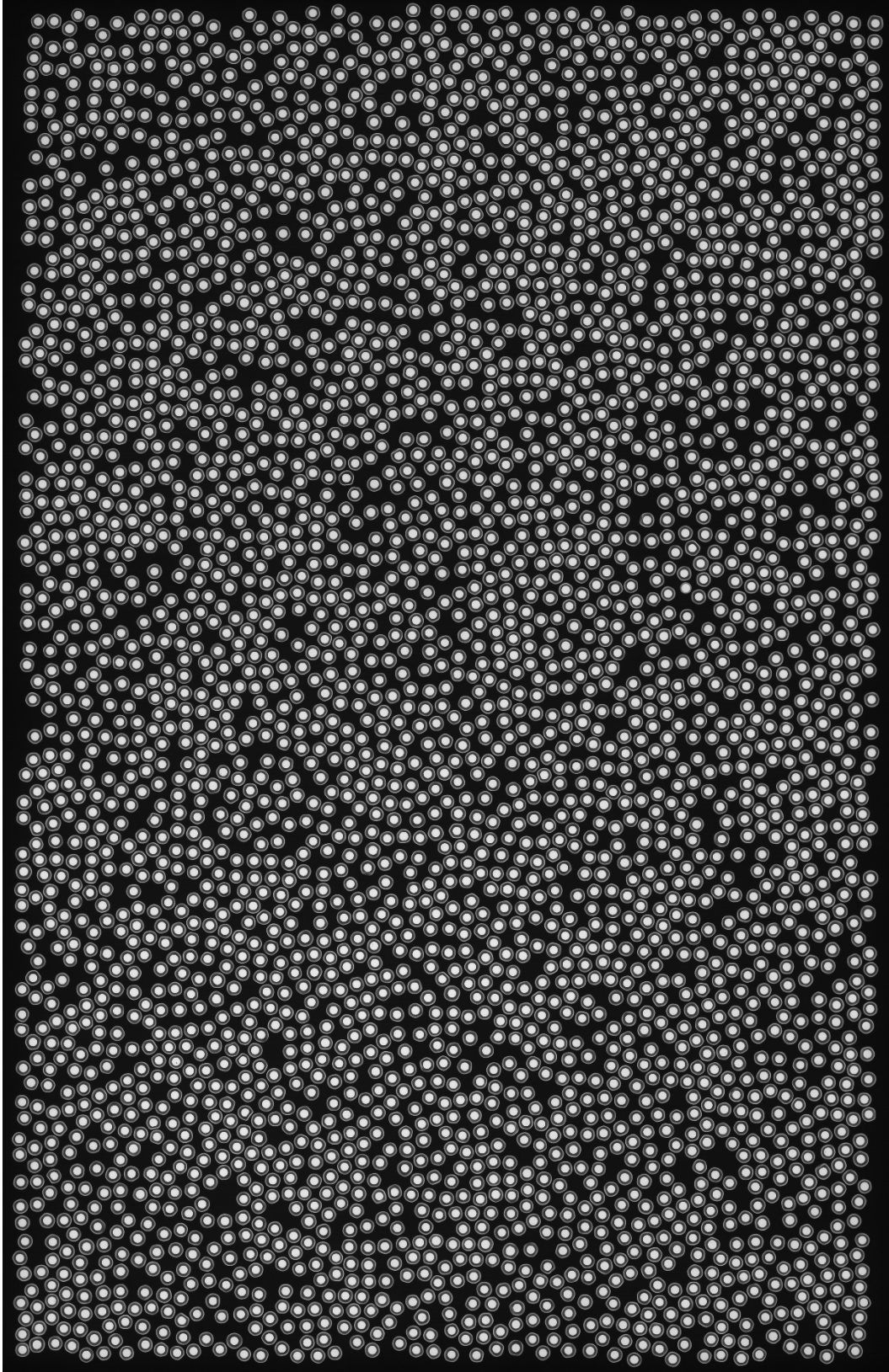
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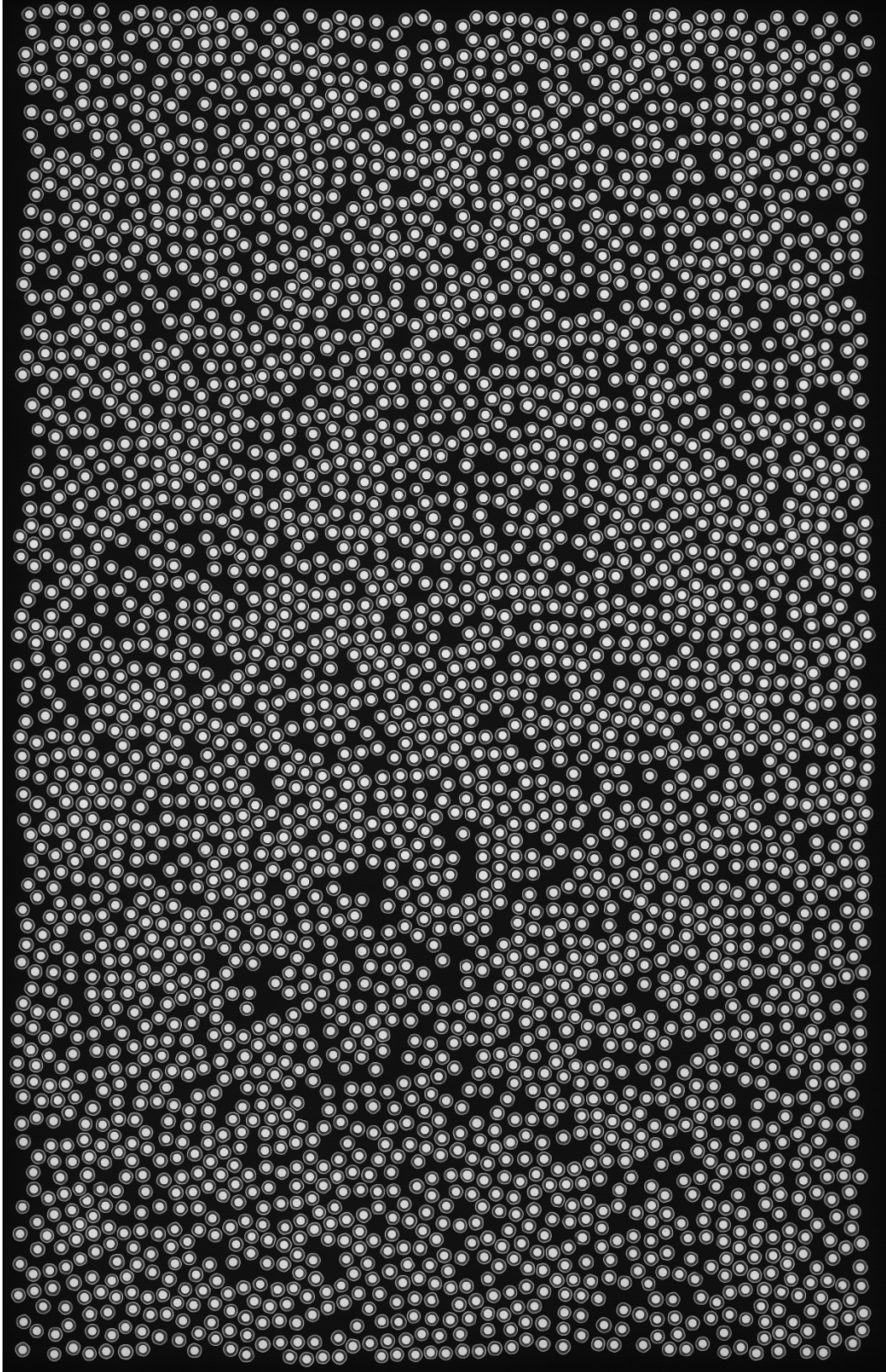


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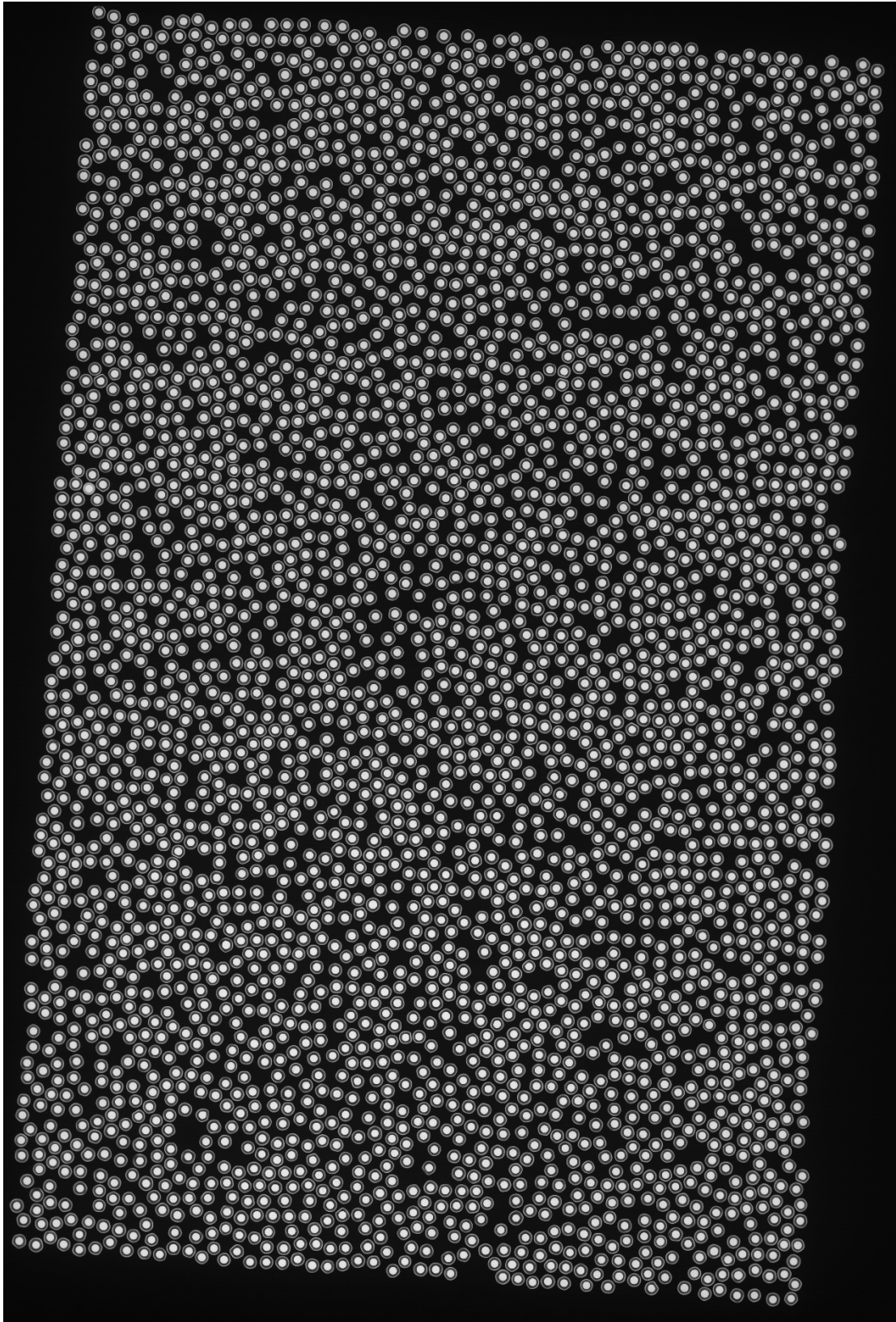




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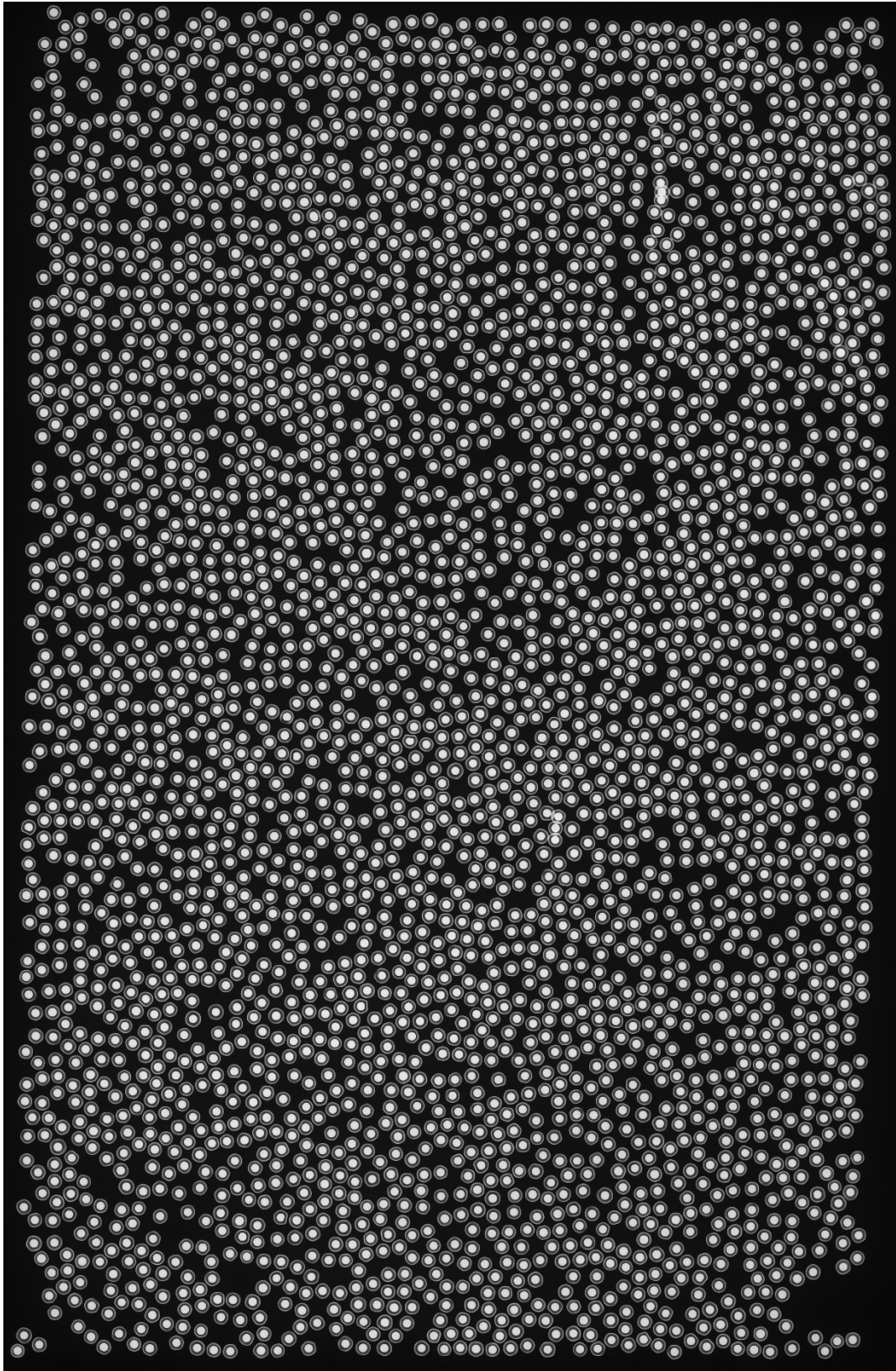


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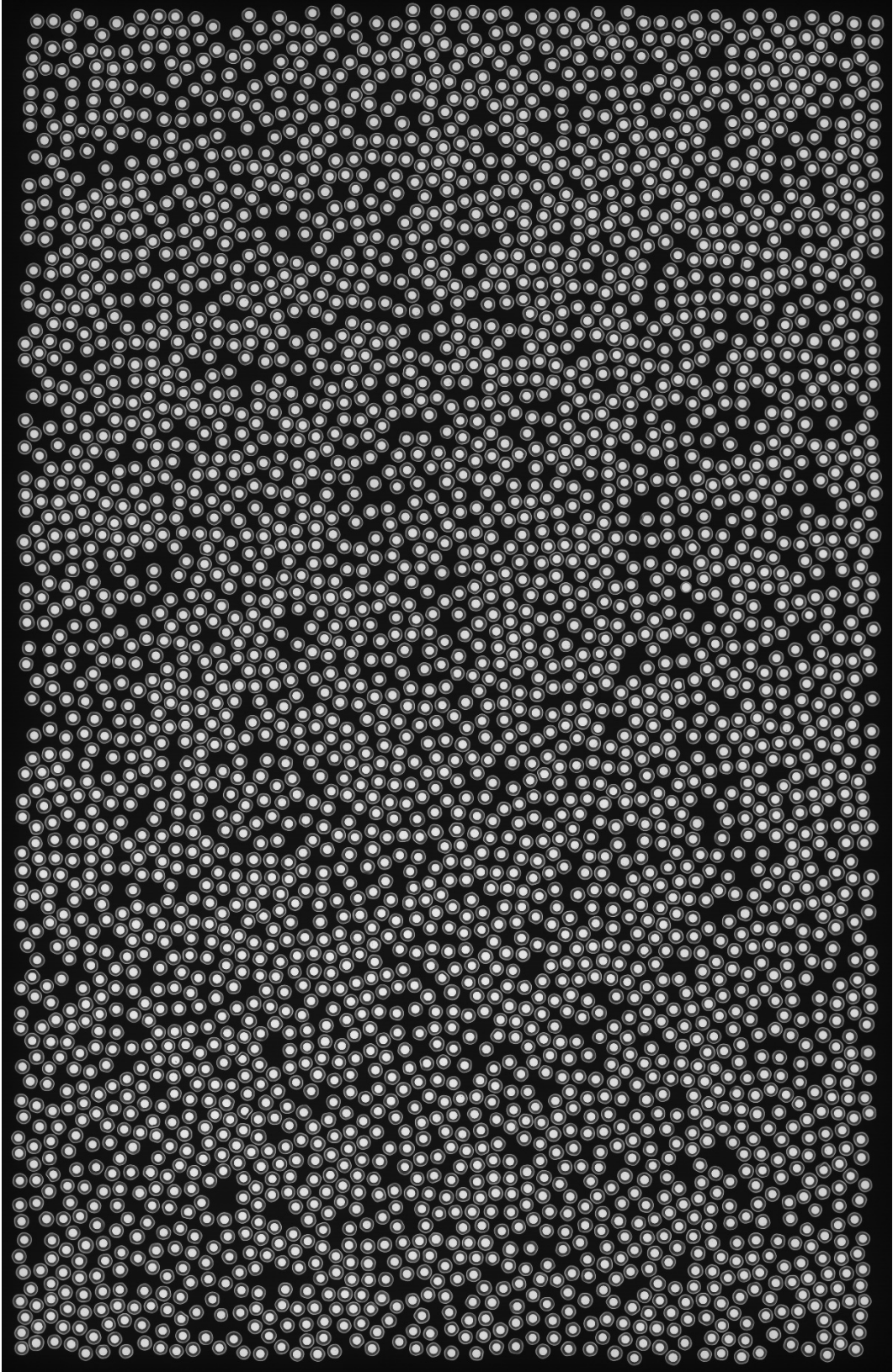
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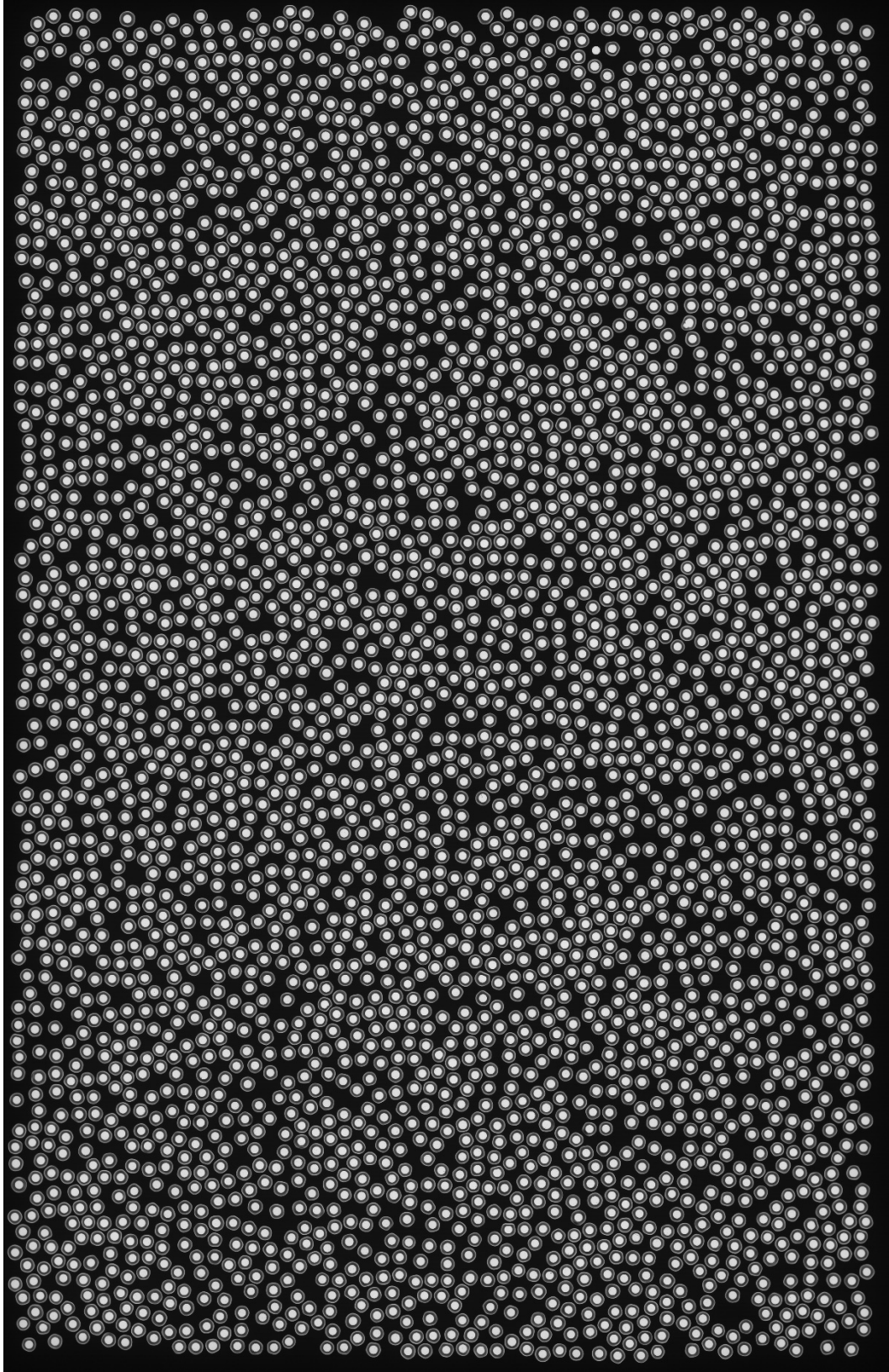


