



The Printer Working Group

March 18, 2019  
Working Draft

Deleted: January 14

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## PWG Safe G-Code Subset for 3D Printing v1.0

Status: Stable

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-pwgsafegcode10-20190318.docx>

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190318.pdf>

Field Code Changed

Deleted: <https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190117.docx>

Field Code Changed

Deleted: <https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190117.pdf>

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29 Title: *PWG Safe G-Code Subset for 3D Printing v1.0*

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## 83 1. Introduction

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

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

99 The IPP Shared Infrastructure Extensions (INFRA) [PWG5100.18] define the model and  
100 semantics for Cloud printing, however it does not specify an intermediate format suitable for  
101 3D printing.

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

105 The goal of this document is to enable the use of IPP with existing entry-level FDM printers  
106 that are not able to perform their own slicing and to enable generic Cloud and local  
107 infrastructure services to provide slicing services to existing FDM printers. Support for other  
108 kinds of 3D printers will likely require an intermediate format such as the 3MF Slice Extension  
109 [3MF-SLICE].

110

111 **2. Terminology**

112 **2.1 Terms Used in This Document**

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

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

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

121 **2.2 Acronyms and Organizations**

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

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

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

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

126

### 127 **3. PWG Safe G-Code Subset**

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

132 G0: Rapid Linear Move

133 G1: Controlled Linear Move

134 G4: Dwell

135 G21: Set Units to Millimeters

136 G28: Move to Origin (Home)

137 G90: Set Absolute Positioning

138 G91: Set Relative Positioning

139 G92: Set Position

140 M82: Set Absolute Extrusion

141 M83: Set Relative Extrusion

142 Tnnn: Set Tool

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

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

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

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

#### 153 **3.1 G0 and G1: (Rapid/Controlled) Linear Move**

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

- 156 Xnnn: Set X position in millimeters
- 157 Ynnn: Set Y position in millimeters
- 158 Znnn: Set Z position in millimeters
- 159 Ennn: Extrude the specified number of millimeters of material
- 160 Fnnn: Set the feed rate in millimeters/minute
- 161 Note: The "S" parameter is not allowed in safe G-Code.

### 162 **3.2 G4: Dwell**

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

### 165 **3.3 G21: Set Units to Millimeters**

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

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

### 169 **3.4 G28: Move to Origin (Home)**

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

### 173 **3.5 G90: Set Absolute Positioning**

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

### 175 **3.6 G91: Set Relative Positioning**

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

### 177 **3.7 G92: Set Position**

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

- 180 Xnnn: Set X position in millimeters

181 Ynnn: Set Y position in millimeters

182 Znnn: Set Z position in millimeters

183 Ennn: Set extrusion to the specified number of millimeters of material

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

185 **3.8 M82: Set Absolute Extrusion**

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

188 **3.9 M83: Set Relative Extrusion**

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

190 **3.10 Tnnn: Set Tool**

191 This command sets the current tool (extruder) to use, starting at 0. Tool numbers correspond  
192 to the index within the "materials-col" Job Template attribute.

193



194 **4. Generating Safe G-Code**

195 IPP Clients [STD92] and Infrastructure Printers [PWG5100.18] can generate safe G-Code  
 196 using the values of Printer Description attributes reported by the IPP Printer or Proxy. Table  
 197 1 shows the information that is needed to generate safe G-Code for a printer. The "materials-  
 198 col" values are obtained from the "materials-col-database" and/or "materials-col-ready"  
 199 Printer Description attributes which provide a list of all possible materials and those that are  
 200 loaded in the Printer, respectively.

201 **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 4.1.
Filament diameter	materials-col.material-diameter (integer)
Retraction support	See section 4.1.

Commented [MS1]: PT1: Editorial Comment - Table 1 on page 9 has two "Error! Reference source not found" entries in the Current IPP Attribute column, which need to be fixed.

Deleted: Error! Reference source not found.

Deleted: Error! Reference source not found.

202 **4.1 Material Extrusion Parameters**

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

206 "material-nozzle-diameter (integer(0:MAX))": Specifies the required extruder  
 207 diameter in nanometers, with the value 0 indicating the nozzle diameter is less than  
 208 1 nanometer.

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

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

215 **4.2 Support for Additional "Safe" G-Code Commands**

216 In addition to the common subset of G-Code commands listed in the previous sections,  
 217 newer FDM printers support additional "safe" commands such as mixing of extruded material  
 218 ("M163", "M164", and "M165"), controlled arc ("G2" and "G3") and Bézier cubic spline ("G5").  
 219 In order for a generic slicer to support these commands, a printer needs to advertise its  
 220 support for them. The usual method employed for IPP is a PDL-specific capability attribute,  
 221 such as "safe-gcode-supported (1setOf text(MAX))" with each value corresponding to a  
 222 named command.

