



The Printer Working Group

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Working Draft

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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-pwgsafegcode10-20190117.docx>

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

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Deleted: <https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190114.pdf>

Field Code Changed

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

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82 1. Introduction

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

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

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

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

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

109

110 **2. Terminology**

111 **2.1 Terms Used in This Document**

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

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

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

120 **2.2 Acronyms and Organizations**

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

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

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

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

125

126 **3. PWG Safe G-Code Subset**

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

131 G0: Rapid Linear Move

132 G1: Controlled Linear Move

133 G4: Dwell

134 G21: Set Units to Millimeters

135 G28: Move to Origin (Home)

136 G90: Set Absolute Positioning

137 G91: Set Relative Positioning

138 G92: Set Position

139 M82: Set Absolute Extrusion

140 M83: Set Relative Extrusion

141 Tnnn: Set Tool

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

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

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

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

152 **3.1 G0 and G1: (Rapid/Controlled) Linear Move**

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

155 Xnnn: Set X position in millimeters

156 Ynnn: Set Y position in millimeters

157 Znnn: Set Z position in millimeters

158 Ennn: Extrude the specified number of millimeters of material

159 Fnnn: Set the feed rate in millimeters/minute

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

161 **3.2 G4: Dwell**

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

164 **3.3 G21: Set Units to Millimeters**

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

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

168 **3.4 G28: Move to Origin (Home)**

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

172 **3.5 G90: Set Absolute Positioning**

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

174 **3.6 G91: Set Relative Positioning**

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

176 **3.7 G92: Set Position**

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

179 Xnnn: Set X position in millimeters

180 Ynnn: Set Y position in millimeters

181 Znnn: Set Z position in millimeters

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

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

184 **3.8 M82: Set Absolute Extrusion**

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

187 **3.9 M83: Set Relative Extrusion**

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

189 **3.10 Tnnn: Set Tool**

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

192

193 4. Generating Safe G-Code

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

200 **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 Error! Reference source not found.
Filament diameter	materials-col.material-diameter (integer)
Retraction support	See section Error! Reference source not found.

201 4.1 Material Extrusion Parameters

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

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

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

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

214 4.2 Support for Additional "Safe" G-Code Commands

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

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

222 5. Printing Safe G-Code

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

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

229 5.1 Adding Printer-Specific Machine Commands

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

233 **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	

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

238 **5.2 Printer-Specific Attributes and Values**

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

243 **5.3 Canceling Jobs**

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

247

248 6. IANA Considerations

249 6.1 Attribute Registrations

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

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

253 The registry entries will contain the following information:

254	Job Template attributes:	Reference
255	-----	-----
256	materials-col (1setOf collection)	[PWG5100.21]
257	material-extruder-diameter (integer(0:MAX))	[SAFEGCODE]
258	material-retraction (boolean)	[SAFEGCODE]
259		
260	Printer Description attributes:	Reference
261	-----	-----
262	material-extruder-diameter-supported (1setOf (integer(0:MAX)	
263	rangeOfInteger(0:MAX))	[SAFEGCODE]
264	safe-gcode-supported (1setOf text(MAX))	[SAFEGCODE]

265 6.2 MIME Media Type Registration

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

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

270 The registry will contain the following information:

```

271 Type name: application
272
273 Subtype name: vnd.pwg-safe-gcode
274
275 Required parameters: N/A
276
277 Optional parameters: N/A
278
279 Encoding considerations: US ASCII
280
281 Security considerations: Safe G-code prohibits machine control commands,
282 however it is up to the consumer to verify that such commands are not part
283 of the print file.
284
285 Interoperability considerations: While the format is interoperable, the
286 contents of each file are still specific to the combination of material
287 parameters and printer capabilities used for the G-code.
288
```

289 Published specification: [this white paper]
290
291 Applications that use this media type: IPP 3D
292
293 Fragment identifier considerations: N/A
294
295 Additional information:
296
297 Deprecated alias names for this type: N/A
298 Magic number(s): N/A
299 File extension(s): pwggc
300 Macintosh file type code(s): N/A
301
302 Person & email address to contact for further information: Michael Sweet,
303 msweet@apple.com
304
305 Intended usage: COMMON
306
307 Restrictions on usage: N/A
308
309 Author/Change controller: The Printer Working Group, c/o The IEEE Industry
310 Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ
311 08854, USA
312
313 Provisional registration? (standards tree only): No

314 **7. References**

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343 8011, January 2017, <https://tools.ietf.org/html/std92>
344

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356 **9. Change History**

357 **[9.1 January 17, 2019](#)**

- 358
 - [Added document version number to page headings.](#)

359 **9.2 January 14, 2019**

- 360
 - Updated status to stable
- 361
 - Added version number to title
- 362
 - Section 3.10: Tool number corresponds to the materials-col index.
- 363
 - Section 5: Added subsection on canceling jobs.
- 364
 - Section 7: Fixed reference link for STD92.

365 **9.3 July 4, 2018**

- 366
 - Removed old comments.
- 367
 - RFC 8011 is now STD 92.

368 **9.4 June 4, 2018**

- 369
 - Status: Prototype
- 370
 - Type: Best Practice
- 371
 - Section 3: Reword M command prohibition.
- 372
 - Changed registered extension to ".pwggc".
- 373
 - Added RS274NGC reference.

374 **9.5 April 26, 2018**

- 375
 - Made a PWG Best Practice working draft.
- 376
 - Added reference to RepRapWiki for G-Code
- 377
 - Added reference to ISO 6983-1 for current official G-Code specification
- 378
 - Section 4: Mention materials-col-database and materials-col-ready
- 379
 - Section 4.1: Retitle as "Material Extrusion Parameters"

380 **9.6 April 16, 2018**

- 381
 - Status: Interim

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

390 **9.7 April 12, 2018**

391 Initial revision.