



The Printer Working Group

June 4, 2018  
Working Draft

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23

**PWG Safe G-Code Subset for 3D Printing**

Status: **Prototype**

Abstract: This **Best Practice document** defines a "safe" subset of G-code for use in 3D printing with IPP along with the capabilities and parameters needed to allow a client to generate G-code compatible with the printer.

This is a PWG Working Draft. For a definition of a "PWG Working Draft", see:

<https://ftp.pwg.org/pub/pwg/general/pwg-process30.pdf>

This white paper is available electronically at:

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20180604.docx>

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20180604.pdf>

**Deleted:** Working Draft - The 'mailto' Delivery Method for Event Notifications February 2, 2005

**Deleted:** A

**Deleted:** Interim

**Deleted:** white paper

**Field Code Changed**

**Deleted:** <https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20180426.docx>

**Deleted:** <https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20180426.pdf>

**Field Code Changed**

31 Copyright © 2018 The Printer Working Group. All rights reserved.

32 Title: *PWG Safe G-Code Subset for 3D Printing*

33 The material contained herein is not a license, either expressed or implied, to any IPR owned  
34 or controlled by any of the authors or developers of this material or the Printer Working  
35 Group. The material contained herein is provided on an “AS IS” basis and to the maximum  
36 extent permitted by applicable law, this material is provided AS IS AND WITH ALL FAULTS,  
37 and the authors and developers of this material and the Printer Working Group and its  
38 members hereby disclaim all warranties and conditions, either expressed, implied or  
39 statutory, including, but not limited to, any (if any) implied warranties that the use of the  
40 information herein will not infringe any rights or any implied warranties of merchantability or  
41 fitness for a particular purpose.

42

43 **Table of Contents**

44 1. Introduction ..... 4

45 2. Terminology ..... 5

46 2.1 Terms Used in This Document ..... 5

47 2.2 Acronyms and Organizations..... 5

48 3. PWG Safe G-Code Subset..... 6

49 3.1 G0 and G1: (Rapid/Controlled) Linear Move ..... 6

50 3.2 G4: Dwell ..... 7

51 3.3 G21: Set Units to Millimeters ..... 7

52 3.4 G28: Move to Origin (Home)..... 7

53 3.5 G90: Set Absolute Positioning ..... 7

54 3.6 G91: Set Relative Positioning ..... 7

55 3.7 G92: Set Position..... 7

56 3.8 M82: Set Absolute Extrusion..... 8

57 3.9 M83: Set Relative Extrusion..... 8

58 3.10 Tnnn: Set Tool ..... 8

59 4. Generating Safe G-Code..... 9

60 4.1 Material Extrusion Parameters..... 9

61 4.2 Support for Additional "Safe" G-Code Commands..... 9

62 5. Printing Safe G-Code ..... 10

63 5.1 Adding Printer-Specific Machine Commands..... 10

64 5.2 Printer-Specific Attributes and Values ..... 11

65 6. IANA Considerations ..... 12

66 6.1 Attribute Registrations ..... 12

67 6.2 MIME Media Type Registration..... 12

68 7. References ..... 14

69 8. Author's Address ..... 15

70 9. Change History..... 16

71 9.1 June 4, 2018..... 16

72 9.2 April 26, 2018..... 16

73 9.3 April 16, 2018..... 16

74 9.4 April 12, 2018..... 16

75

76 **List of Tables**

77 Table 1 - Information Needed to Generate Safe G-Code ..... 9

78 Table 2 - IPP Job Template Attributes..... 10

79

80

## 81 1. Introduction

82 G-Code [ISO6893-1][RS274D][RS274NGC][REPRAP] is a commonly-used format for 3D  
83 printing with so-called Fused Deposition Modeling (FDM) printers. Besides the commands  
84 used to move the print head and/or platform and to extrude material, G-Code includes a  
85 variety of device control (e.g., set extruder temperature) and hardware access (e.g., write  
86 file to SD card) commands that pose serious safety and security concerns. To make matters  
87 worse, such commands are often printer-specific or have printer-specific variations in syntax,  
88 requiring the equivalent of printer driver software to produce G-Code suitable for a particular  
89 model or firmware version. Finally, differences in filament and extruder nozzle diameters  
90 mean that G-Code created for one print job may not work on the same printer due to changes  
91 to the material or extruder.