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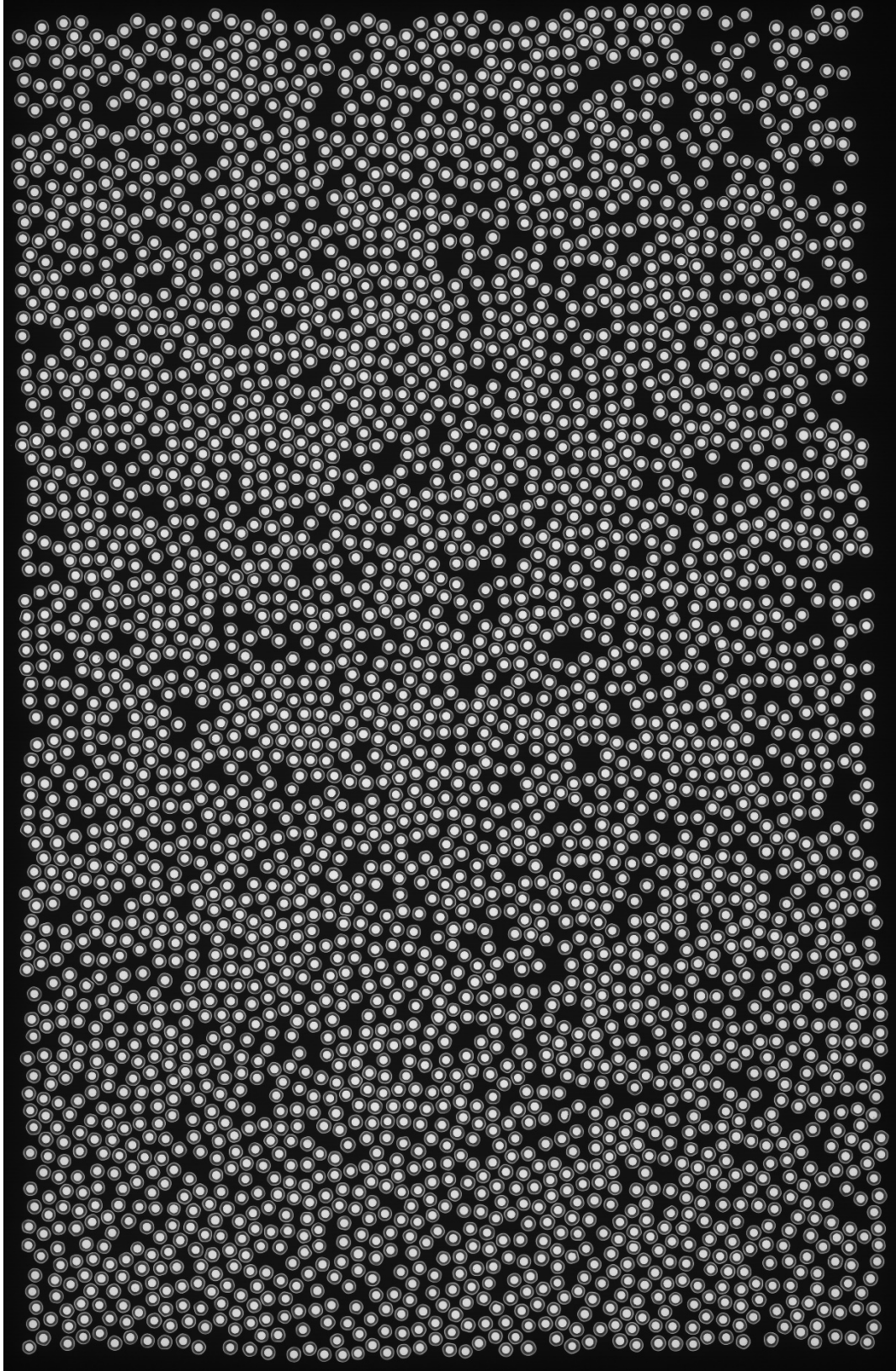




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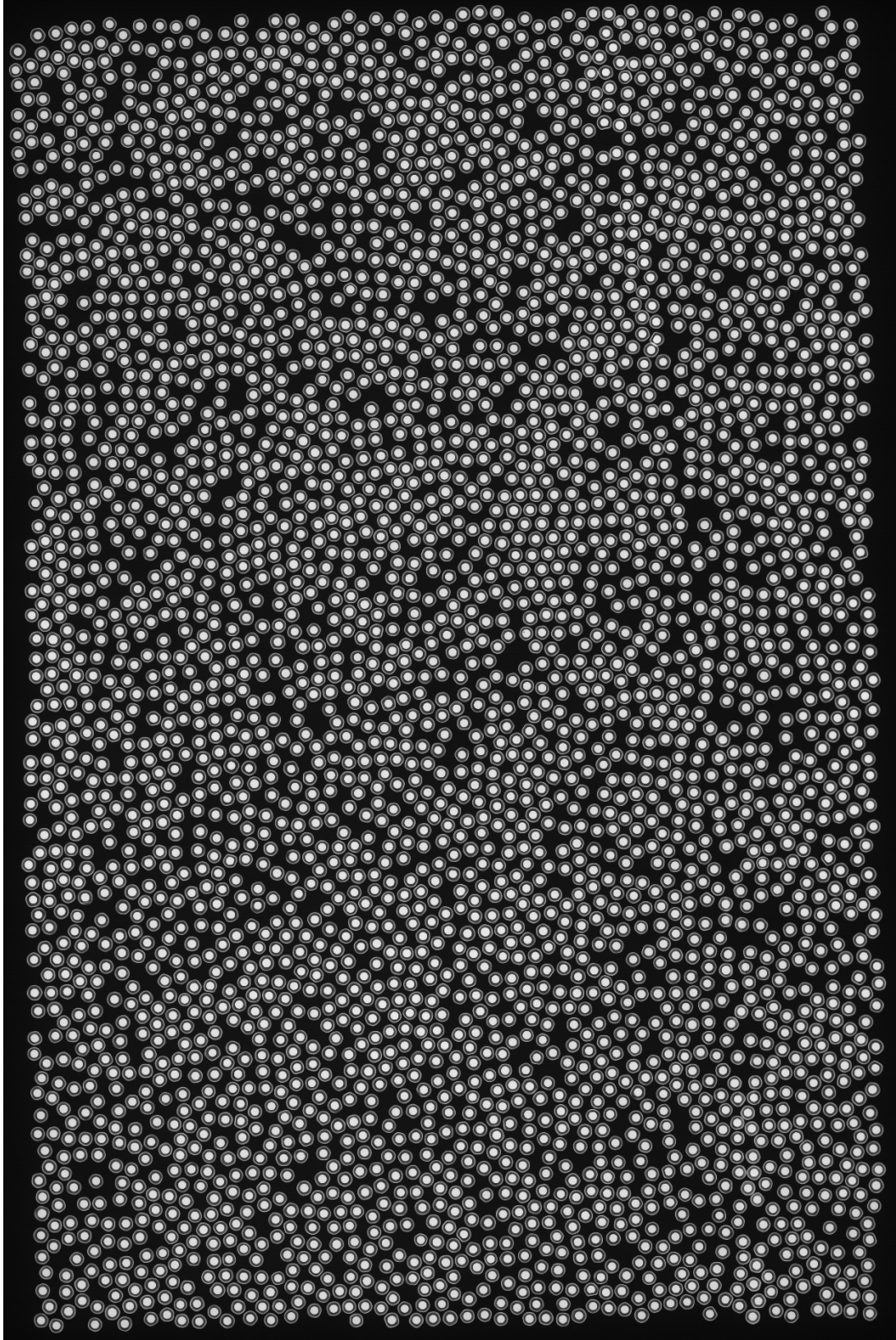


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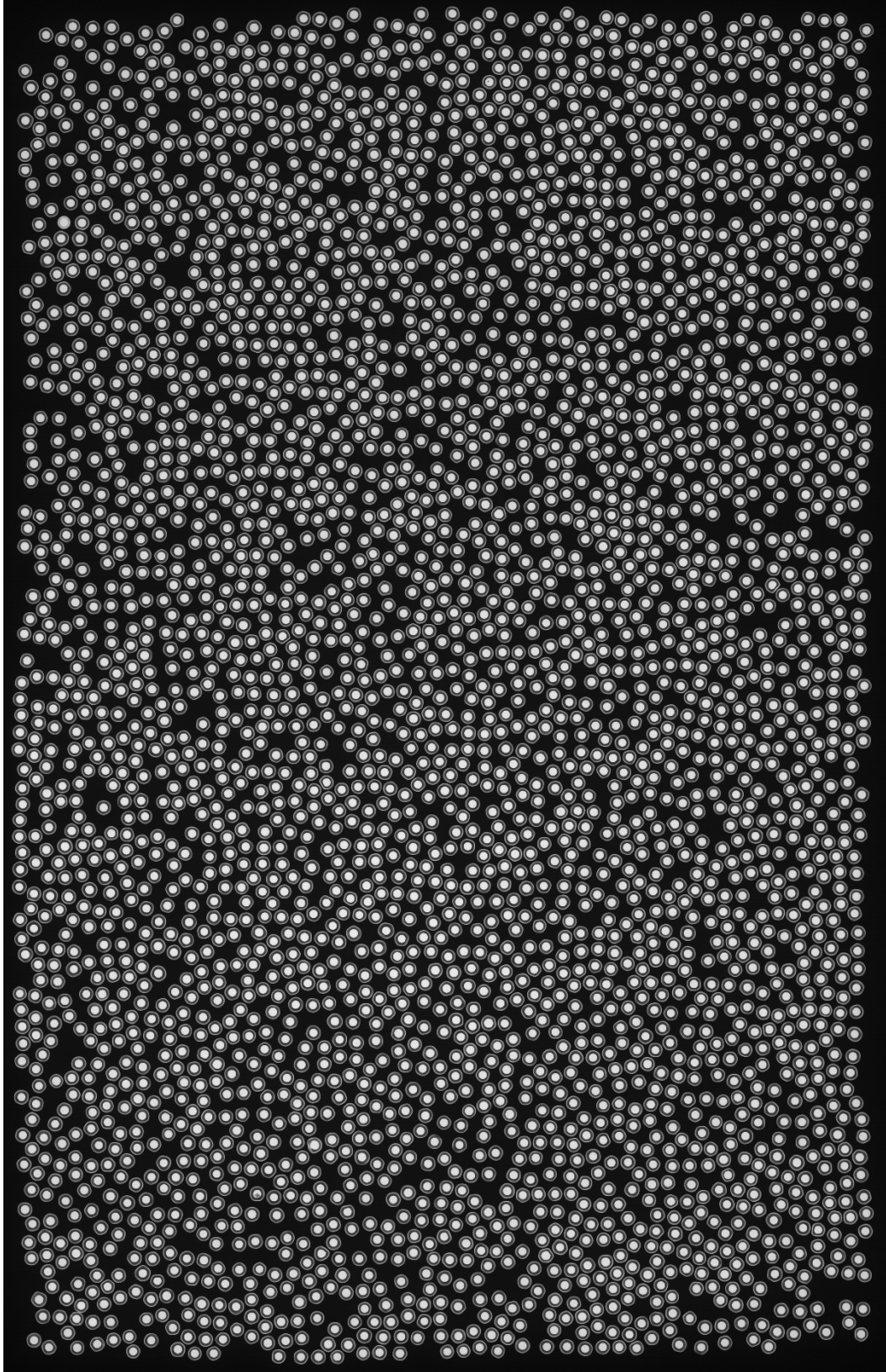


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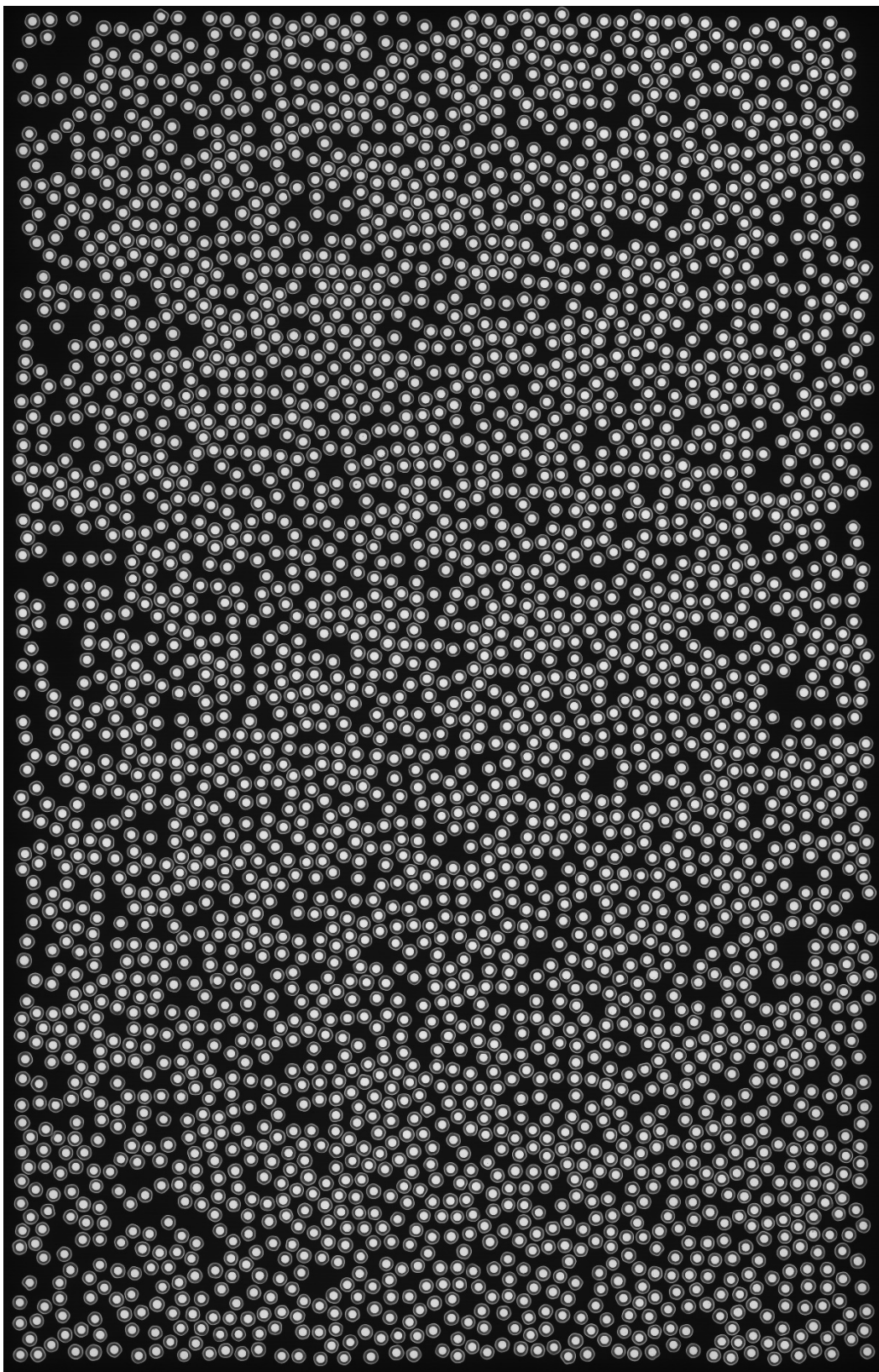


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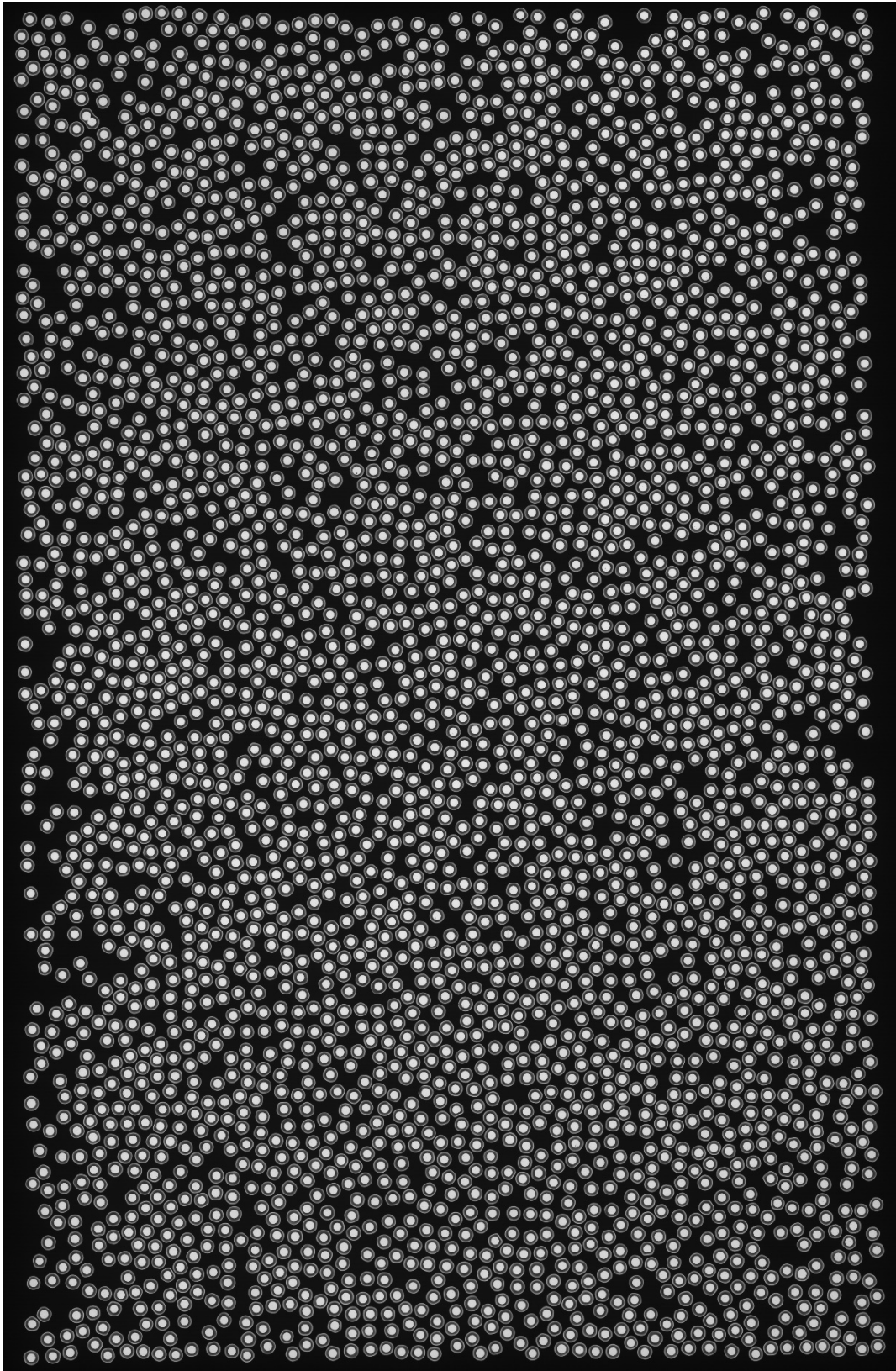