## 226 5. Printing Safe G-Code

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

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

### 233 5.1 Adding Printer-Specific Machine Commands

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

237 **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	

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

### 242 5.2 Printer-Specific Attributes and Values

243 IPP allows implementors to add printer-specific attributes and values as defined in section 7  
 244 of [STD92]. However, printers cannot depend on IPP Clients or Infrastructure Printers to  
 245 support such attributes or values, particularly for generation of safe G-Code. Default values  
 246 should be used as a backup when necessary.

247 **5.3 Canceling Jobs**

248 When a Job is canceled, Printers SHOULD stop sending G-Code commands as soon as  
249 possible and then send printer-specific commands to the controller to return the printer to an  
250 idle state.

251

252 **6. IANA Considerations**253 **6.1 Attribute Registrations**

254 The attributes defined in this white paper will be published by IANA according to the  
 255 procedures in IPP/1.1 Model and Semantics [STD92] section 7.2 in the following file:

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

257 The registry entries will contain the following information:

258	Job Template attributes:	Reference
259	-----	-----
260	materials-col (1setOf collection)	[PWG5100.21]
261	material-extruder-diameter (integer(0:MAX))	[SAFEGCODE]
262	material-retraction (boolean)	[SAFEGCODE]
263		
264	Printer Description attributes:	Reference
265	-----	-----
266	material-extruder-diameter-supported (1setOf (integer(0:MAX)	
267	rangeOfInteger(0:MAX))	[SAFEGCODE]
268	safe-gcode-supported (1setOf text(MAX))	[SAFEGCODE]

269 **6.2 MIME Media Type Registration**

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

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

274 The registry will contain the following information:

```

275     Type name: application
276
277     Subtype name: vnd.pwg-safe-gcode
278
279     Required parameters: N/A
280
281     Optional parameters: N/A
282
283     Encoding considerations: US ASCII
284
285     Security considerations: Safe G-code prohibits machine control commands,
286     however it is up to the consumer to verify that such commands are not part
287     of the print file.
288
289     Interoperability considerations: While the format is interoperable, the
290     contents of each file are still specific to the combination of material
291     parameters and printer capabilities used for the G-code.
292
```

293           Published specification: [this white paper]  
294  
295           Applications that use this media type: IPP 3D  
296  
297           Fragment identifier considerations: N/A  
298  
299           Additional information:  
300  
301                Deprecated alias names for this type: N/A  
302                Magic number(s): N/A  
303                File extension(s): pwggc  
304                Macintosh file type code(s): N/A  
305  
306           Person & email address to contact for further information: Michael Sweet,  
307           msweet@apple.com  
308  
309           Intended usage: COMMON  
310  
311           Restrictions on usage: N/A  
312  
313           Author/Change controller: The Printer Working Group, c/o The IEEE Industry  
314           Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ  
315           08854, USA  
316  
317           Provisional registration? (standards tree only): No

318 **7. References**

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- 346 [STD92] M. Sweet, I. McDonald, "Internet Printing Protocol/1.1", STD 92 / RFC  
347 8011, January 2017, <https://tools.ietf.org/html/std92>  
348

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358 white paper:

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## 360 **9. Change History**

### 361 [9.1 March 18, 2019](#)

- 362 • [PT1: Fix references in table 1.](#)

### 363 **9.2 January 17, 2019**

- 364 • Added document version number to page headings.

### 365 **9.3 January 14, 2019**

- 366 • Updated status to stable
- 367 • Added version number to title
- 368 • Section 3.10: Tool number corresponds to the materials-col index.
- 369 • Section 5: Added subsection on canceling jobs.
- 370 • Section 7: Fixed reference link for STD92.

### 371 **9.4 July 4, 2018**

- 372 • Removed old comments.
- 373 • RFC 8011 is now STD 92.

### 374 **9.5 June 4, 2018**

- 375 • Status: Prototype
- 376 • Type: Best Practice
- 377 • Section 3: Reword M command prohibition.
- 378 • Changed registered extension to ".pwggc".
- 379 • Added RS274NGC reference.

### 380 **9.6 April 26, 2018**

- 381 • Made a PWG Best Practice working draft.
- 382 • Added reference to RepRapWiki for G-Code
- 383 • Added reference to ISO 6983-1 for current official G-Code specification
- 384 • Section 4: Mention materials-col-database and materials-col-ready
- 385 • Section 4.1: Retitle as "Material Extrusion Parameters"



386 **9.7 April 16, 2018**

- 387 • Status: Interim
- 388 • Introduction: Added discussion of nozzle and filament diameter influencing
- 389 portability of G-code, and why we want this.
- 390 • Added G21, M82, and M83 commands, and hooks for other printer-specific
- 391 commands (safe-gcode-supported)
- 392 • Updated T command (set tool) to use 0 as the first index.
- 393 • Added sections on generating and printing safe G-code
- 394 • Added IANA registration of new attributes and the MIME media type
- 395 • Added references to 3MF slicing and RFC 8011.

396 **9.8 April 12, 2018**

397 Initial revision.