92 The IPP 3D Printing Extensions v1.0 [PWG5100.21] define the model and semantics for  
93 networked 3D printing, along with a required high-level 3D file format. However, the  
94 processing requirements of such a format require either improved printer controllers with  
95 greater memory, storage, and CPU capacity or the use of Cloud services to offload that  
96 processing.

97 The IPP Shared Infrastructure Extensions (INFRA) [PWG5100.18] define the model and  
98 semantics for Cloud printing, however it does not specify an intermediate format suitable for  
99 3D printing.

100 This document defines a "safe" subset of G-Code that can be used for direct and Cloud  
101 printing configurations, along with a description of the capabilities and parameters that will  
102 be needed to generate suitable layers for printing to the target printer.

103 The goal of this document is to enable the use of IPP with existing entry-level FDM printers  
104 that are not able to perform their own slicing and to enable generic Cloud and local  
105 infrastructure services to provide slicing services to existing FDM printers. Support for other  
106 kinds of 3D printers will likely require an intermediate format such as the 3MF Slice Extension  
107 [3MF-SLICE].

108

## 109 2. Terminology

### 110 2.1 Terms Used in This Document

111 *Cloud*: the environment supporting services such as Cloud Computing.

112 *Cloud Computing*: "... a model for enabling ubiquitous, convenient, on demand network  
113 access to a shared pool of configurable computing resources (e.g., networks, servers,  
114 storage, applications, and services) that can be rapidly provisioned and released with  
115 minimal management effort or service provider interaction." The NIST Definition of Cloud  
116 Computing [NISTSP800-145].

117 *Fused Deposition Modeling*: A 3D printing process that extrudes a molten material to draw  
118 layers, sometimes also called material extrusion.

### 119 2.2 Acronyms and Organizations

120 *IANA*: Internet Assigned Numbers Authority, <https://www.iana.org/>

121 *IETF*: Internet Engineering Task Force, <https://www.ietf.org/>

122 *ISO*: International Organization for Standardization, <https://www.iso.org/>

123 *PWG*: Printer Working Group, <https://www.pwg.org/>

124

### 125 3. PWG Safe G-Code Subset

126 This document defines a safe G-Code subset with the MIME Media Type  
127 "application/vnd.pwg-safe-gcode". Safe G-Code files consist solely of the following  
128 commands which represent the common subset of commands supported by most FDM  
129 printers:

130 G0: Rapid Linear Move

131 G1: Controlled Linear Move

132 G4: Dwell

133 G21: Set Units to Millimeters

134 G28: Move to Origin (Home)

135 G90: Set Absolute Positioning

136 G91: Set Relative Positioning

137 G92: Set Position

138 M82: Set Absolute Extrusion

139 M83: Set Relative Extrusion

140 Tnnn: Set Tool

141 **Most** machine ("M") commands are not allowed since they directly control or access the  
142 machine hardware. Temperature control and other machine settings are the responsibility  
143 of the IPP Printer, which will likely use the IPP Job Template attribute values to send the  
144 corresponding printer-specific G-code commands to a lower-level controller.

145 The line number command ("N") and checksum ("\*") are similarly not allowed because they  
146 are used for direct communications with the controller - IPP provides the necessary  
147 infrastructure for reliable communication of the G-Code file to the IPP Printer.

148 Comments starting with the ";" character are allowed and continue to the end of the current  
149 line.

150 For simplicity, safe G-Code always uses millimeters for the units (the default).

#### 151 3.1 G0 and G1: (Rapid/Controlled) Linear Move

152 These commands move the current tool (extruder) and/or extrude material for printing.  
153 Parameters for this command are:

154 Xnnn: Set X position in millimeters

155 Ynnn: Set Y position in millimeters

156 Znnn: Set Z position in millimeters

157 Ennn: Extrude the specified number of millimeters of material

158 Fnnn: Set the feed rate in millimeters/minute

159 Note: The "S" parameter is not allowed in safe G-Code.

### 160 **3.2 G4: Dwell**

161 This command pauses printing for a specifies amount of time. The "Pnnn" parameter  
162 specifies the time interval in milliseconds.

### 163 **3.3 G21: Set Units to Millimeters**

164 This command explicitly specifies that coordinates are in millimeters (the default).

165 Note: This command is only provided for completeness - there is no support in safe G-Code  
166 for any other units.

### 167 **3.4 G28: Move to Origin (Home)**

168 This command moves the current tool to the home position (end stops). The "X", "Y", and  
169 "Z" parameters may optionally be specified to move the tool on the specified axes - if not  
170 supplied the tool is moved on all axes.