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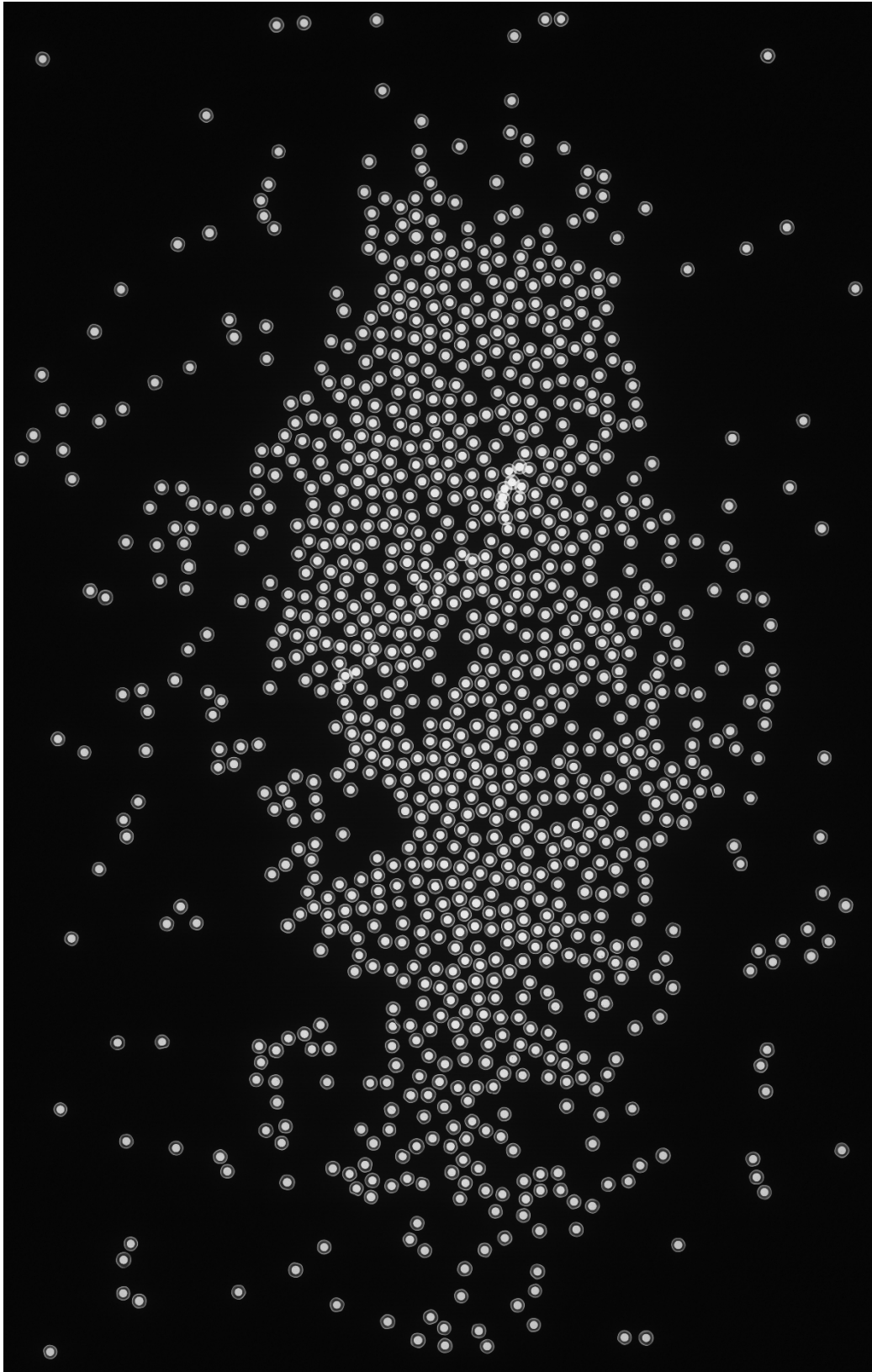




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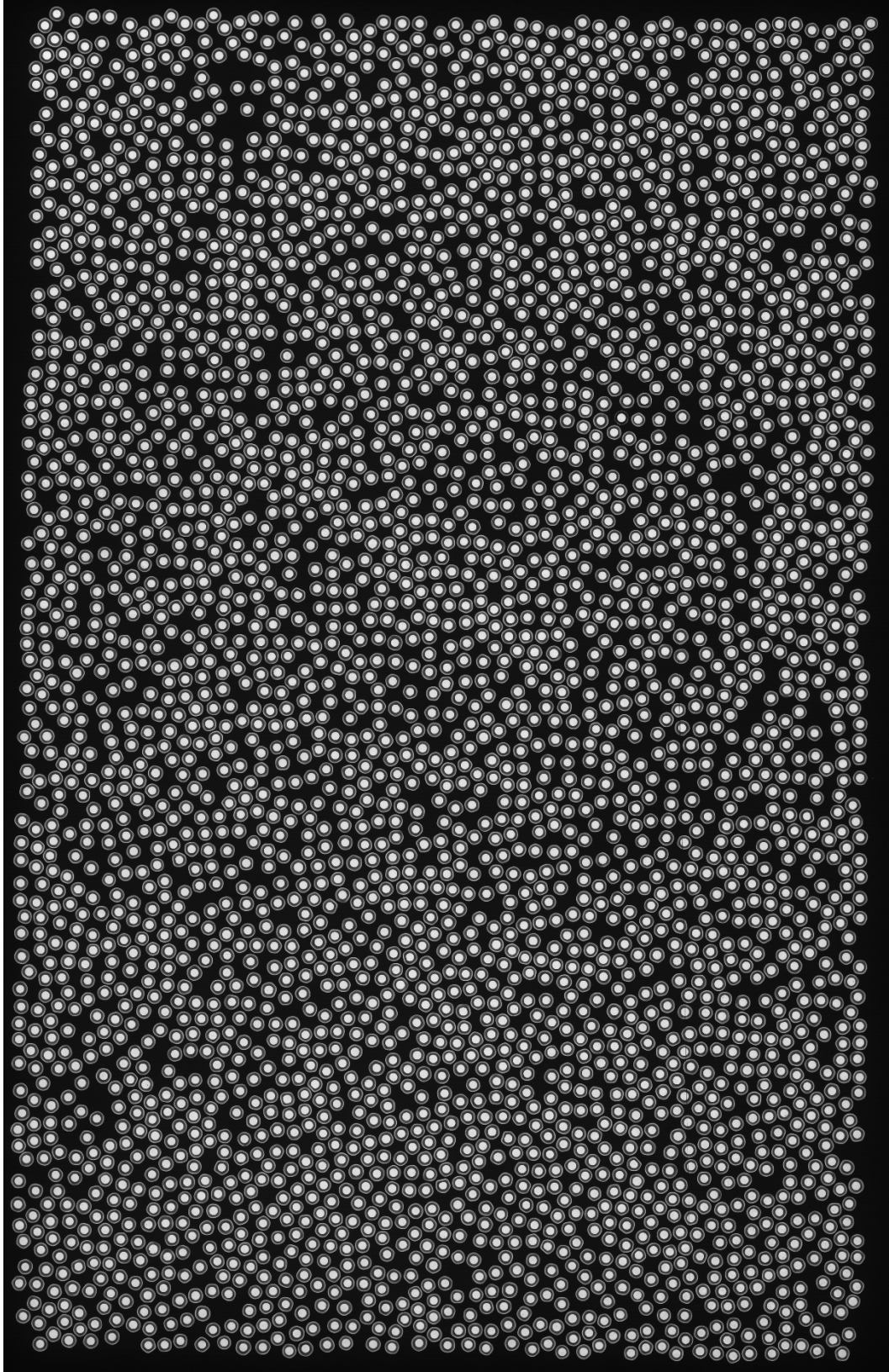


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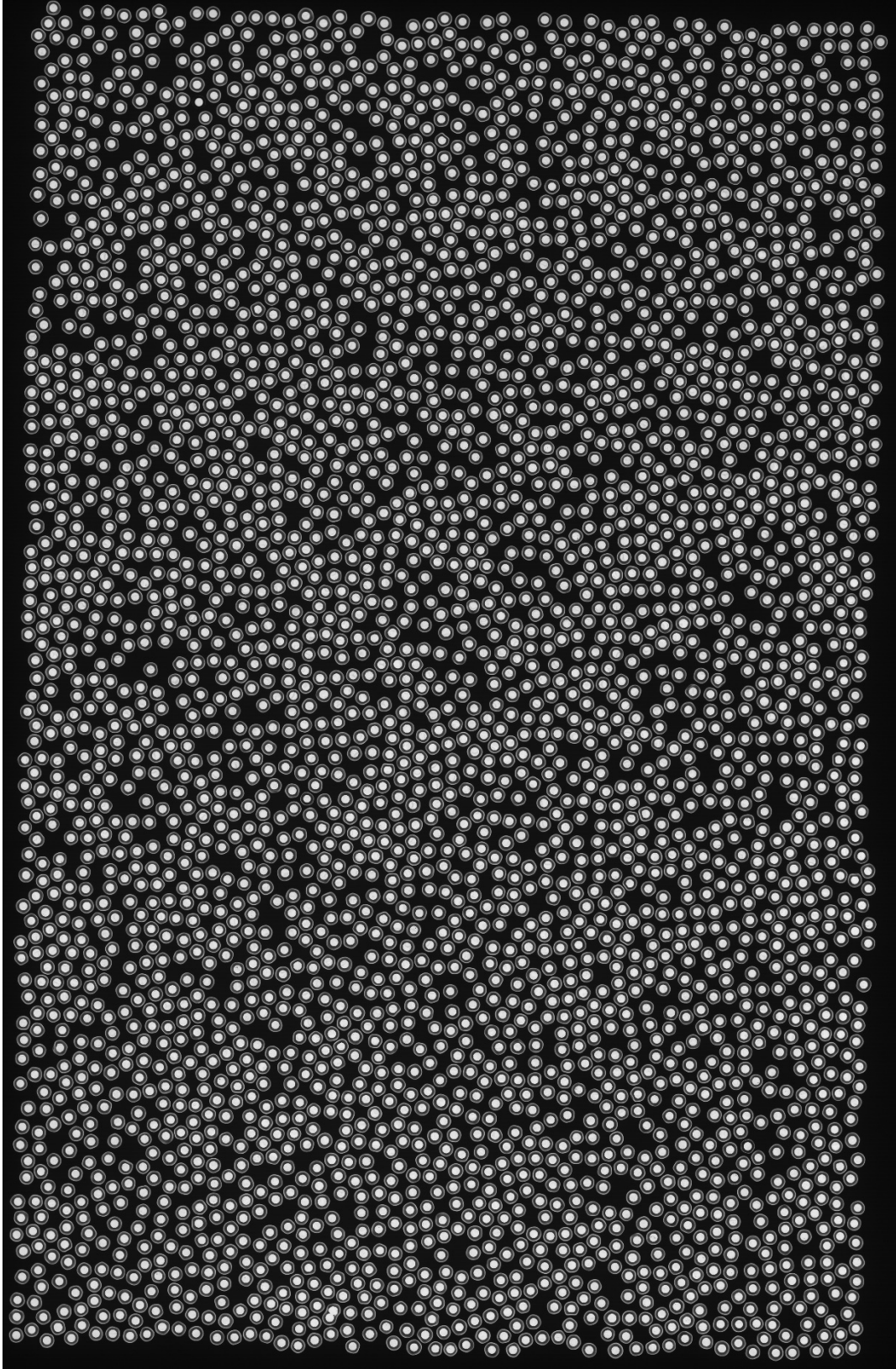


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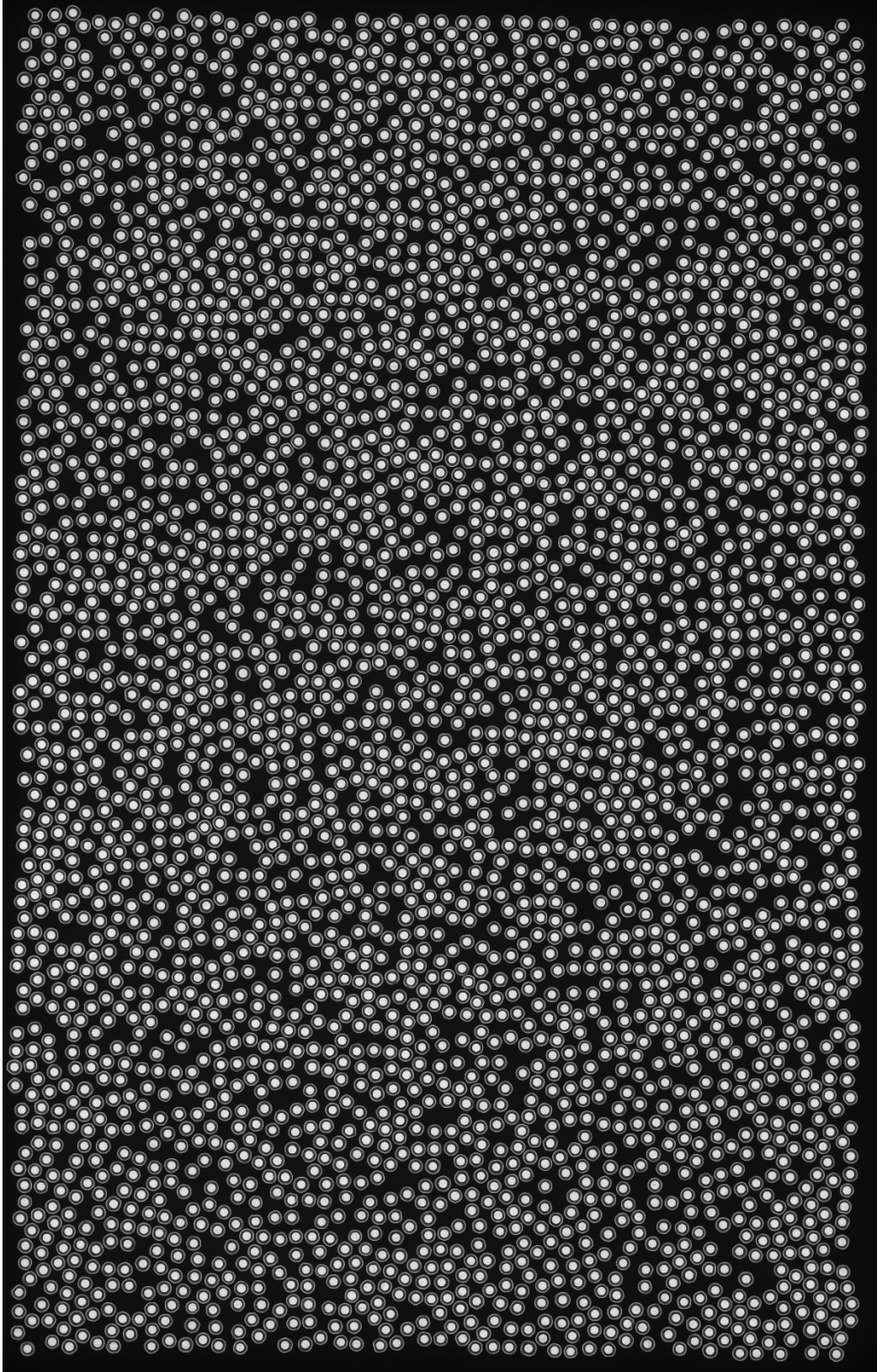


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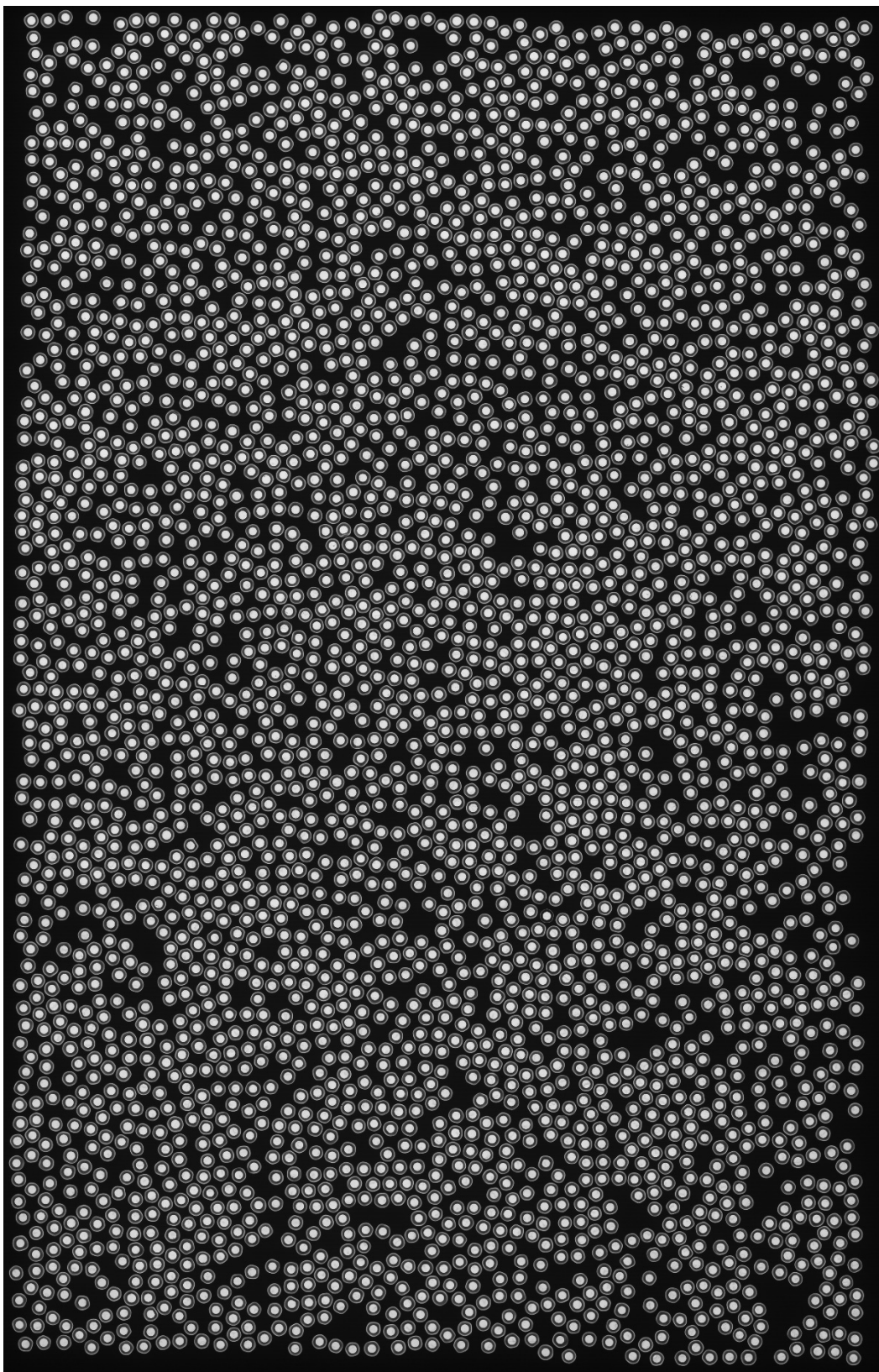


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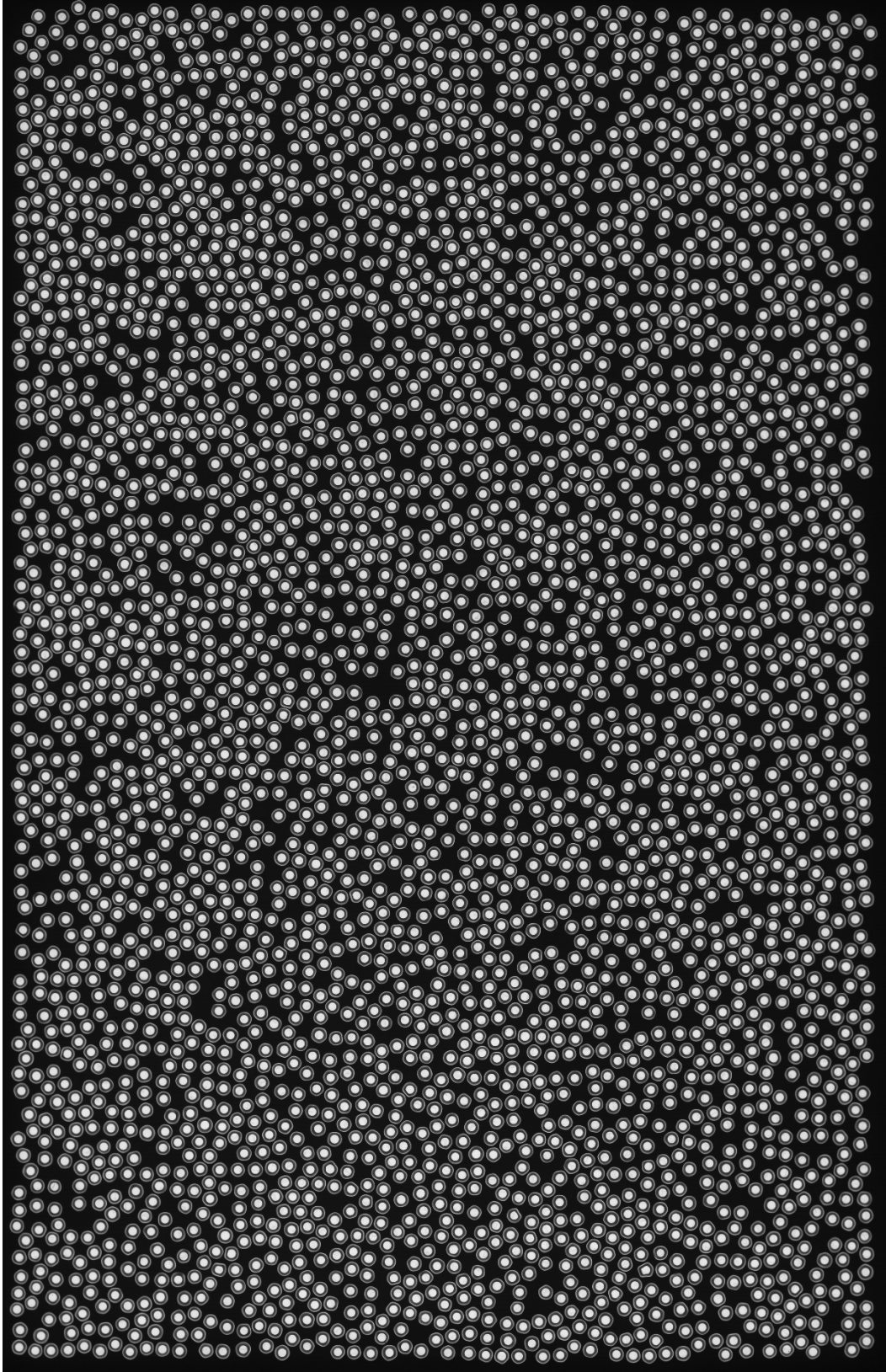




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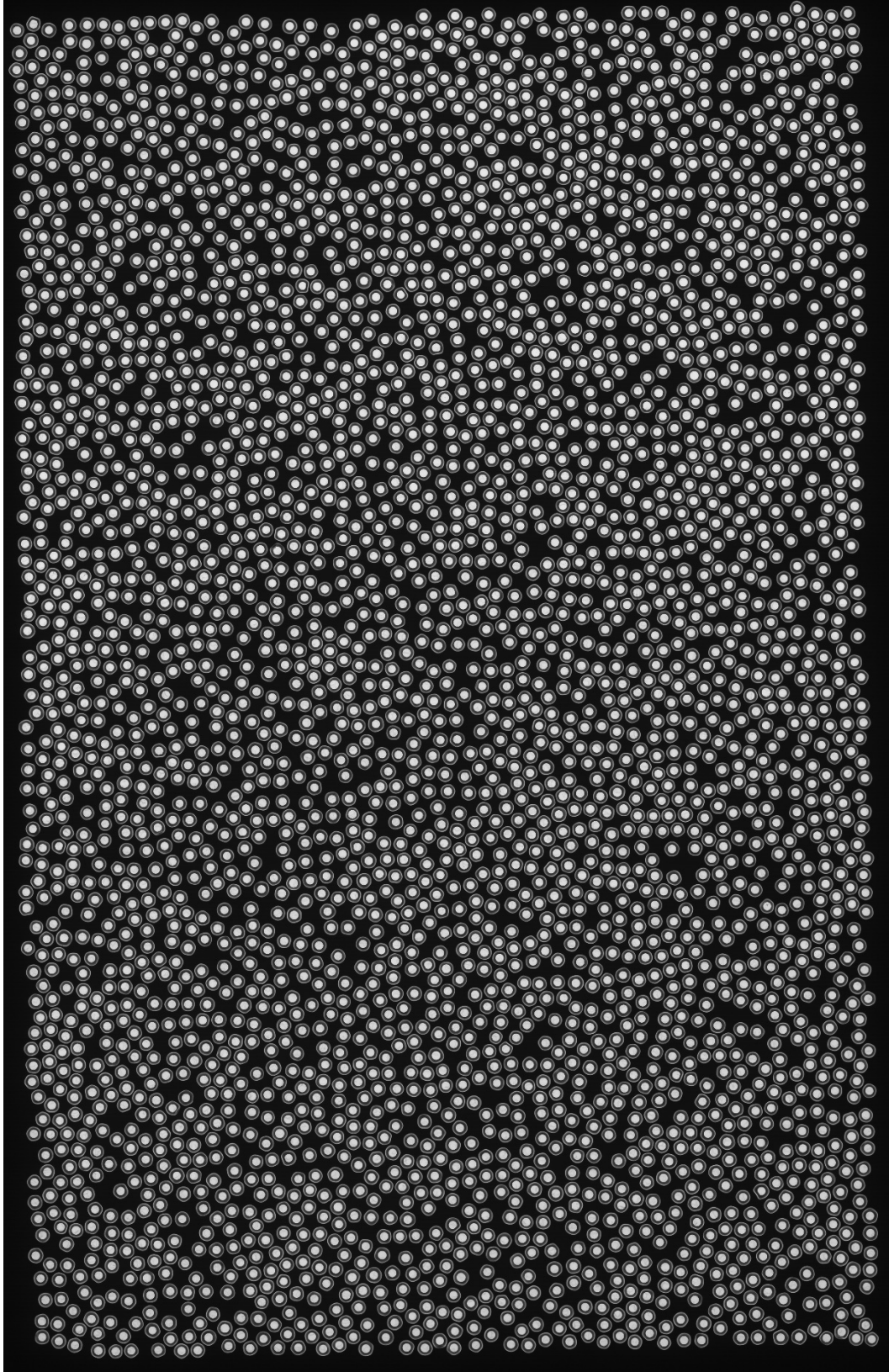


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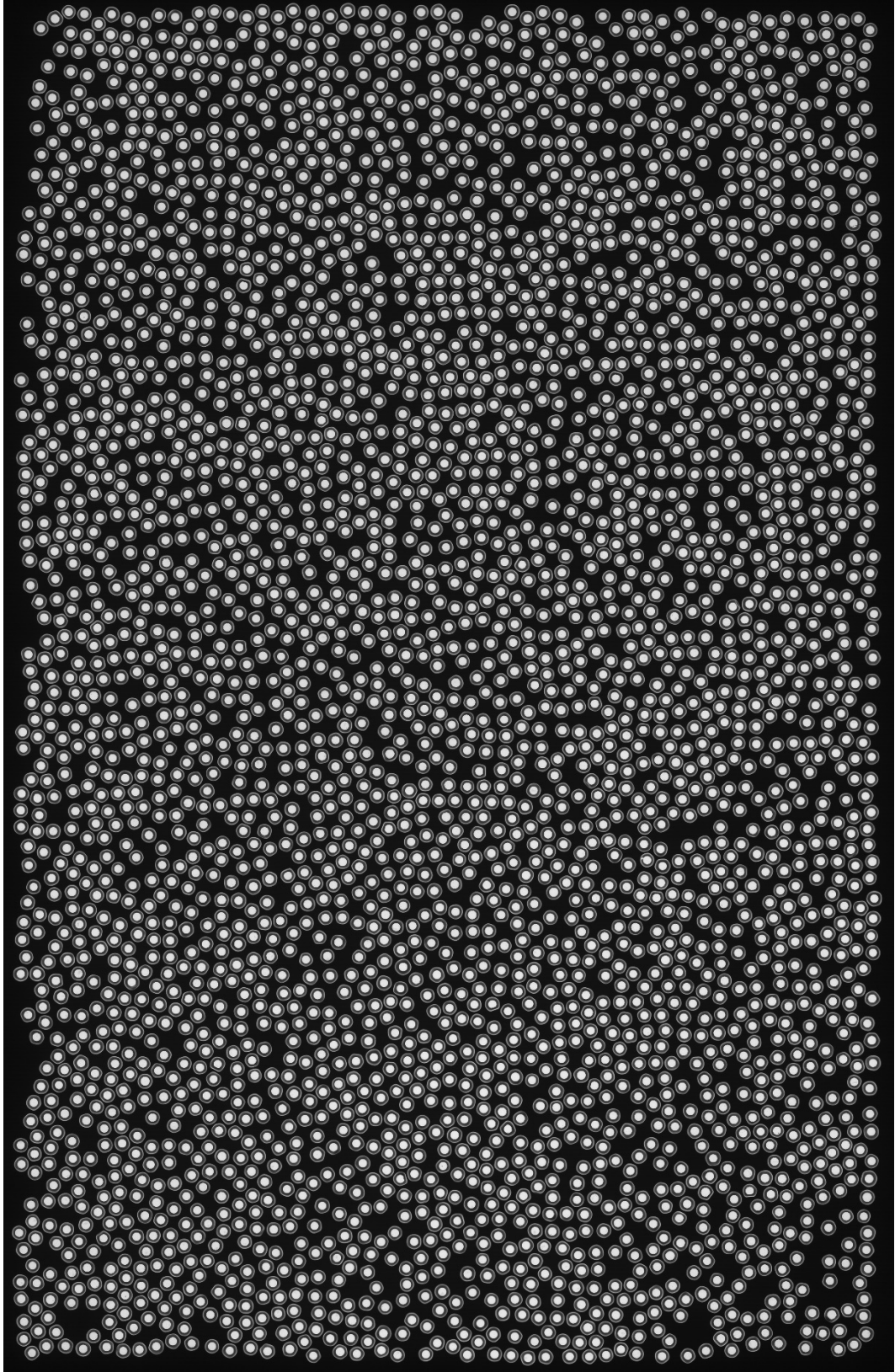


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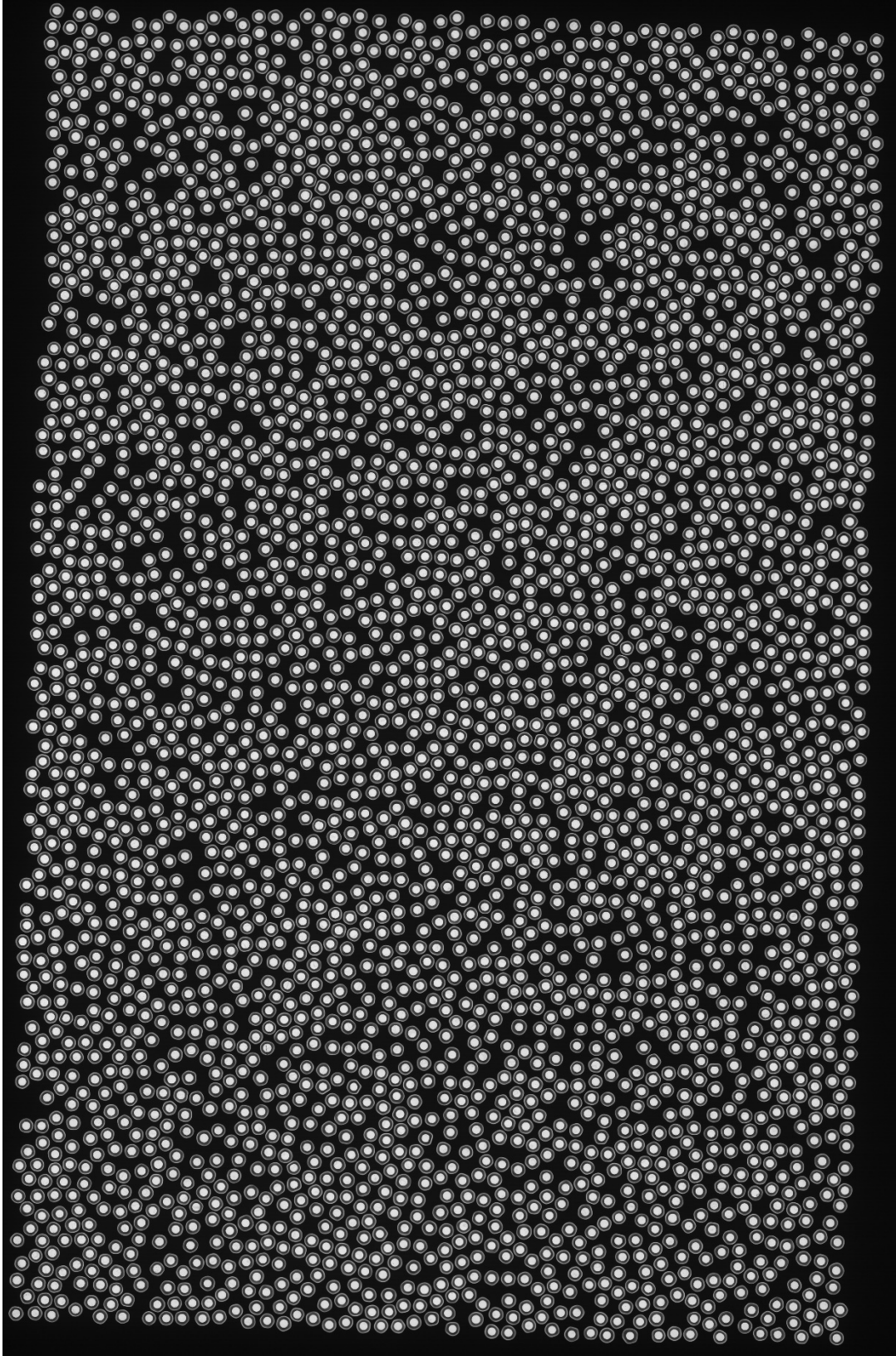


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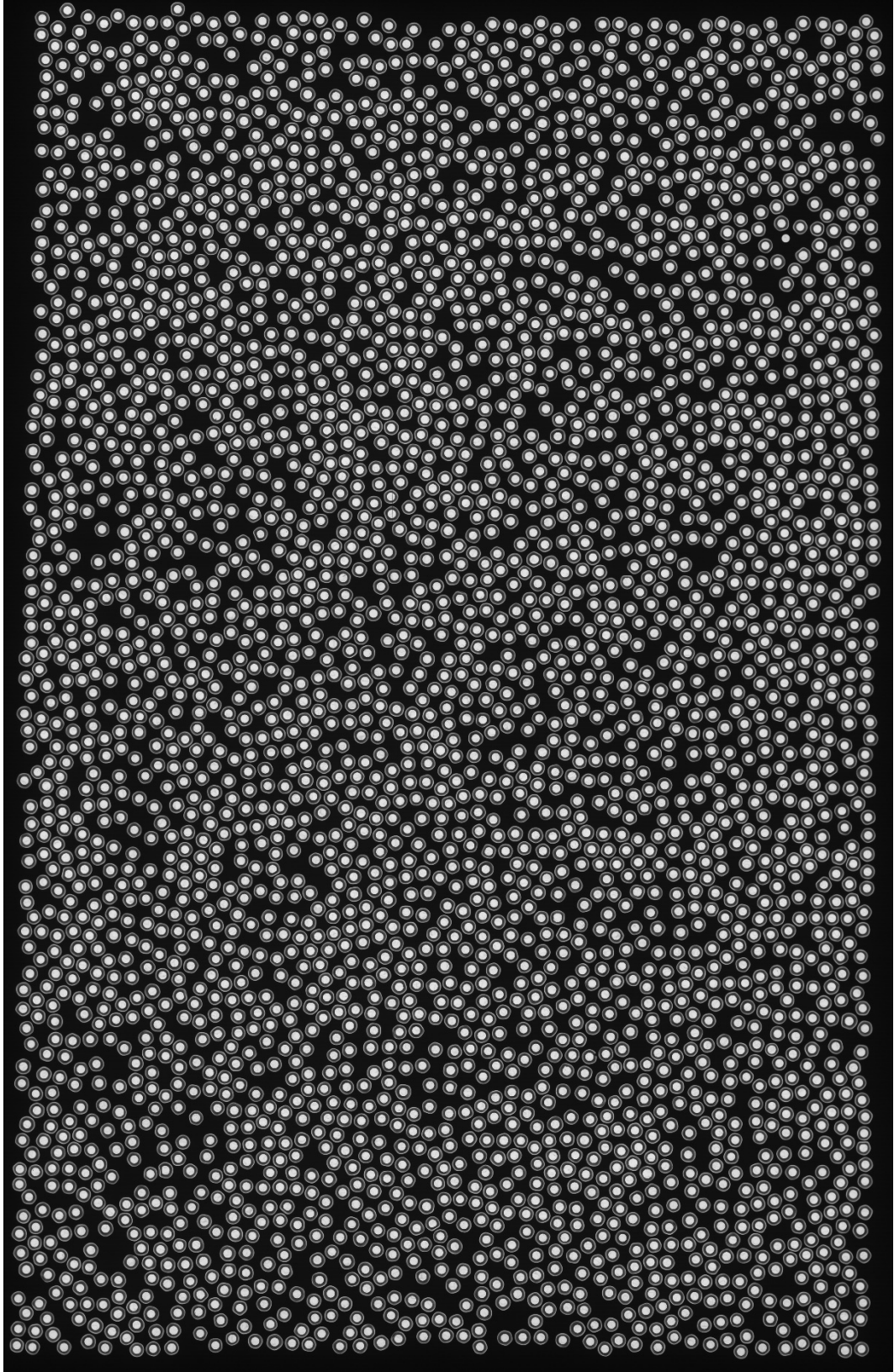


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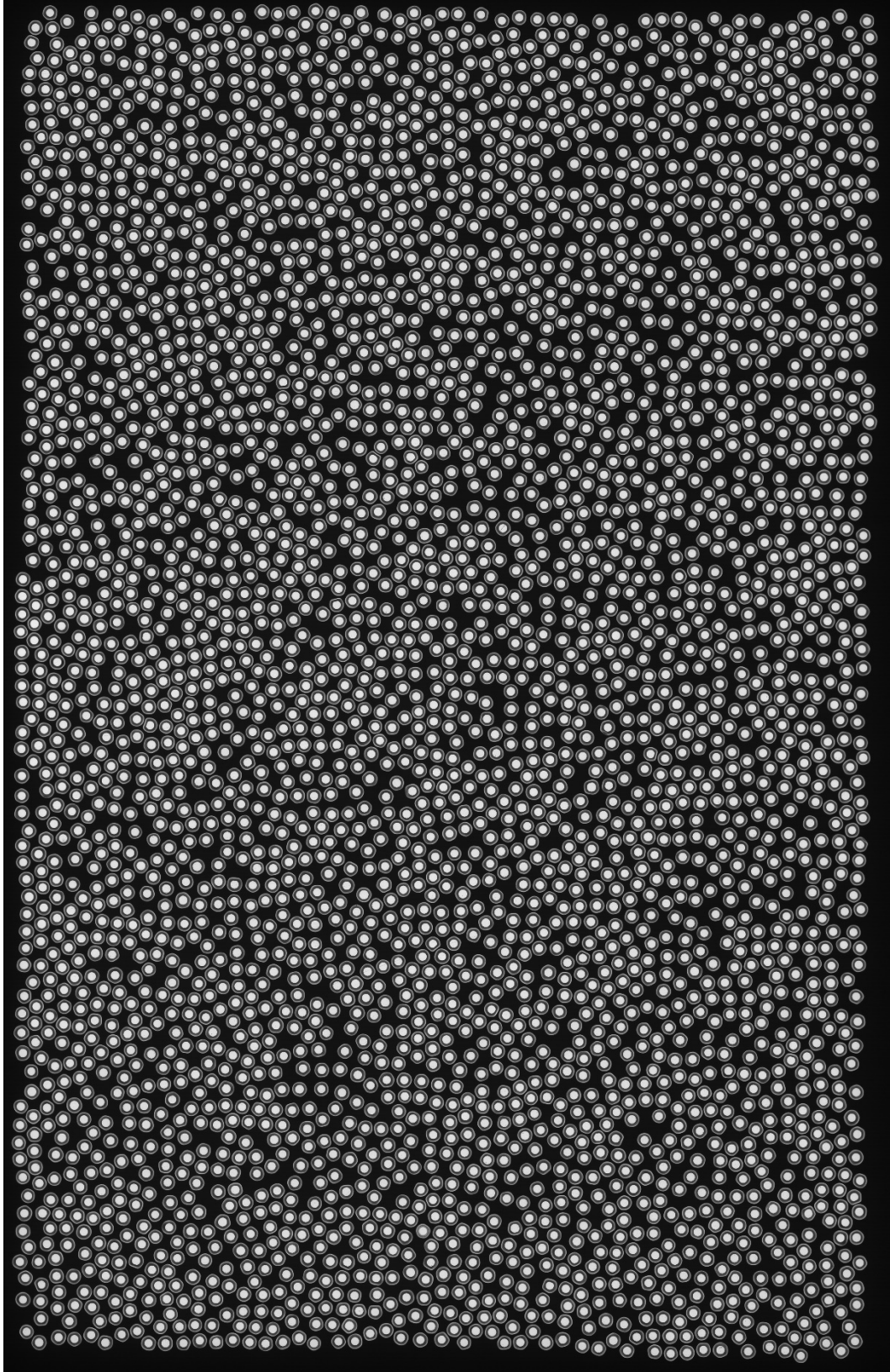