### 171 **3.5 G90: Set Absolute Positioning**

172 This command specifies that all coordinates are relative to the origin of the machine.

### 173 **3.6 G91: Set Relative Positioning**

174 This command specifies that all coordinates are relative to the current position of the tool.

### 175 **3.7 G92: Set Position**

176 This command sets the current tool positions without moving or extruding material.  
177 Parameters for this command are:

178 Xnnn: Set X position in millimeters

179 Ynn: Set Y position in millimeters

180 Znn: Set Z position in millimeters

181 Enn: Set extrusion to the specified number of millimeters of material

182 All positions are set to 0 if no parameters are specified.

183 **3.8 M82: Set Absolute Extrusion**

184 This command specifies that the extrusion ("E") coordinates in move commands are  
185 absolute.

186 **3.9 M83: Set Relative Extrusion**

187 This command specifies that the extrusion ("E") coordinates in move commands are relative.

188 **3.10 Tnn: Set Tool**

189 This command sets the current tool (extruder) to use, starting at 0.

190 **Editor's Note: Discuss how client maps tool numbers to materials.**

191



## 192 4. Generating Safe G-Code

193 IPP Clients [RFC8011] and Infrastructure Printers [PWG5100.18] can generate safe G-Code  
 194 using the values of Printer Description attributes reported by the IPP Printer or Proxy. Table  
 195 1 shows the information that is needed to generate safe G-Code for a printer. The "materials-  
 196 col" values are obtained from the "materials-col-database" and/or "materials-col-ready"  
 197 Printer Description attributes which provide a list of all possible materials and those that are  
 198 loaded in the Printer, respectively.

199 **Table 1 - Information Needed to Generate Safe G-Code**

Description	Current IPP Attribute
Accuracy limits/minimum layer height	print-accuracy-supported (collection)
Build platform dimensions	printer-volume-supported (collection)
Build platform shape	platform-shape (type2 keyword)
Extruder nozzle size/maximum layer height	See section <b>Error! Reference source not found.</b>
Filament diameter	materials-col.material-diameter (integer)
Retraction support	See section <b>Error! Reference source not found.</b>

### 200 4.1 Material Extrusion Parameters

201 IPP 3D v1.0 [PWG5100.21] does not define attributes or values for the extruder nozzle size,  
 202 nor does it define a way to specify whether retraction is used. These can be added to the  
 203 "materials-col" collection as:

204 "material-nozzle-diameter (integer(0:MAX))": Specifies the required extruder  
 205 diameter in nanometers, with the value 0 indicating the nozzle diameter is less than  
 206 1 nanometer.

207 "material-retraction (boolean)": Specifies whether retraction should be used with the  
 208 material.

209 A corresponding "material-nozzle-diameter-supported (1setOf (integer(0:MAX) |  
 210 rangeOfInteger(0:MAX)))" Printer Description attribute can provide the supported nozzle  
 211 diameter values. The presence of 'material-retraction' in the "materials-col-supported"  
 212 Printer Description attribute indicates that the Printer supports material retraction.

### 213 4.2 Support for Additional "Safe" G-Code Commands

214 In addition to the common subset of G-Code commands listed in the previous sections,  
 215 newer FDM printers support additional "safe" commands such as mixing of extruded material  
 216 ("M163", "M164", and "M165"), controlled arc ("G2" and "G3") and Bézier cubic spline ("G5").  
 217 In order for a generic slicer to support these commands, a printer needs to advertise its  
 218 support for them. The usual method employed for IPP is a PDL-specific capability attribute,

**Commented [MS1]:** DISCUSS: Pause (M226), Display (M70), Sound (M72), Set Build Percentage (M73) commands. Also "printer-state-reasons" keyword for when pause command is active?

219 such as "safe-gcode-supported (1setOf text(MAX))" with each value corresponding to a  
220 named command.

## 221 5. Printing Safe G-Code

222 Printers that support safe G-Code can largely pass the print file to the controller - typically  
223 all that is required is to add printer-specific commands to initialize the printer to set  
224 temperatures and other machine settings, send the print file, and then add printer-specific  
225 commands to return the printer to an idle state.

226 Status information returned by the printer can be used to set the values of the various IPP  
227 Printer Status attributes.

### 228 5.1 Adding Printer-Specific Machine Commands

229 IPP Job Template attributes provide the values for extruder and build platform temperatures,  
230 as well as the list of materials used in the print job. Table 2 lists the standard attributes a  
231 FDM printer can use to configure the machine prior to printing.

232 **Table 2 - IPP Job Template Attributes**

Description	IPP Attribute(s)	Typical G-Code
Build platform temperature	platform-temperature	M140/M190
Chamber humidity	printer-volume-humidity	M146
Chamber temperature	printer-volume-temperature	M141/M191
Extruder nozzle size	materials-col/material-nozzle-diameter	
Extruder temperature	materials-col/material-temperature	M104/M109
Filament color	materials-col/material-color	
Filament diameter	materials-col/material-diameter materials-col/material-diameter-tolerance	M200
Filament type	materials-col/material-type	
Flow rate	materials-col/material-rate materials-col/material-rate-units	M203
Job Name	job-name	M531
Print accuracy	print-accuracy	M201/M202/ M222/M223
Print quality/speed	print-quality	

233 When an IPP Client does not specify one or more of these attributes, the corresponding  
234 default attribute values are used - "materials-col-default", "platform-temperature-default",  
235 "print-accuracy-default", "print-quality-default", "printer-volume-humidity-default", and  
236 "printer-volume-temperature-default" for the attributes in Table 2.

237 **5.2 Printer-Specific Attributes and Values**

238 IPP allows implementors to add printer-specific attributes and values as defined in section 7  
239 of [RFC8011]. However, printers cannot depend on IPP Clients or Infrastructure Printers to  
240 support such attributes or values, particularly for generation of safe G-Code. Default values  
241 should be used as a backup when necessary.

## 242 6. IANA Considerations

### 243 6.1 Attribute Registrations

244 The attributes defined in this white paper will be published by IANA according to the  
245 procedures in IPP/1.1 Model and Semantics [RFC8011] section 7.2 in the following file:

246 <https://www.iana.org/assignments/ipp-registrations>

247 The registry entries will contain the following information:

248	Job Template attributes:	Reference
249	-----	-----
250	materials-col (1setOf collection)	[PWG5100.21]
251	material-extruder-diameter (integer(0:MAX))	[SAFEPCODE]
252	material-retraction (boolean)	[SAFEPCODE]
253		
254	Printer Description attributes:	Reference
255	-----	-----
256	material-extruder-diameter-supported (1setOf (integer(0:MAX)	
257	rangeOfInteger(0:MAX))	[SAFEPCODE]
258	safe-gcode-supported (1setOf text(MAX))	[SAFEPCODE]

### 259 6.2 MIME Media Type Registration

260 The MIME media type defined in this white paper will be published by IANA according to the  
261 procedures in the Media Type Specifications and Registration Procedures [BCP13] in the  
262 following file:

263 <https://www.iana.org/assignments/media-types>

264 The registry will contain the following information:

265 Type name: application  
266  
267 Subtype name: vnd.pwg-safe-gcode  
268  
269 Required parameters: N/A  
270  
271 Optional parameters: N/A  
272  
273 Encoding considerations: US ASCII  
274  
275 Security considerations: Safe G-code prohibits machine control commands,  
276 however it is up to the consumer to verify that such commands are not part  
277 of the print file.  
278  
279 Interoperability considerations: While the format is interoperable, the  
280 contents of each file are still specific to the combination of material  
281 parameters and printer capabilities used for the G-code.  
282

Commented [MS2]: DISCUSS: Make this standards-track or  
leave a vendor extension?

283 Published specification: [this white paper]  
284  
285 Applications that use this media type: IPP 3D  
286  
287 Fragment identifier considerations: N/A  
288  
289 Additional information:  
290  
291 Deprecated alias names for this type: N/A  
292 Magic number(s): N/A  
293 File extension(s): ~~pwggc~~  
294 Macintosh file type code(s): N/A  
295  
296 Person & email address to contact for further information: Michael Sweet,  
297 msweet@apple.com  
298  
299 Intended usage: COMMON  
300  
301 Restrictions on usage: N/A  
302  
303 Author/Change controller: The Printer Working Group, c/o The IEEE Industry  
304 Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ  
305 08854, USA  
306  
307 Provisional registration? (standards tree only): No