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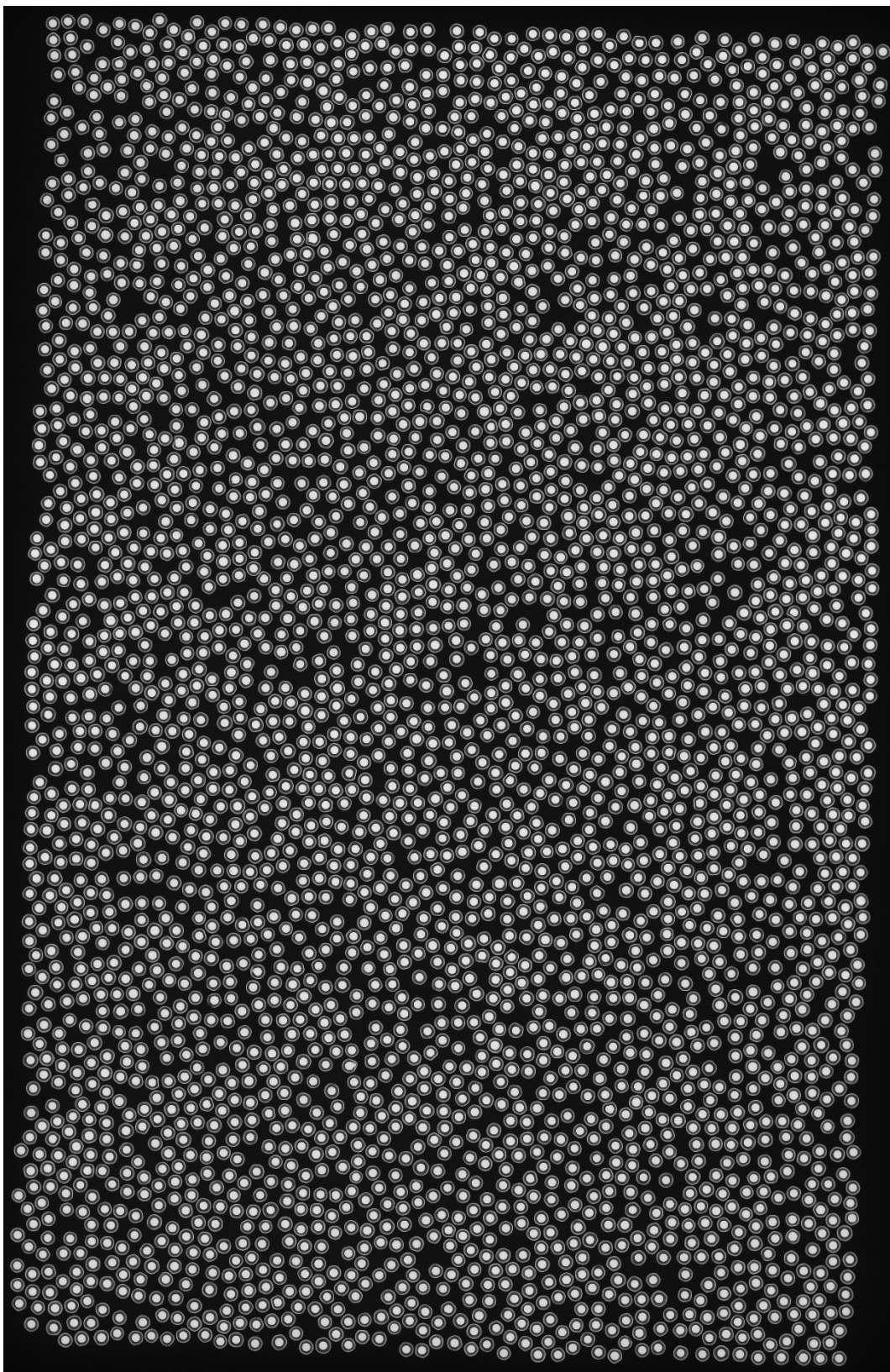


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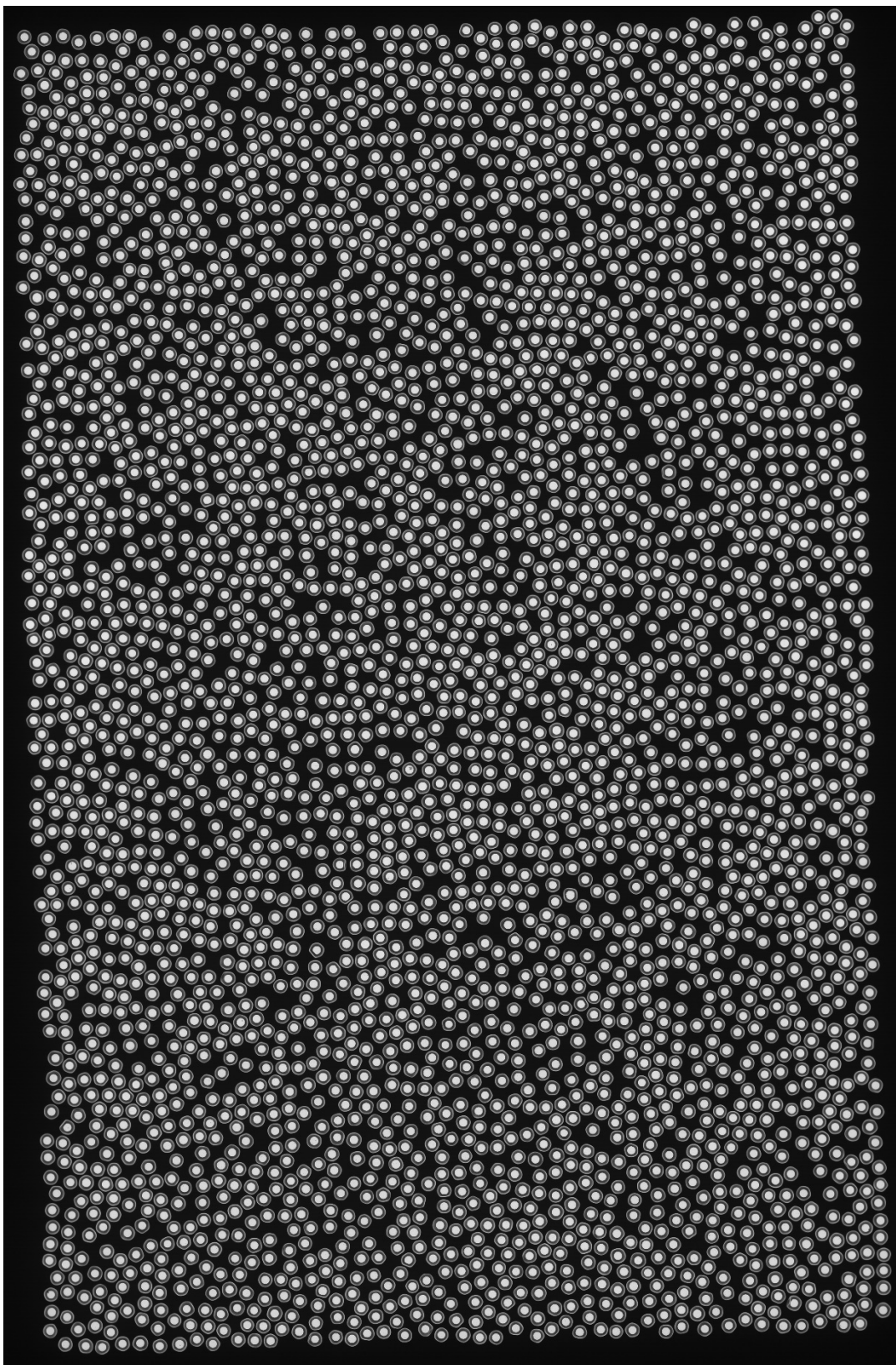


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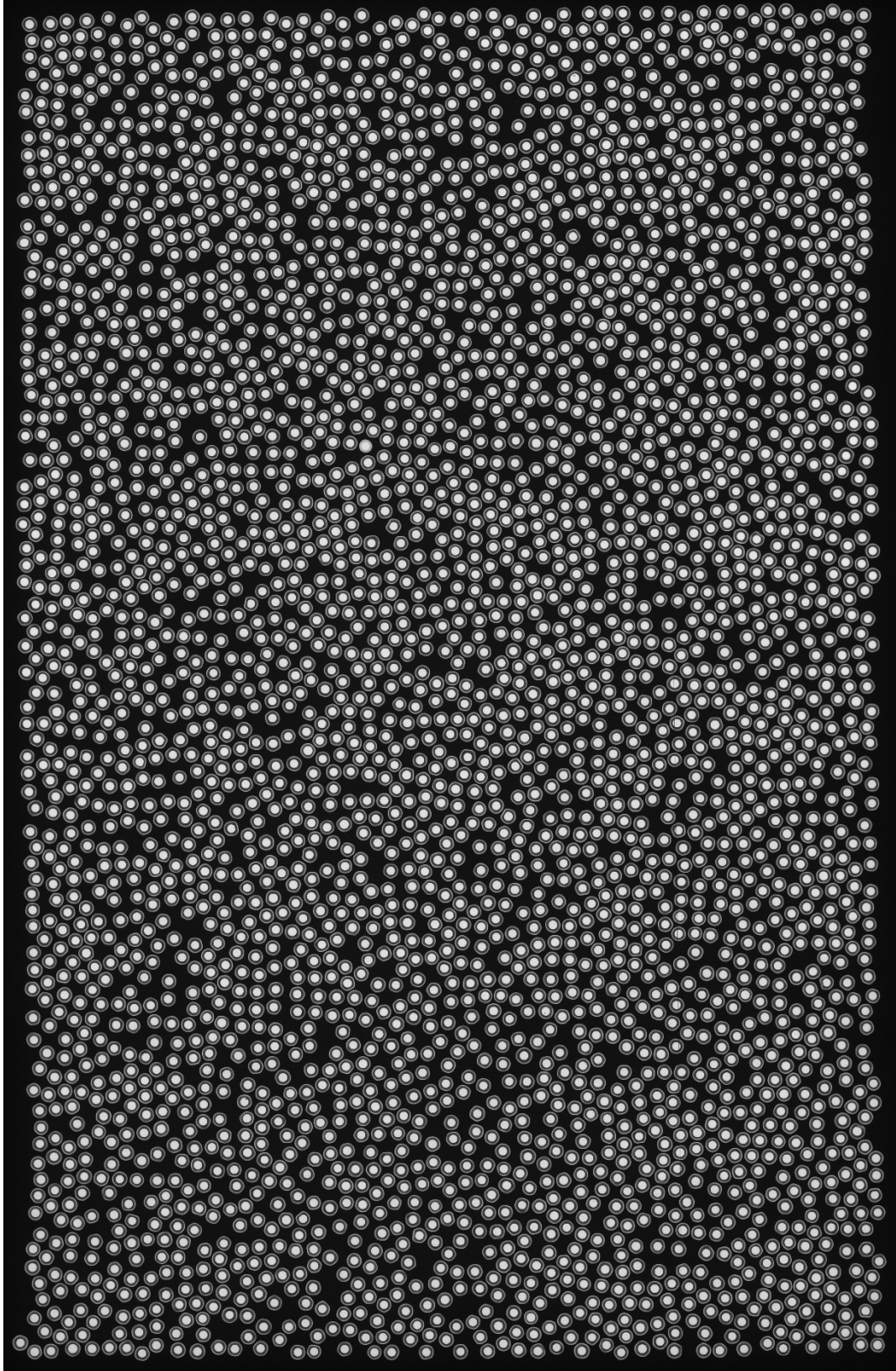


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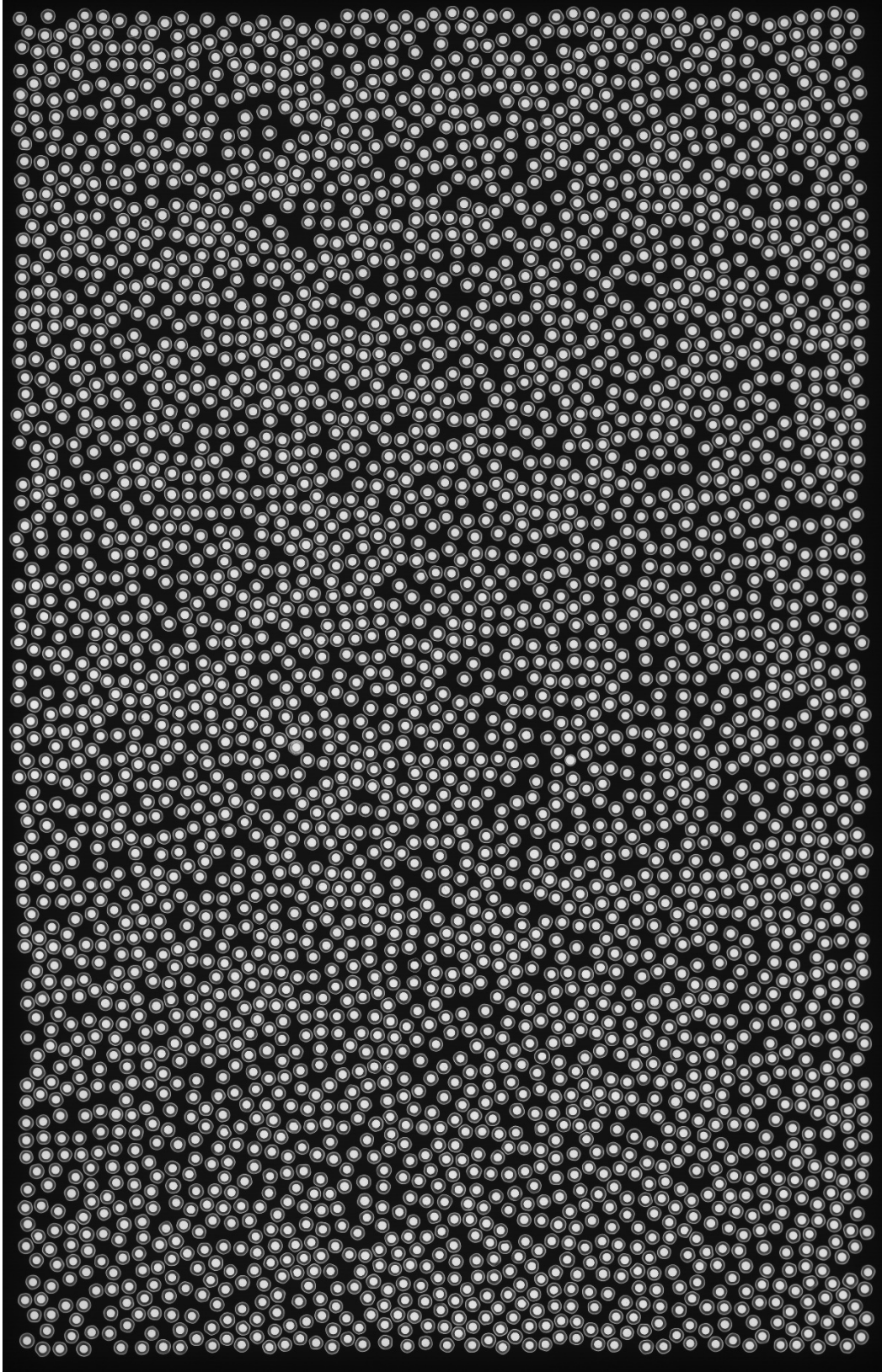


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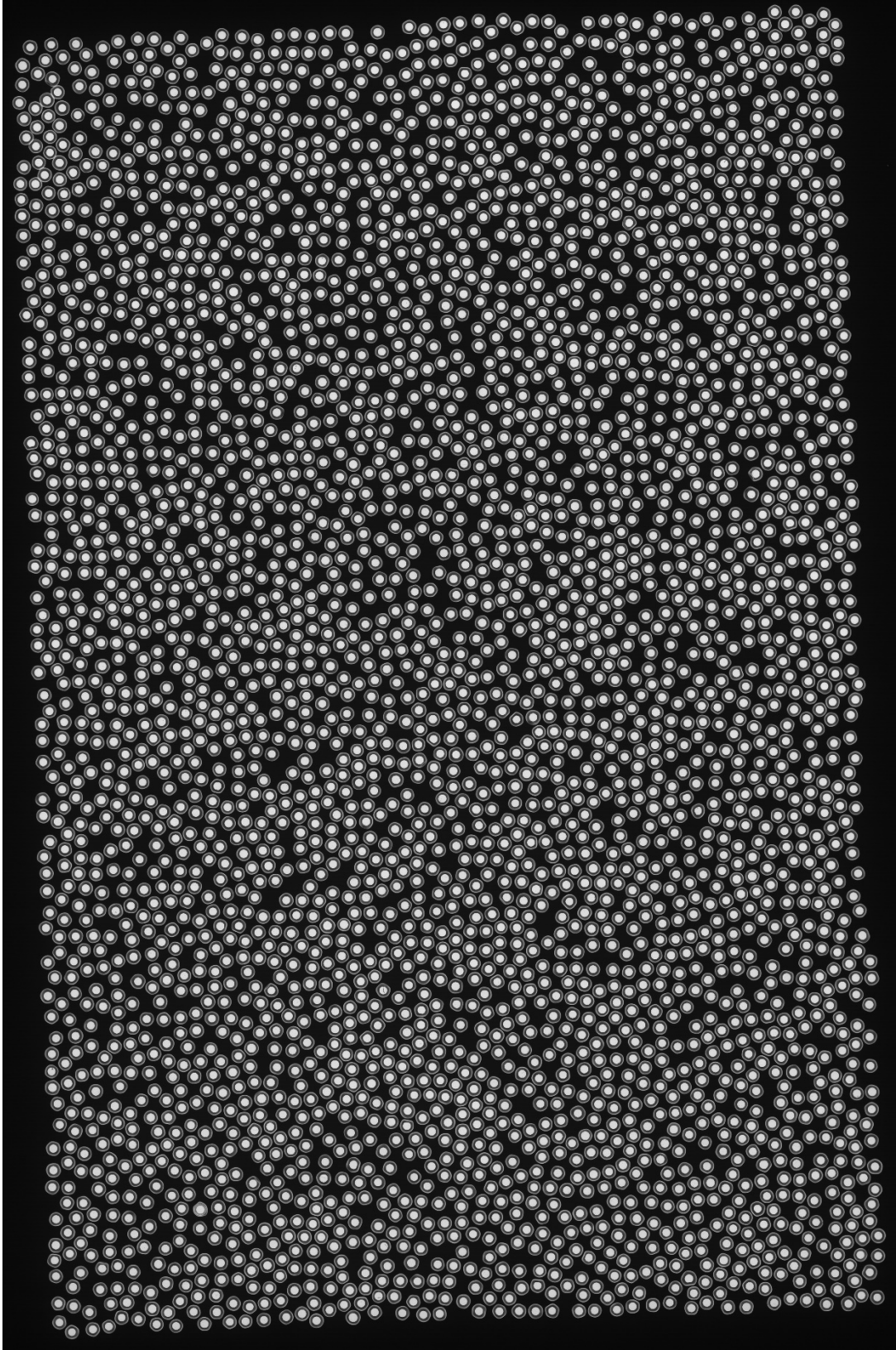




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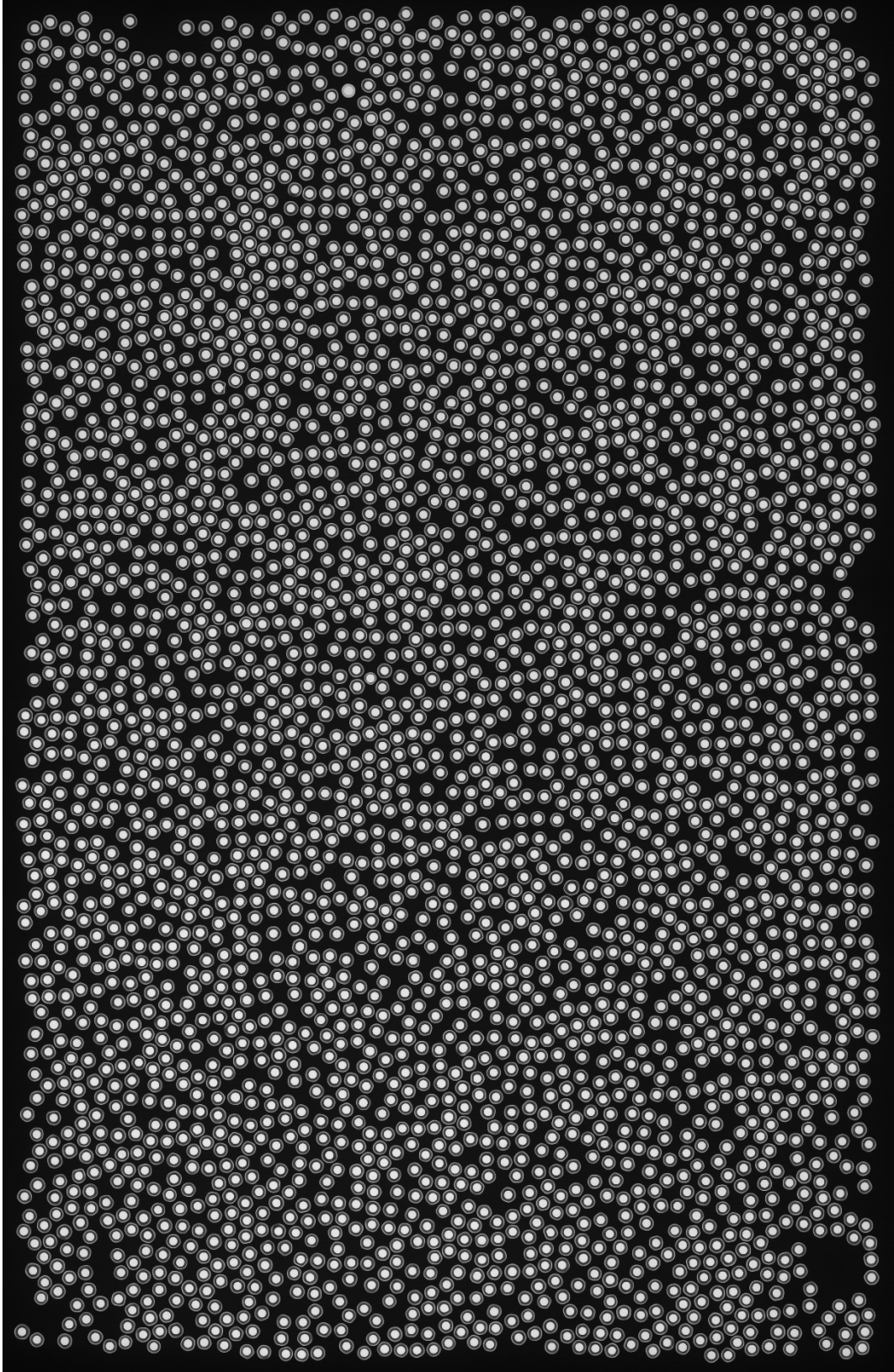


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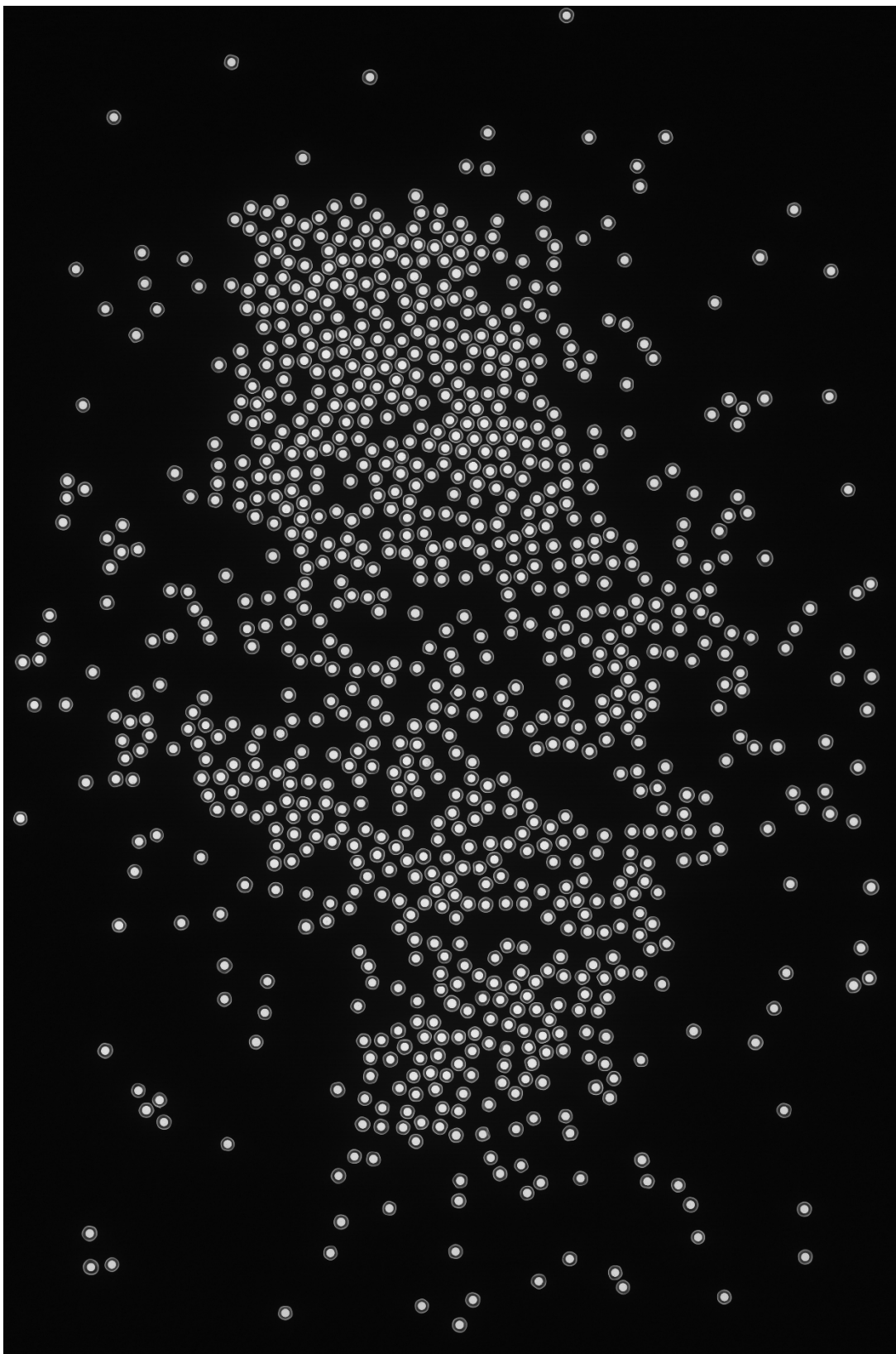
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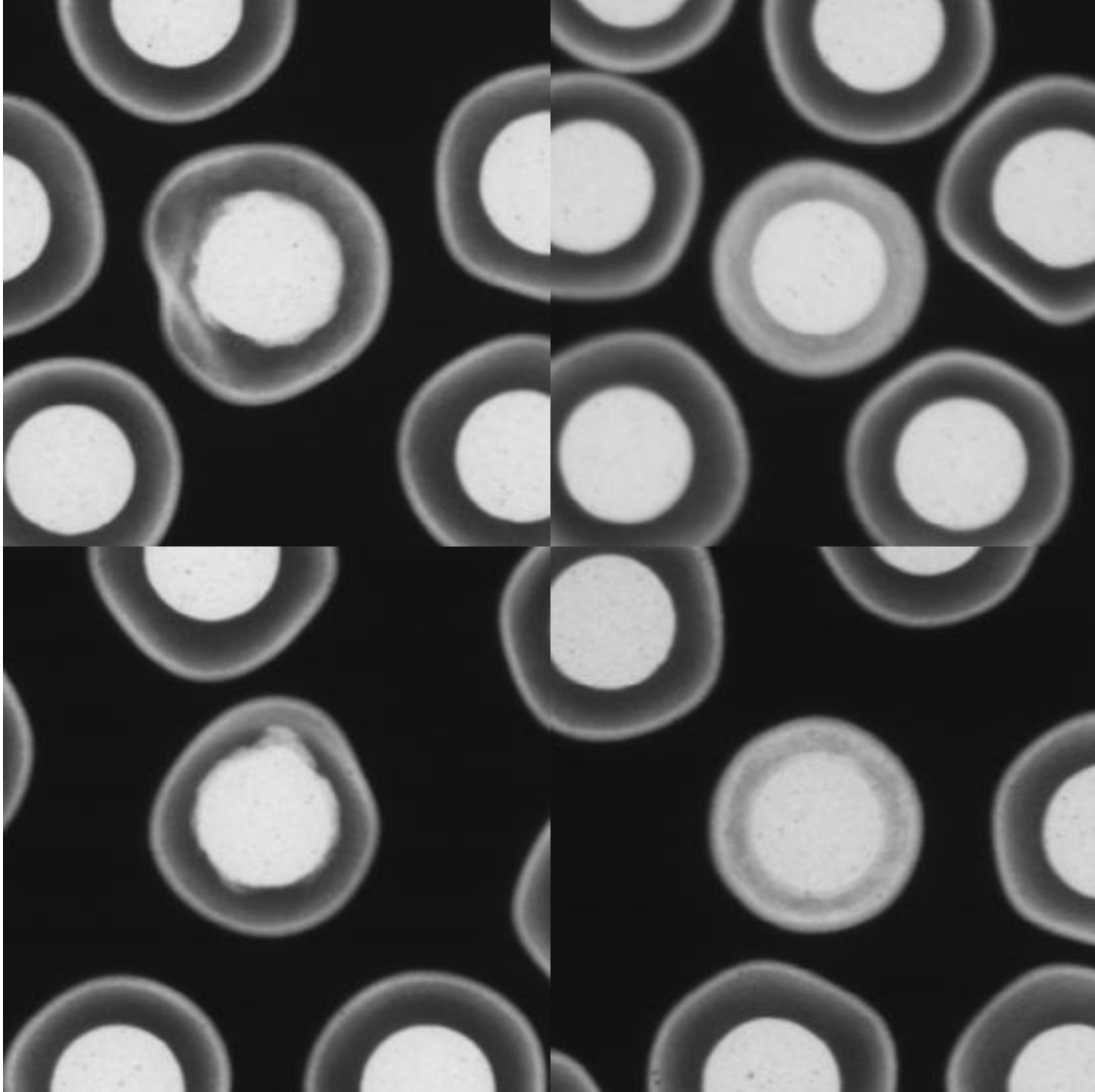


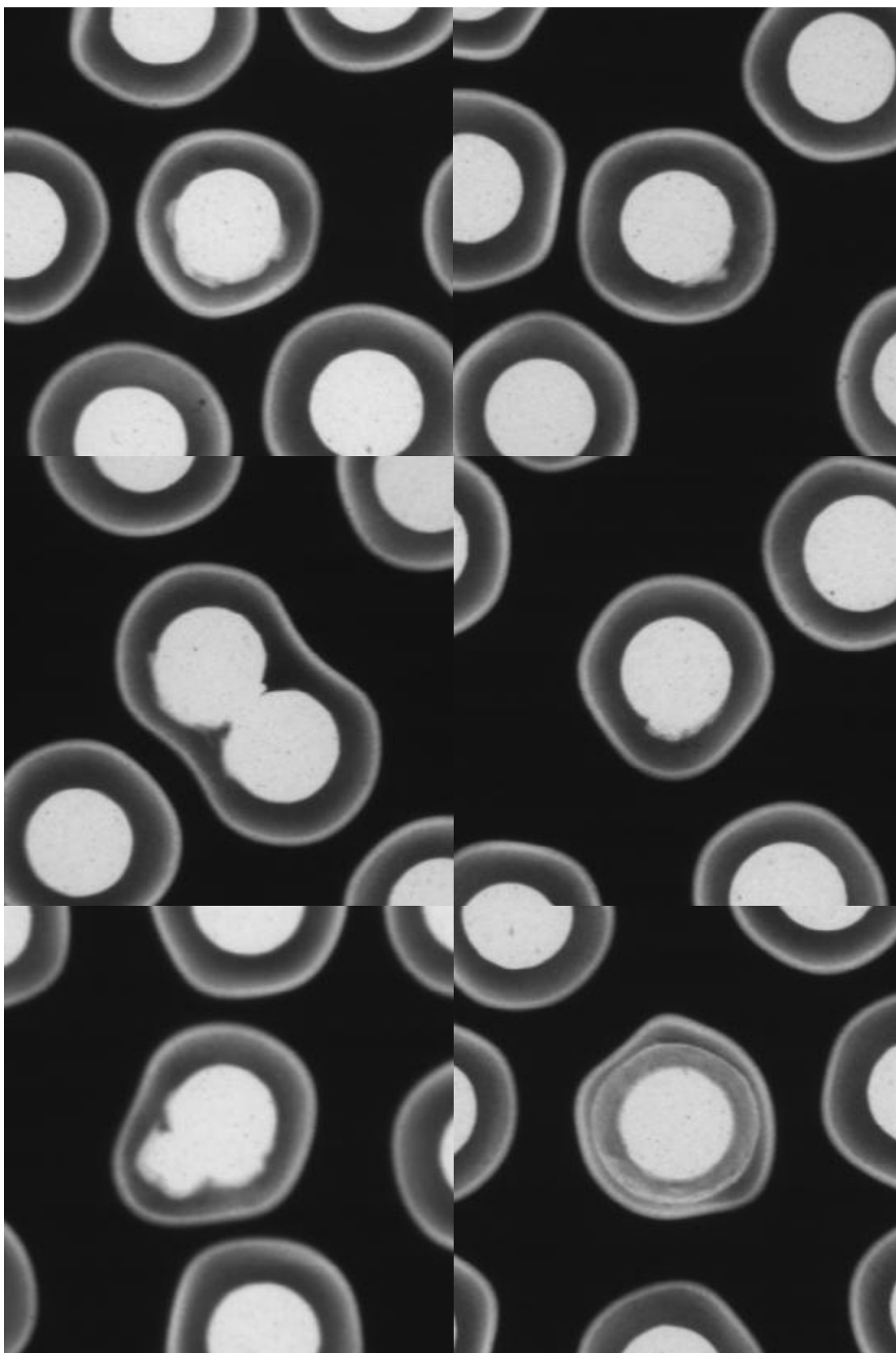


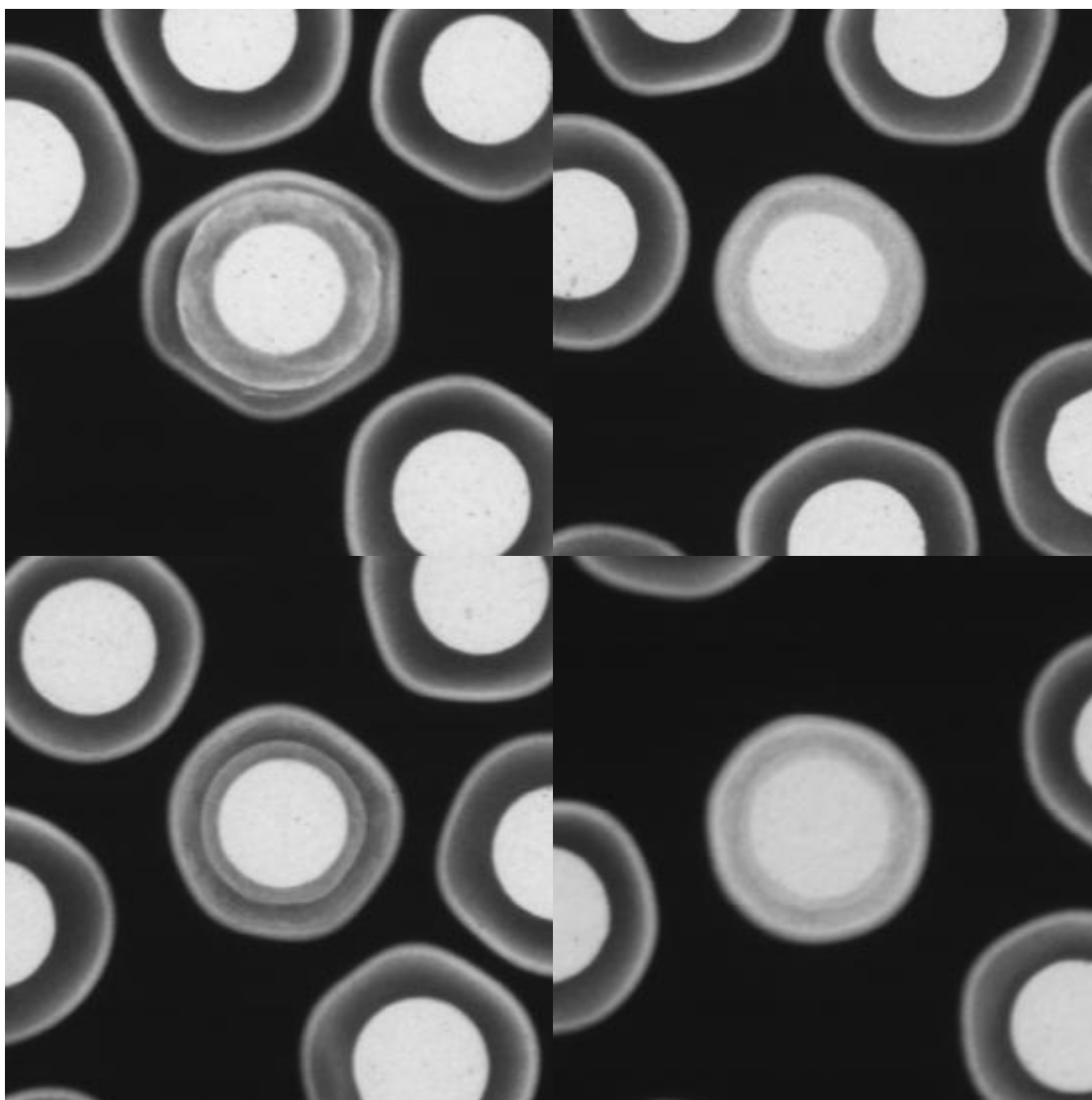
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## **APPENDIX B. EXAMPLE IMAGES OF PARTICLES WITH EXCESSIVE URANIUM DISPERSION**

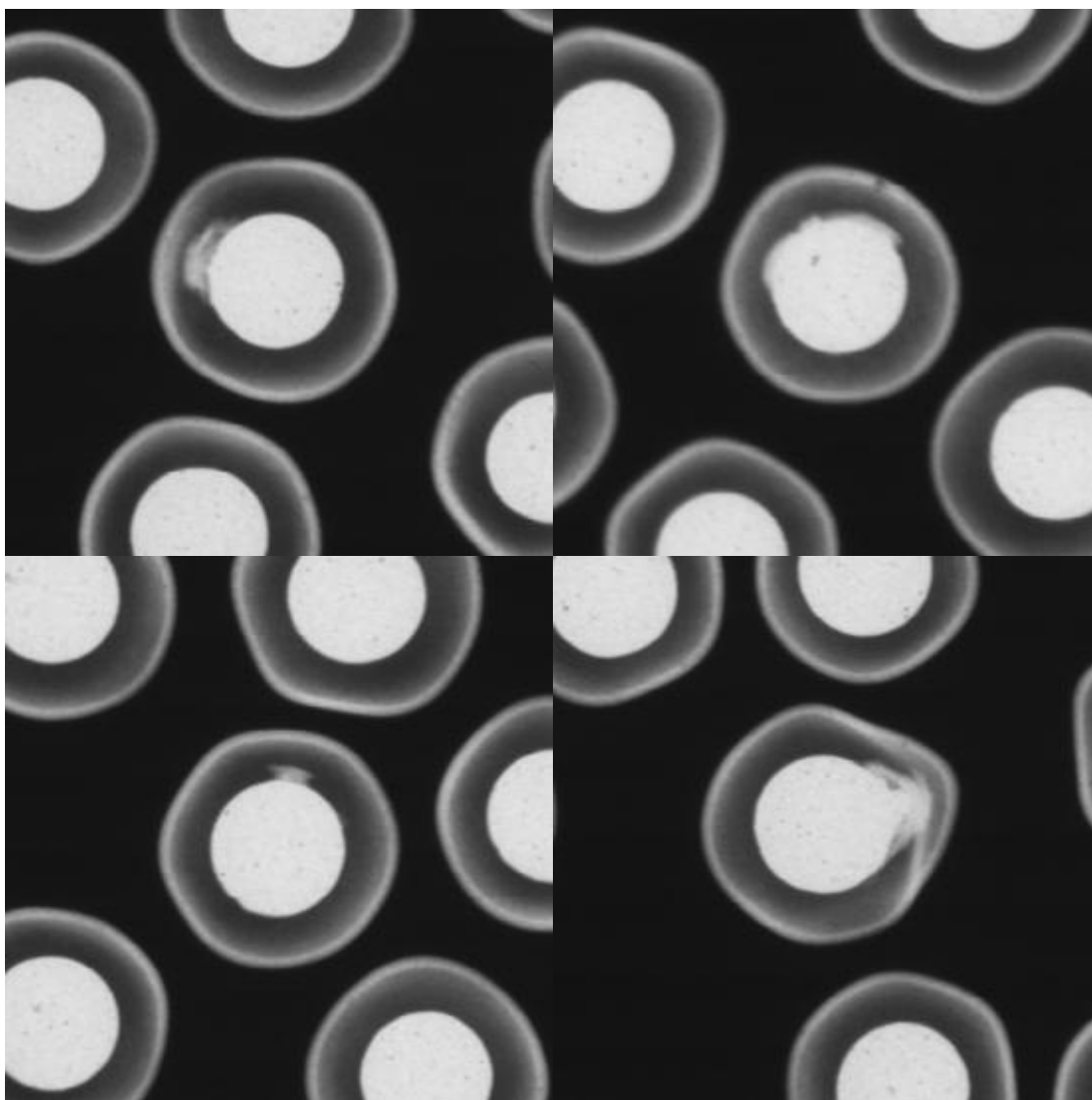
Snipped portions of the images in Appendix A are included in Appendix B. These images show the 18 particles that were identified as having excessive uranium dispersion. The degree of uranium dispersion and apparent root causes varied.