Deleted: ode

## 309 7. References

- 310 [3MF-SLICE] "3MF Slice Extension Specification and Reference Guide", August  
311 2016, <https://3mf.io/specification/>
- 312 [BCP13] N. Freed, J. Klensin, T. Hansen, "Media Type Specifications and  
313 Registration Procedures", BCP 13, RFC 6838, January 2013,  
314 <https://tools.ietf.org/html/rfc6838>
- 315 [ISO6983-1] "Automation systems and integration -- Numerical control of machines  
316 -- Program format and definitions of address words -- Part 1: Data  
317 format for positioning, line motion and contouring control systems",  
318 ISO 6983-1:2009
- 319 [NISTSP800-145] P. Mell, T. Grance, "The NIST Definition of Cloud Computing",  
320 September 2011,  
321 <http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf>
- 322 [REPRAP] "G-code - RepRapWiki", <http://reprap.org/wiki/G-code>
- 323 [RS274D] "Interchangeable Variable Block Data Format for Positioning,  
324 Contouring, and Contouring/Positioning Numerically Controlled  
325 Machines", EIA Standard RS-274-D, February 1979
- 326 ~~[RS274NGC] "The NIST RS274NGC Interpreter - Version 3", NIST Standard RS-  
327 274-NGC, August 2000, [https://www.nist.gov/publications/nist-  
328 rs274ngc-interpreter-version-3](https://www.nist.gov/publications/nist-rs274ngc-interpreter-version-3)~~
- 329 [PWG5100.18] M. Sweet, I. McDonald, "IPP Shared Infrastructure Extensions  
330 (INFRA)", PWG 5100.18-2015, June 2015,  
331 [https://ftp.pwg.org/pub/pwg/candidates/cs-ippinfra10-20150619-  
332 5100.18.pdf](https://ftp.pwg.org/pub/pwg/candidates/cs-ippinfra10-20150619-5100.18.pdf)
- 333 [PWG5100.21] M. Sweet, "IPP 3D Printing Extensions v1.0 (3D)", PWG 5100.21-  
334 2017, February 2017,  
335 [https://ftp.pwg.org/pub/pwg/candidates/cs-ipp3d10-20170210-  
336 5100.21.pdf](https://ftp.pwg.org/pub/pwg/candidates/cs-ipp3d10-20170210-5100.21.pdf)
- 337 [RFC8011] M. Sweet, I. McDonald, "Internet Printing Protocol/1.1: Model and  
338 Semantics", RFC 8011, January 2017,  
339 <https://tools.ietf.org/html/rfc8011>  
340

341 **8. Author's Address**

342 Primary author:

343 Michael Sweet  
344 Apple Inc.  
345 One Apple Park Way  
346 Cupertino, CA 95014  
347 USA  
348 msweet@apple.com

349 The authors would also like to thank the following individuals for their contributions to this  
350 white paper:

351 Kris Iverson (Microsoft)

## 352 9. Change History

### 353 [9.1 June 4, 2018](#)

- 354 [1. Status: Prototype](#)
- 355 [2. Type: Best Practice](#)
- 356 [3. Section 3: Reword M command prohibition.](#)
- 357 [4. Changed registered extension to ".pwggc".](#)
- 358 [5. Added RS274NGC reference.](#)

### 359 9.2 April 26, 2018

- 360 1. Made a PWG Best Practice working draft.
- 361 2. Added reference to RepRapWiki for G-Code
- 362 3. Added reference to ISO 6983-1 for current official G-Code specification
- 363 4. Section 4: Mention materials-col-database and materials-col-ready
- 364 5. Section 4.1: Retitle as "Material Extrusion Parameters"

### 365 9.3 April 16, 2018

- 366 1. Status: Interim
- 367 2. Introduction: Added discussion of nozzle and filament diameter influencing
- 368 portability of G-code, and why we want this.
- 369 3. Added G21, M82, and M83 commands, and hooks for other printer-specific
- 370 commands (safe-gcode-supported)
- 371 4. Updated T command (set tool) to use 0 as the first index.
- 372 5. Added sections on generating and printing safe G-code
- 373 6. Added IANA registration of new attributes and the MIME media type
- 374 7. Added references to 3MF slicing and RFC 8011.

### 375 9.4 April 12, 2018

- 376 Initial revision.