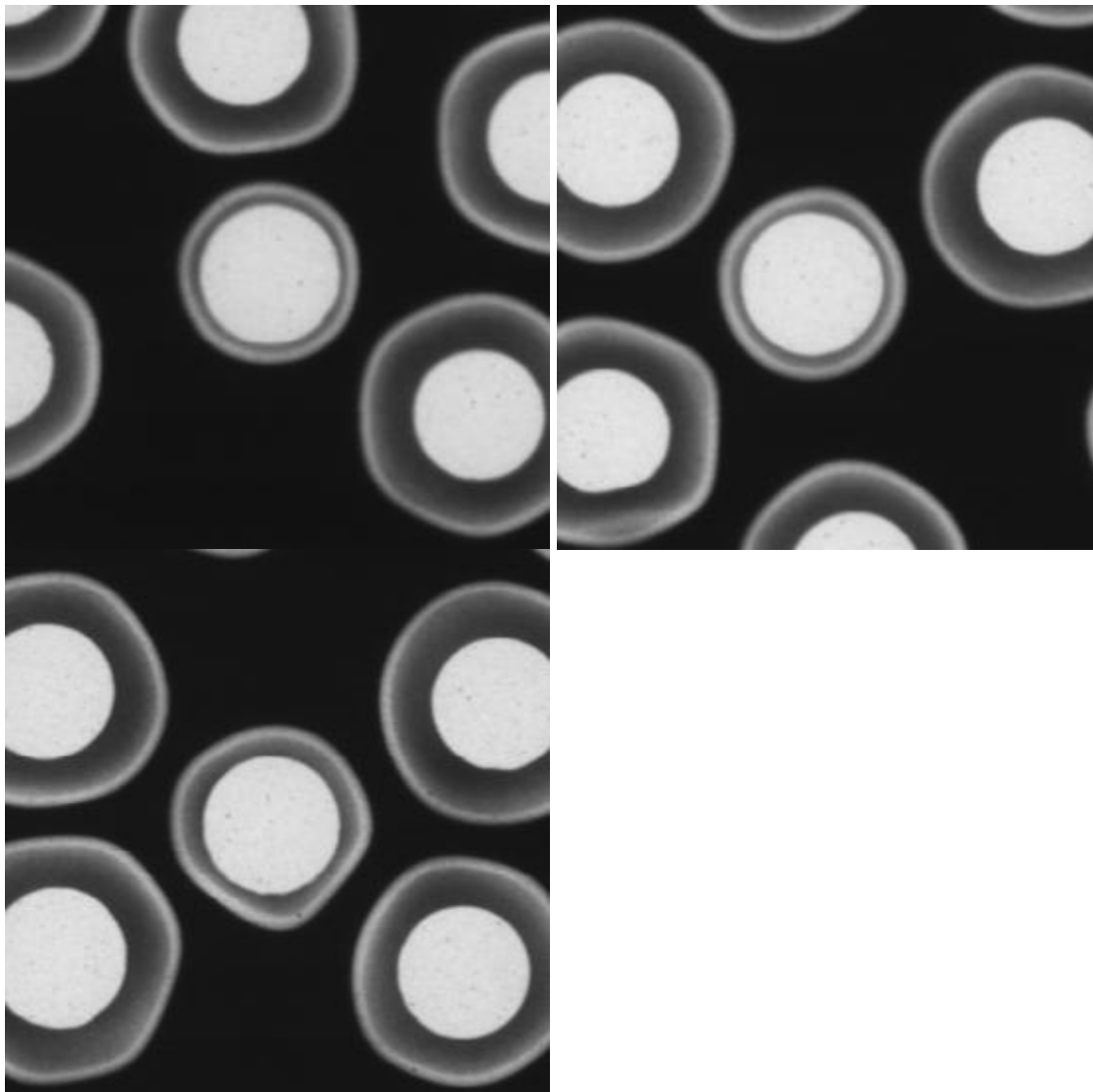






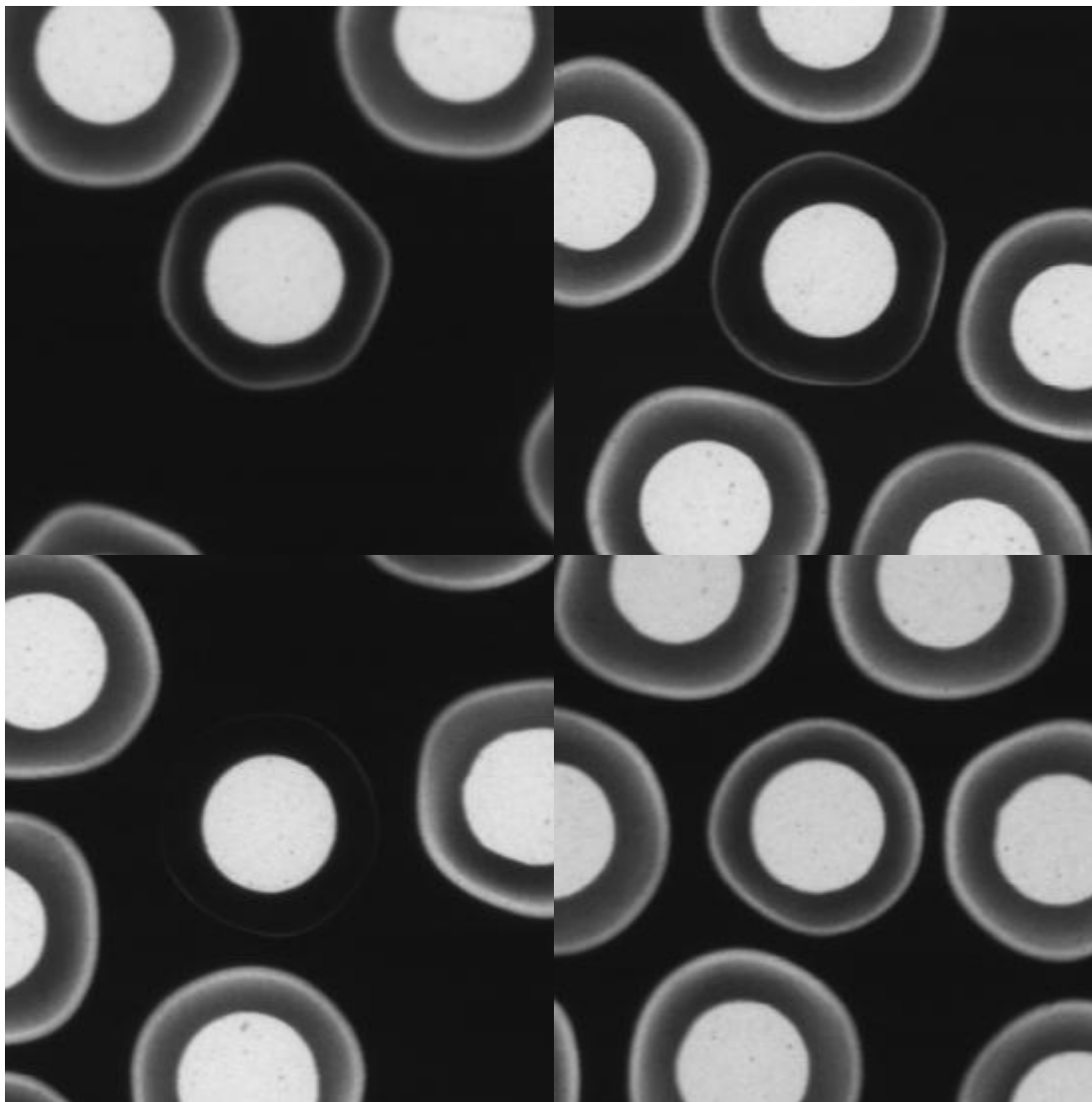
## **APPENDIX C. EXAMPLE IMAGES OF PARTICLES WITH MISSING OR THIN BUFFER**

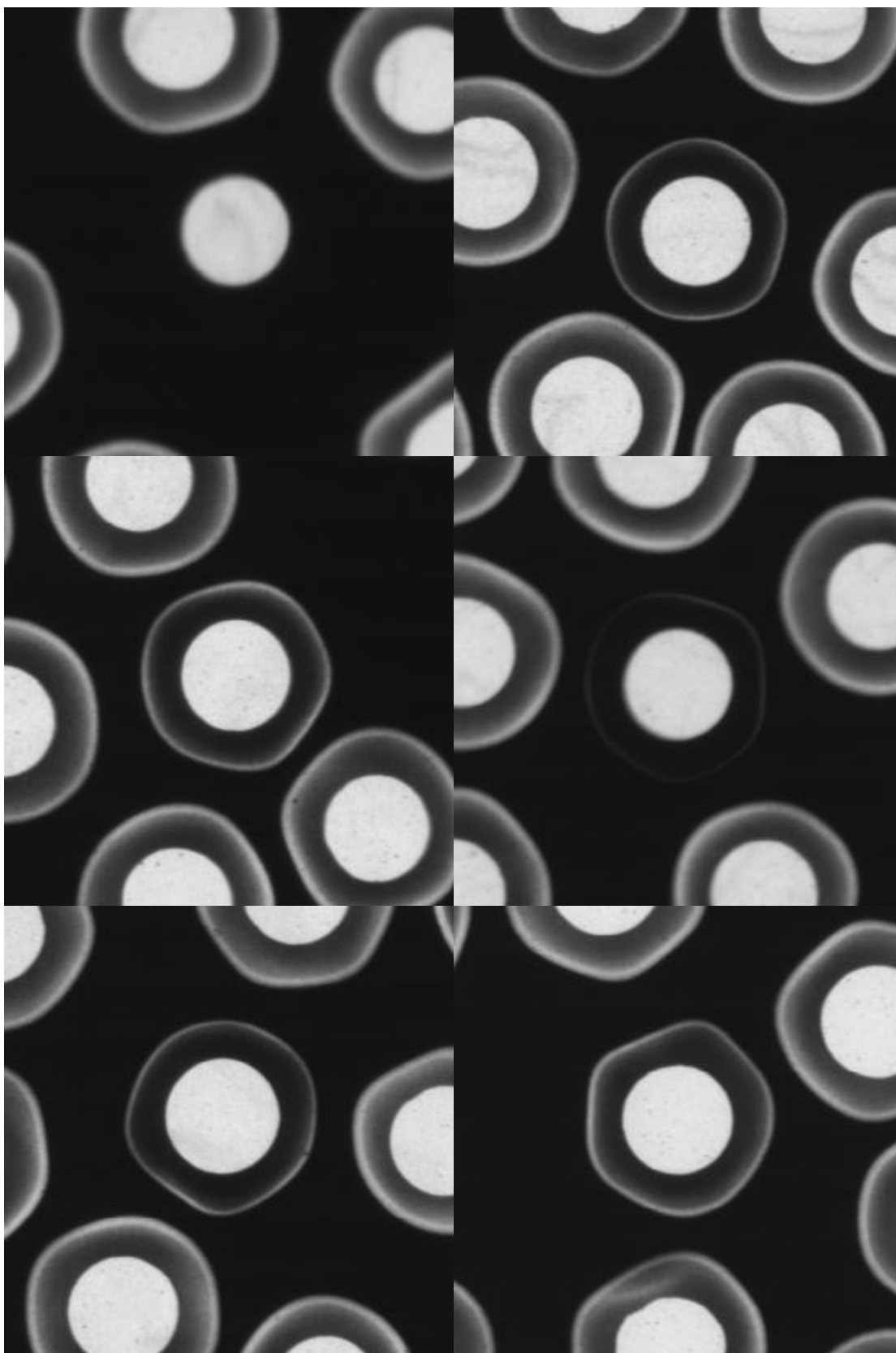
Three particles were identified with either thin or missing buffer layers because of coating irregularities. Additional sieving was used to upgrade later batches of potential AGR-5/6/7 particles to remove these particles from the population.



## APPENDIX D. EXAMPLE IMAGES OF PARTICLES WITH THIN OR MISSING SIC

Ten particles were identified with either thin or missing SiC.

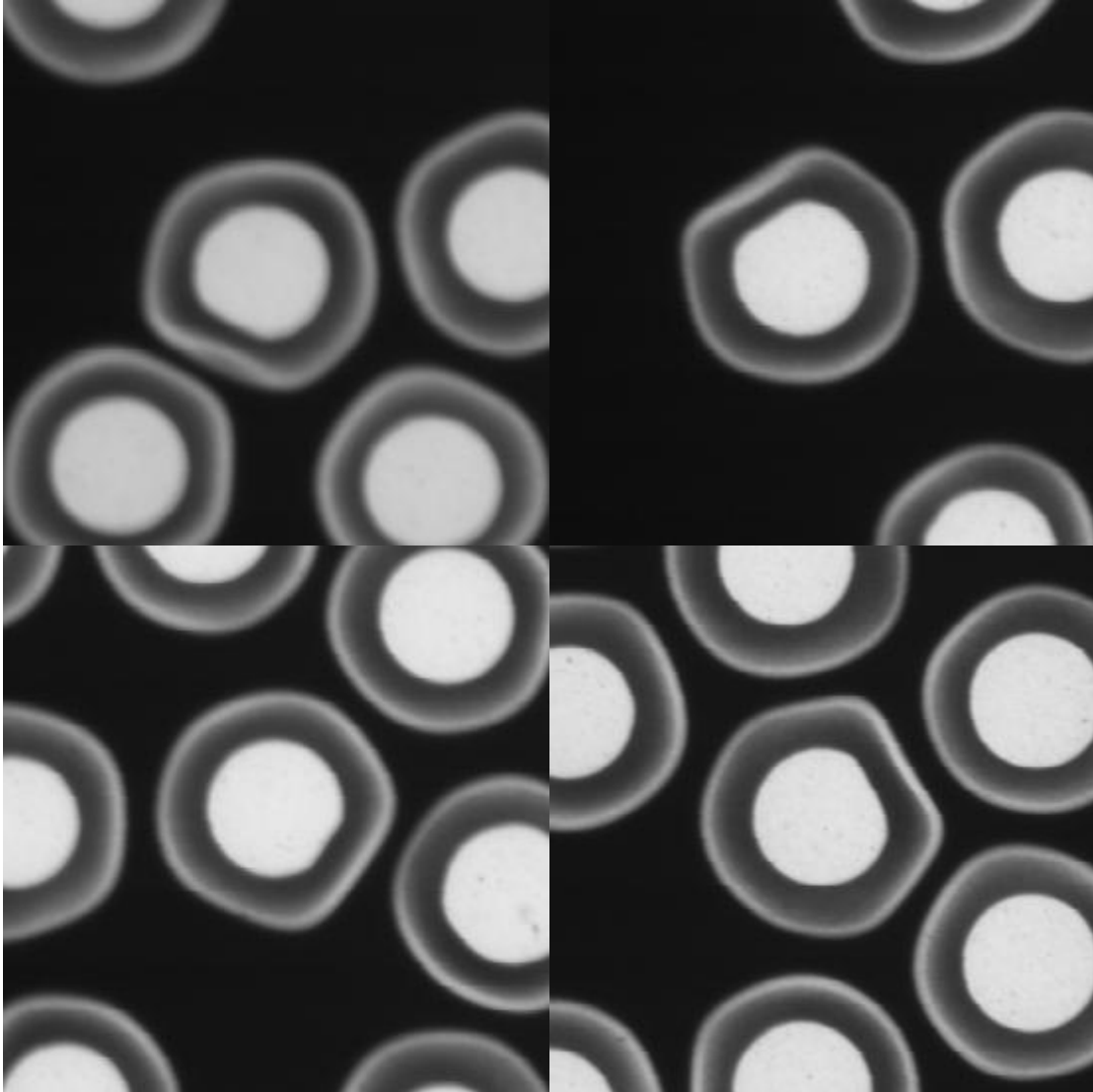


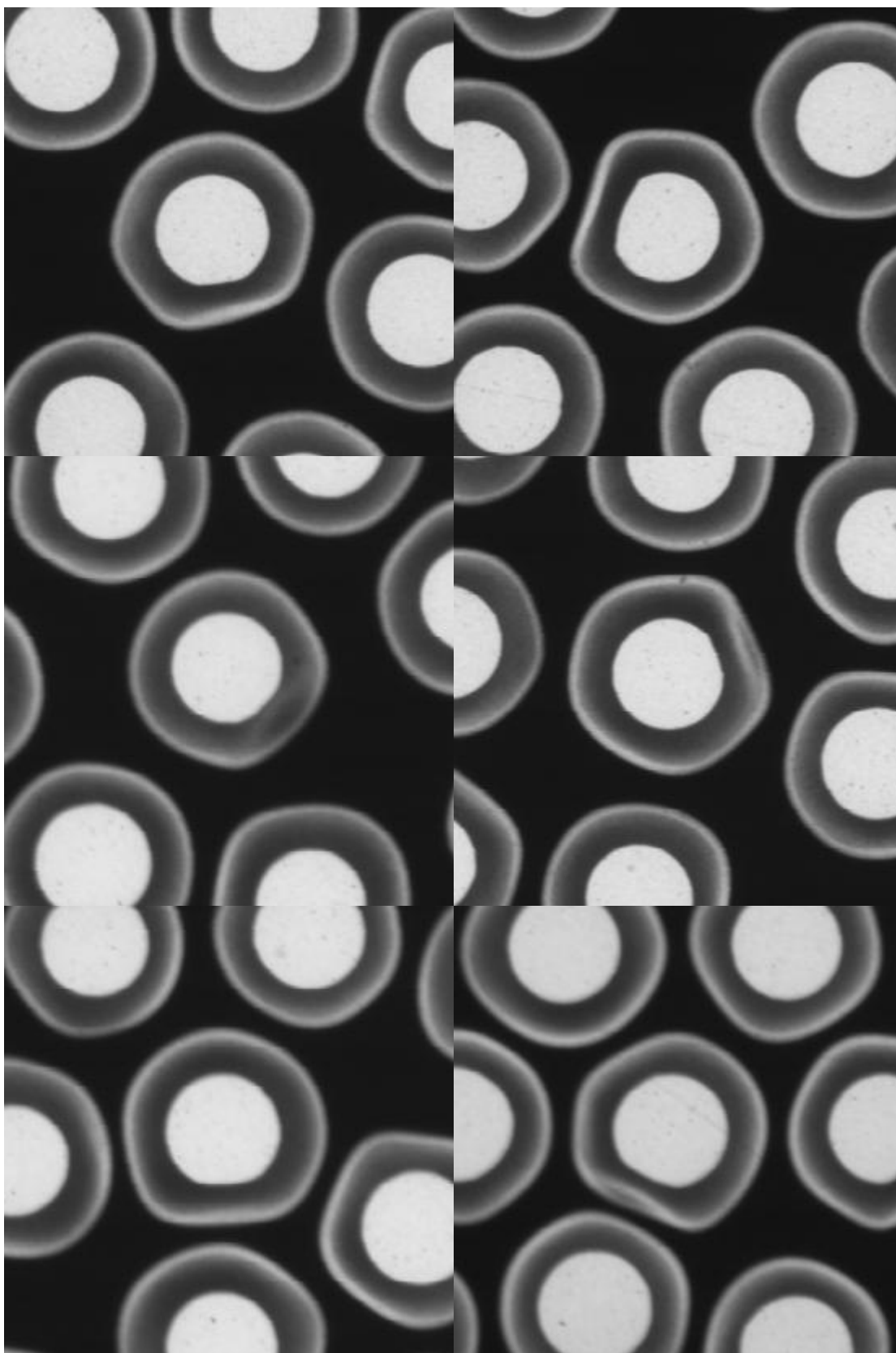




## APPENDIX E. EXAMPLE IMAGES OF PARTICLES WITH DIMPLES OR FACETS

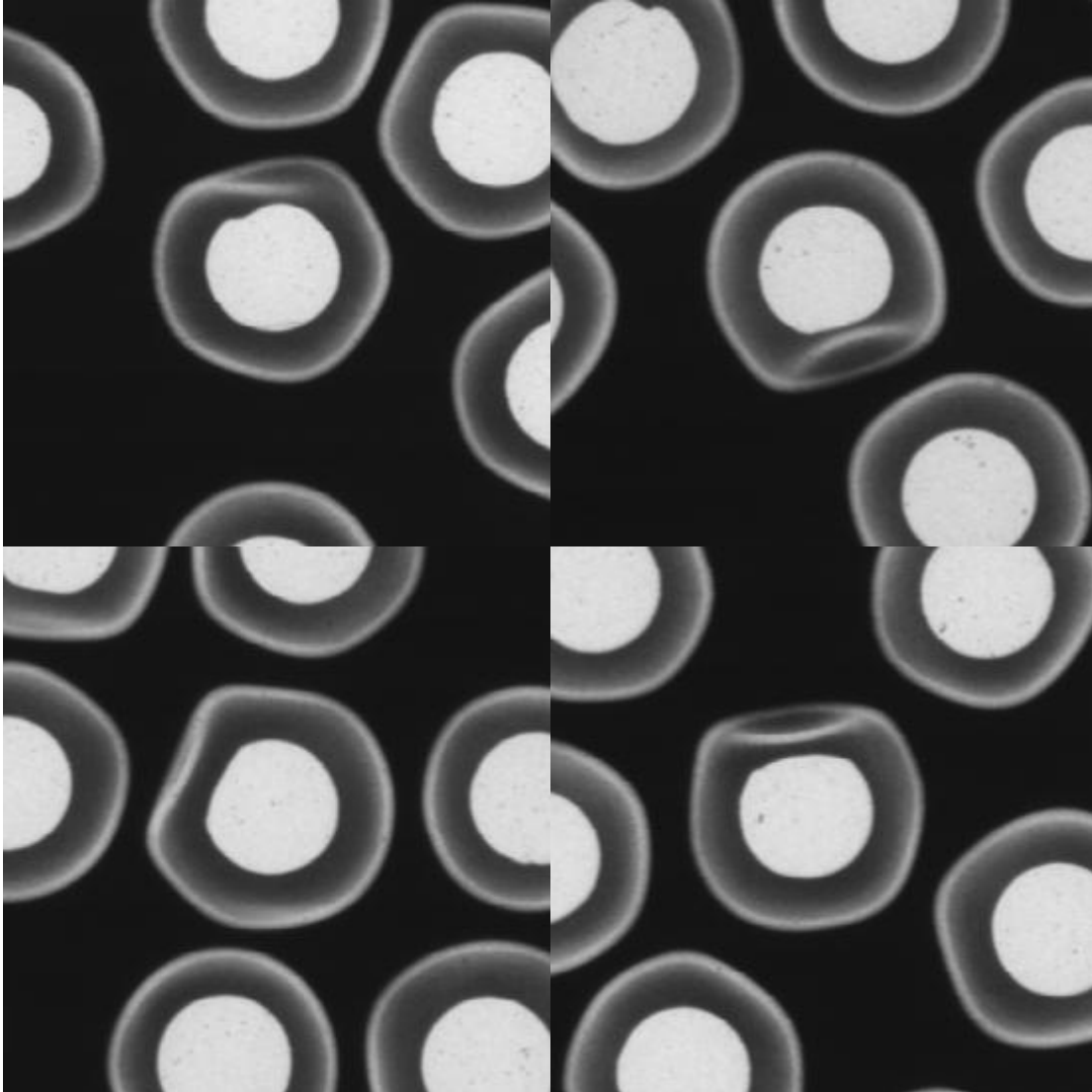
Example images of particles identified as having a dimple in the coating layers (based on the SiC layer in radiography) or a faceted kernel are shown below. Identification of these particles was qualitative based on operator judgement, and example images were used for training.

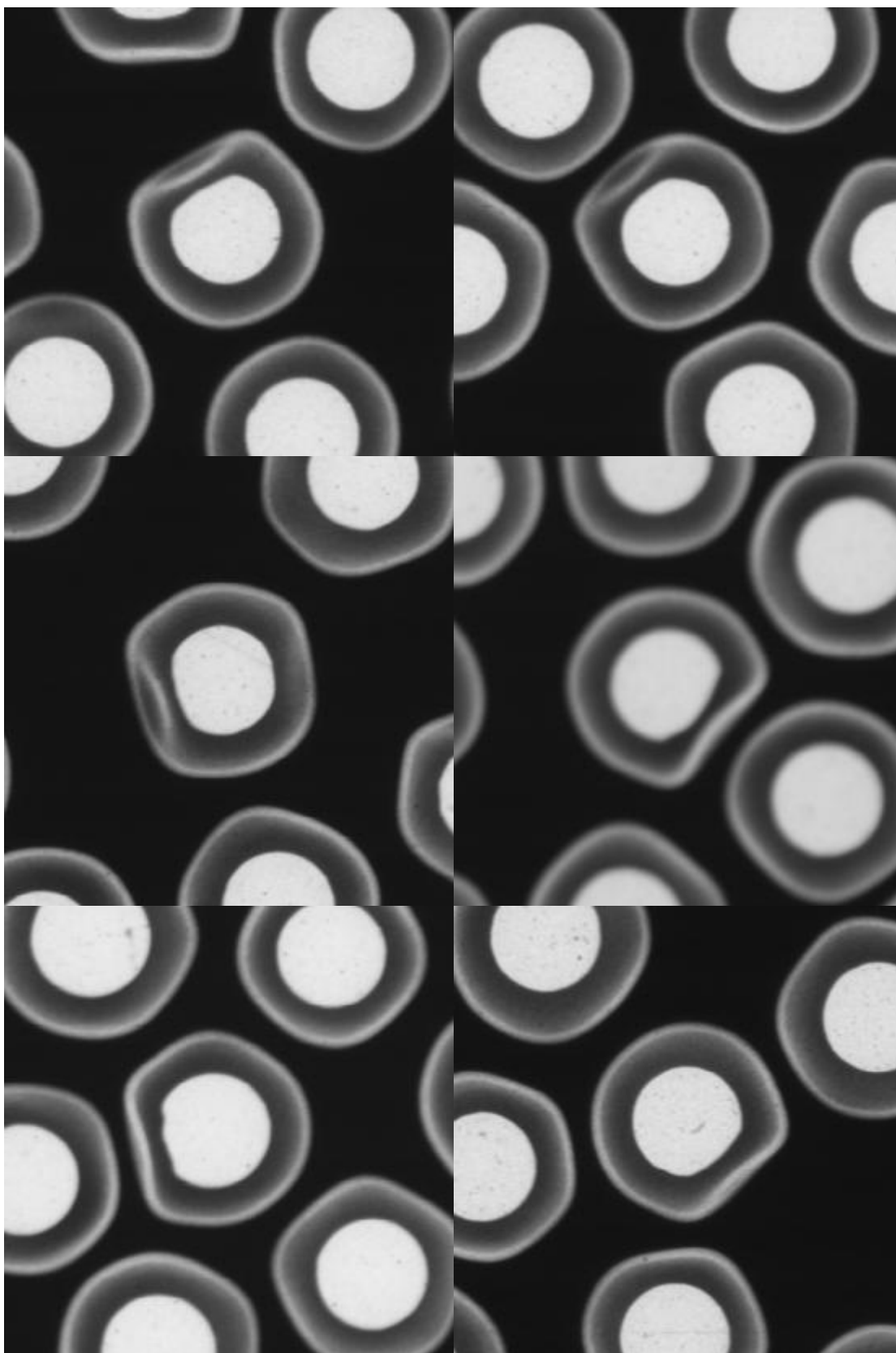




## **APPENDIX F. EXAMPLE IMAGES OF PARTICLES WITH SEVERE DIMPLES OR FACETS**

Example images of particles with severe dimples (based on the SiC layer) or kernel facets are provided below. Identification of these particles was qualitative based on operator judgement, and example images were used for training.

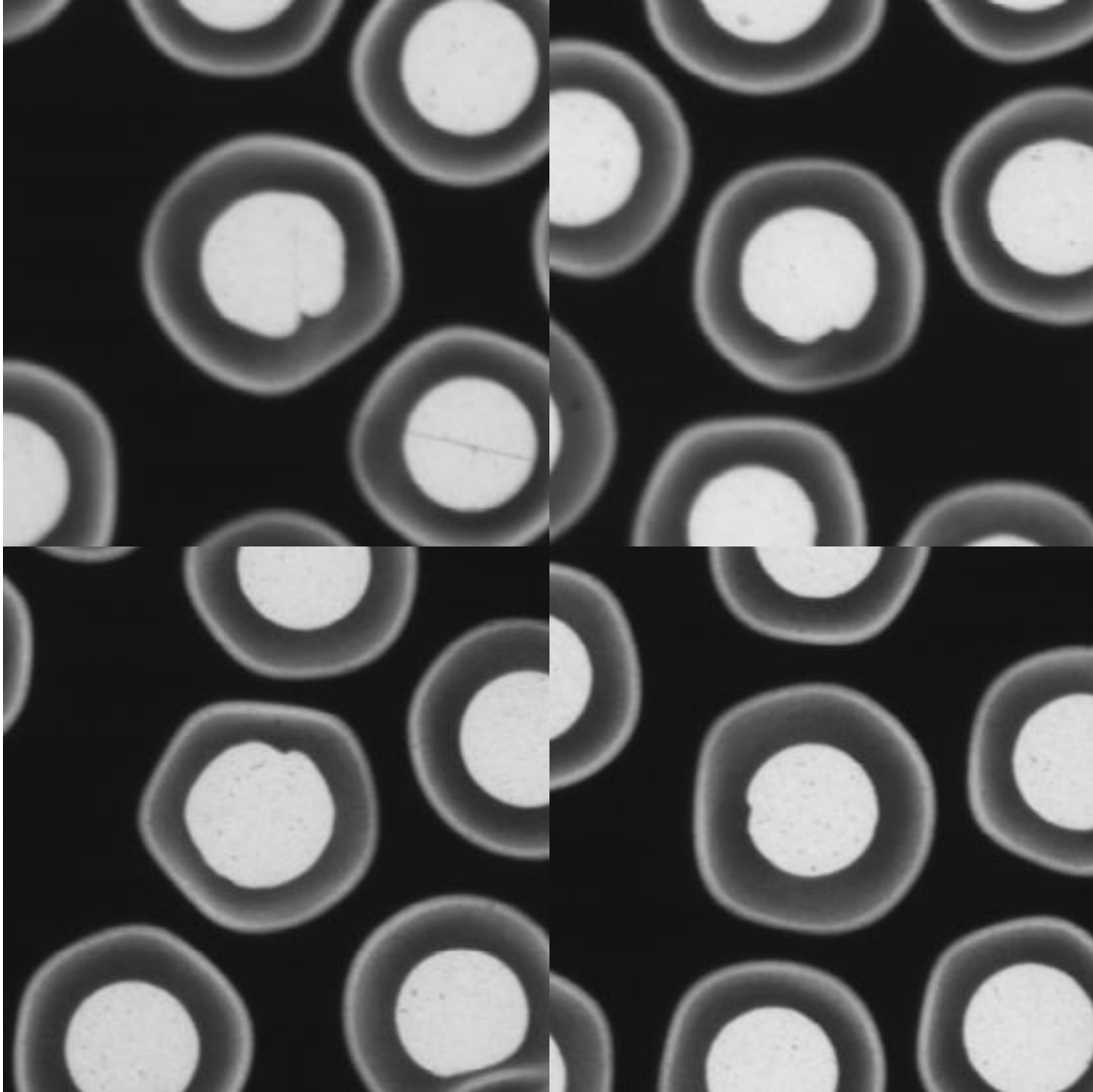


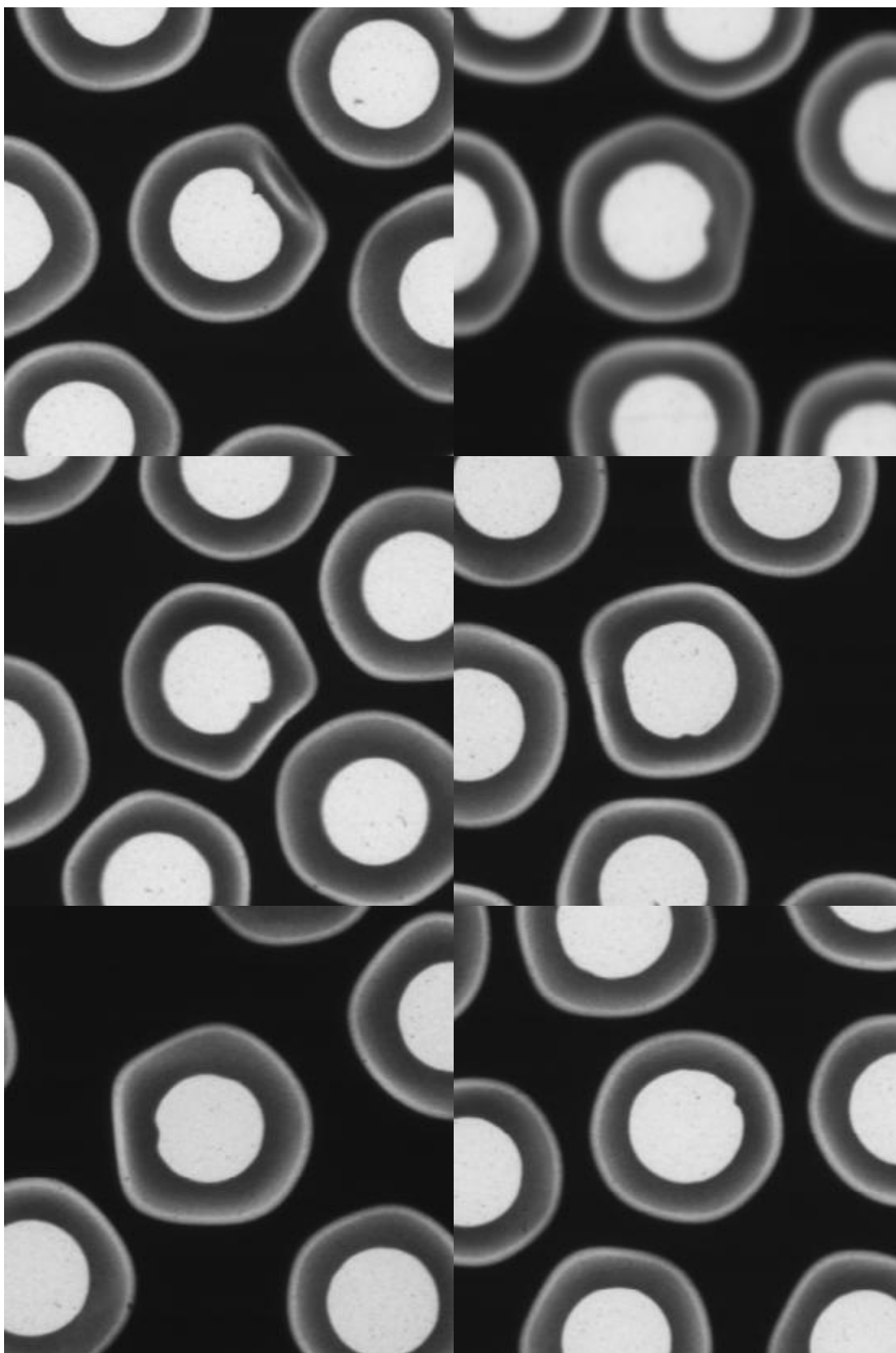




## **APPENDIX G. EXAMPLE IMAGES OF PARTICLES WITH NOTCHED KERNELS**

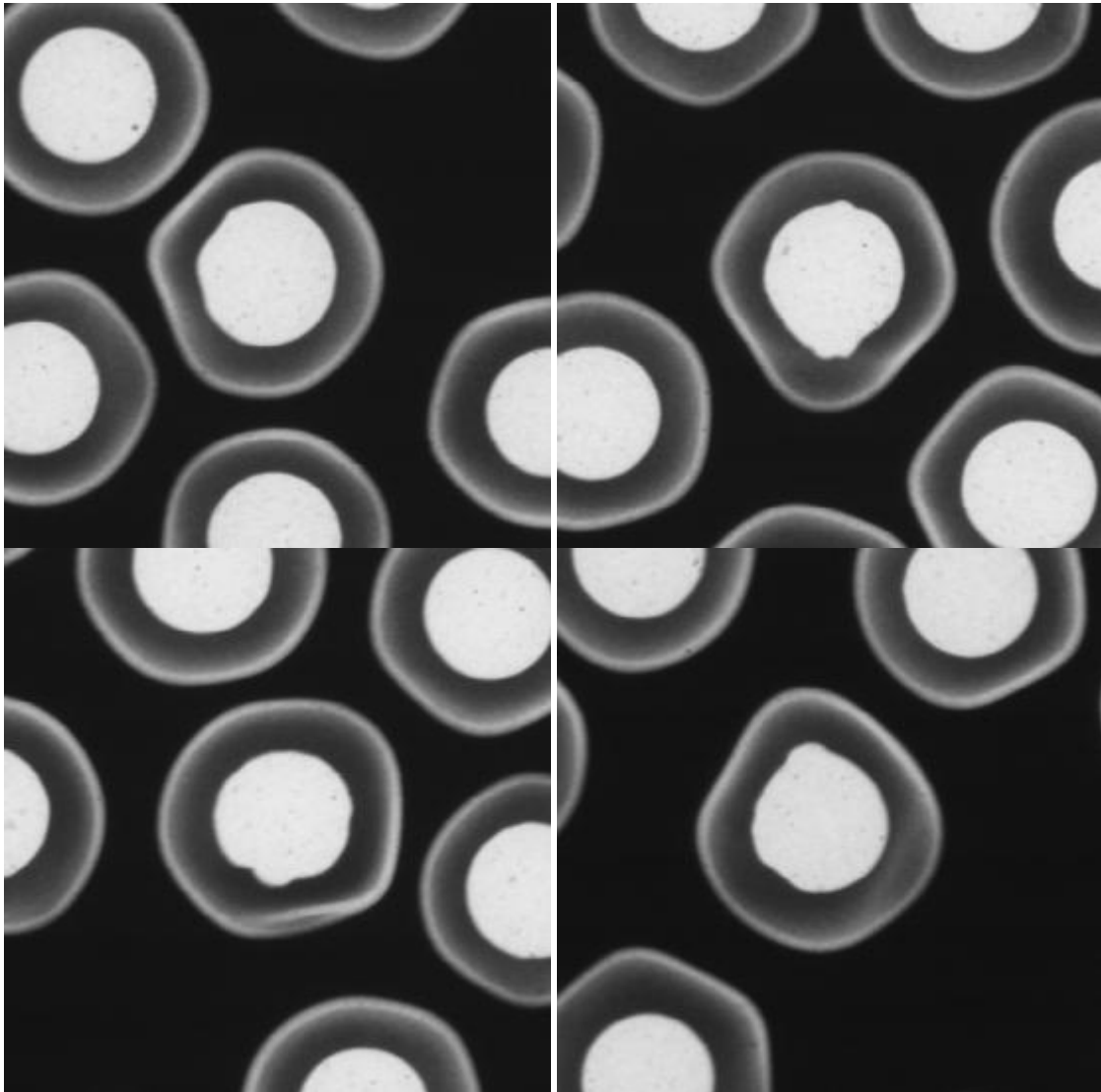
Example images of particles identified as having notched kernels are provided below . The notches are likely because kernels were chipped during rough handling or indentation by wires during sieving.

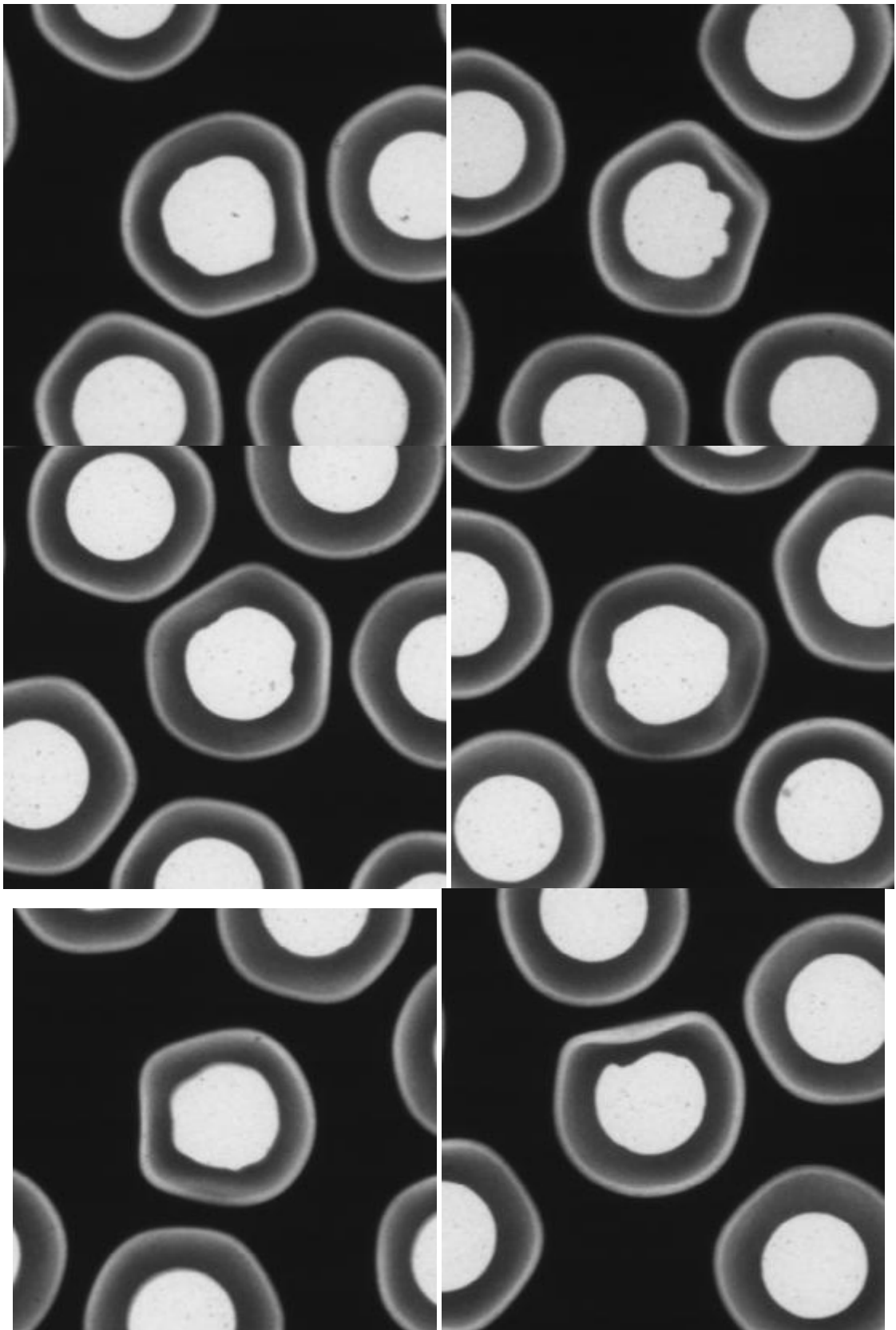




## APPENDIX H. EXAMPLE IMAGES OF PARTICLES WITH IRREGULAR KERNELS

Example images of particles identified as having irregularly shaped kernels are provided below. Identification of these particles was qualitative based on example images, and they generally included aspherical kernels with more than a single notch or facet, an overall oblong shape, or protrusions.







## APPENDIX I. EXAMPLE IMAGES OF PARTICLES WITH MULTIPLE KERNELS

Example images of particles which were identified as having more than a singular kernel are shown below. In some cases, doublets of two kernels were coated together, although in most there was one primary kernel with a fragment of additional kernel material present in the buffer layer. In some cases, multiple kernels were associated with uranium dispersion, whereas in others, the additional kernel material remained discrete.

